

IOCEN
2026
Conference

The 3rd International Online Conference on Energies

12–15 May 2026 | Online

Program and Abstract Book

Organizers



Media Partners



sciforum.net/event/IOCEN2026
[#IOCEN2026](https://twitter.com/IOCEN2026)

The 3rd International Online Conference on Energies

12–15 May 2026 | Online



Organizing Committee

Conference Chair

Prof. Dr. Enrico Sciubba

Session Chairs

Dr. José Ramón Fernández
Prof. Efstathios Michaelides
Prof. Tassos Stamatelos
Prof. Dr. Adrian Ilinca
Prof. Dr. Antonio Zuerro
Prof. Dr. Benjamin McLellan

Prof. Dr. Elisa Sani
Prof. Dr. Giovanni Esposito
Prof. Dr. Josep M. Guerrero
Prof. Dr. Marco Pasetti
Prof. Dr. Ramiro S. Barbosa

Scientific Committee

Dr. Adrián Mota Babiloni
Dr. Aldo Di Carlo
Dr. Fabio Bisegna
Dr. Nausika Querejeta
Prof. Dr. Abdul Ghani Olabi
Prof. Dr. Alberto Abánades
Prof. Dr. Antonino Laudani
Prof. Dr. Antonio Zuerro
Prof. Dr. Arturo de Risi

Prof. Dr. Basu Saha
Prof. Dr. Bevilacqua Piero
Prof. Dr. Daniel Sanin Villa
Prof. Dr. Elisa Sani
Prof. Dr. Karen Butler Purry
Prof. Dr. Maurizio Filippo Acciarri
Prof. Dr. Miccio Francesco
Prof. Dr. Sun Hongtao

Organised by



Conference Secretariat

Email: iocen2026@mdpi.com

Table of Contents

Welcome from the Chair.....	1
Keynote Speakers.....	3
Program at a Glance	4
IOCD 2025 Program.....	Error! Bookmark not defined.
Session 1. Energy Sources (Fossil & Renewable).....	12
Session 2. Energy Conversion (Heat and Mass Transfer, Combustion, Thermodynamics, Entropy & Exergy Analysis).....	44
Session 3. Energy and Environment. Sustainable Transition.....	65
Session 4. Smart Cities and Urban Management	149
Session 5. Advanced Energy Materials	167
Session 6. Electrical Power Systems	205
Session 7. Energy Economics and Policy (Thermo-Economics, Exergy Economics).....	225
Session 8. AI Applications to Energy Conversion Systems	246

Welcome from the Chair

Dear Colleagues,

We are excited to announce the **3rd International Online Conference on Energies (IOCEN 2026)**, which will be held virtually from **12 to 15 May 2026**.

This conference will showcase the latest research and advancements in energy resource management, focusing on areas such as energy sources, energy conversion, energy policy, energy fundamentals, smart energy, and other energy innovations, with an eye open towards sustainable use of resources. We aim to explore the current landscape, address existing challenges, and identify opportunities.

We warmly invite all energy researchers, professionals, and innovators to participate and share their expertise in the following thematic areas and related topics:

- S1. Energy Sources (Fossil & Renewable);**
- S2. Energy Conversion (Heat and Mass Transfer, Combustion, Thermodynamics, Entropy & Exergy Analysis);**
- S3. Energy and Environment. Sustainable Transition;**
- S4. Smart Cities and Urban Management;**
- S5. Advanced Energy Materials;**
- S6. Electrical Power Systems;**
- S7. Energy Economics and Policy (Thermo-Economics, Exergy Economics);**
- S8. AI Applications to Energy Conversion Systems.**

The conference committee will review the submitted abstracts. All accepted abstracts will be available online in open access format on Sciforum.net during and after the conference. Following the conference, selected contributions will be invited for submission to the *Energies* journal (ISSN 1996-1073, Impact Factor: 3.2), with a **20% discount** on the publication fee.

We look forward to your participation in this inspiring event.

Best regards,



Prof. Dr. Enrico Sciubba
Conference Chair

Department of Mechanical and
Industrial Engineering, University
Niccolò Cusano, 00166 Roma, Italy



energies

an Open Access Journal by MDPI

Energies (ISSN 1996-1073) is an open access journal and publishes papers on scientific research, technology development, engineering policy, and management studies related to the general field of energy, from technological problems in energy supply, conversion, dispatch, and final use to the thermodynamics of the physical and chemical processes behind such technologies. Acceptable paper types are reviews, regular research papers, and communications. Our aim is to encourage scientists to publish their experimental, numerical, and theoretical results in as much detail as possible. There is no restriction on the maximum length of the papers. Full experimental details must be provided so that results can be reproduced. For numerical simulations, an accurate description of methods and mesh sensitivity is mandatory.

Impact Factor: 3.2 (2024); **5-Year Impact Factor:** 3.1 (2024)

Keynote Speakers



Dr. Md Ohirul Qays
CQUniversity, Gladstone
Marina, Australia



Dr. Roby Soni
University College London,
United Kingdom



Prof. Dr. Andrew Dicks
Griffith University, Australia



Prof. Dr. Mattia Bartoli
Italian Institute of Technology,
Genoa, Italy



Prof. Dr. Michele De Santis
University of Campania "Luigi
Vanvitelli", Naples, Italy



Prof. Dr. Syed Zaheer Abbas
University of Southampton, UK

Program at a Glance

	Day 1	Day 2	Day 3	Day 4
Morning	S3. Energy and Environment. Sustainable Transition	S8. AI Applications to Energy Conversion Systems	S4. Smart Cities and Urban Management	S7. Energy Economics and Policy (Thermo-Economics, Exergy Economics)
Afternoon	S6. Electrical Power Systems	S5. Advanced Energy Materials	S2. Energy Conversion (Heat and Mass Transfer, Combustion, Thermodynamics, Entropy & Exergy Analysis)	S1. Energy Sources (Fossil & Renewable)

IOCN 2026 Program

12 May 2026 (Tuesday)

S3. Energy and Environment. Sustainable Transition

9:00 (CEST, Basel) | 03:00 (EDT, New York) | 15:00 (CST Asia, Beijing)

CEST Time	Speaker	Title
9:00–9:10	Prof. Dr. Enrico Sciubba Event Chair	<i>Welcome & Opening Remarks</i>
9:10–9:20	Prof. Dr. José Ramón Fernández Session Chair	<i>Welcome from the Session Chair</i>
9:20–9:45	Prof. Dr. Syed Zaheer Abbas Keynote Speaker	Advancing sustainable transition through Chemical Looping Reverse Water Gas Shift for industrial CO ₂ utilization
9:45–10:00	Rebeca María Simion Selected Speaker	Electrochemical Behavior and Surface Activation of Ni ₂ O ₃ Electrodes under Dynamic Alkaline Electrolysis: Effects on Hydrogen and Oxygen Evolution with Renewable Power Supply
10:00–10:15	Arturo Barragán Alonso Selected Speaker	Experimental Validation of Steam-Enhanced Calcium Looping for CO ₂ Capture
10:15–10:30	Encarnación Cruz Sánchez Selected Speaker	CO ₂ valorization in portable pilot plants for e-fuel production
10:30–10:45	Noelia Díaz Navarro Selected Speaker	Symmetric SOECs based on PrBaMn ₂ O _{5+δ} electrodes for co-electrolysis processes
10:45–11:00	Alejandro Cánovas Sánchez Selected Speaker	E-fuel production from lignocellulosic biomass oxy-gasification
11:00–11:15	Pedro Juan Martínez Román Selected Speaker	SIMULATION AND OPTIMISATION OF METHANOL PRODUCTION AND FISHER-TROSCHE PROCESS FROM BIOGAS METHANE REFORMING
11:15–11:30	Elena Duque Rivera Selected Speaker	Meat industry waste as raw materials for renewable gases production
11:30–11:45	Lorena Sánchez-Relaño Selected Speaker	Comprehensive Life Cycle Assessment (LCA) of the Spanish Electricity Mix: Evaluating Environmental Trade-offs in the Energy Transition
11:45–12:00	Basudeb Saha Selected Speaker	Turning Tyre Waste into Energy: Sustainable Valorisation via Microwave-Induced Plasma Gasification
12:00–12:15	Roberto García Selected Speaker	Recent advances in Direct Air Capture (DAC) using Ca-solid forms
12:15–12:30	Mana Dastoum Selected Speaker	Practical Implications of Tessellated Geometric Façades for Optimal Daylighting Performance

S6. Electrical Power Systems

14:00 (CEST, Basel) | 09:00 (EDT, New York) | 21:00 (CST Asia, Beijing)

CEST Time	Speaker	Title
14:00–14:10	Prof. Dr. Antonio Zorro Session Chair	<i>Welcome from the Session Chair</i>
14:10–14:40	Dr. Michele De Santis Keynote Speaker	Voltage optimization in distribution network exploiting distributed energy resource flexibility
14:40–14:55	Kaouthar Kerboua Selected Speaker	The Energetic Compromise in Small-Scale H ₂ Energy Storage: A Comparative Experimental Study Based on Electrolyzer's Separators and Architectures
14:55–15:10	Wei Lu Selected Speaker	A Two-Stage Random Forest Analysis Framework for Electricity Price Forecasting and Spike Driver Interpretation
15:10–15:25	Mana Dastoum Selected Speaker	Practical Implications of Tessellated Geometric Façades for Optimal Daylighting Performance
15:25–15:35	Daniel Sanin-Villa Selected Speaker	Population-Based Genetic Algorithm for Loss and CO ₂ Emission Reduction in AC Microgrids with Distributed Energy Resources
15:35–15:50	Himmat Singh Selected Speaker	Optimal Reactive Power Dispatch Management of Renewable Energy integration Using Improved Salp Swarm Algorithm

15:50–16:05	Abhishek Bajirao Katkar Selected Speaker	A Resilient Multi-Objective MOABC–NSGA-II Optimization approach for Fault Location and Restoration Time Reduction in Wind-integrated Power Grid Networks
16:05–16:20	Mohamed Louzazni Selected Speaker	Non-Iterative Lagrange Multiplier Approach for Maximum Power Point Tracking in Photovoltaic Systems
16:20–16:35	Paul John Infante Selected Speaker	Design and Development of a Low-Cost Power Harmonics Monitoring Device for LED Lighting Systems: An Experimental Case Study

13 May 2026 (Wednesday)**S8. AI Applications to Energy Conversion Systems****9:00 (CEST, Basel) | 03:00 (EDT, New York) | 15:00 (CST Asia, Beijing)**

CEST Time	Speaker	Title
9:00–9:10	Prof. Dr. Ramiro S. Barbosa Session Chair	<i>Welcome & Opening Remarks</i>
9:10–9:25	Sanjith Balamurali Selected Speaker	AI-Optimized Pyrolysis: A Machine Learning Framework for Predictive Waste-to-Energy Conversion
9:25–9:40	Prashant Steele Selected Speaker	Machine Learning–Based Predictive Maintenance Framework for Performance Degradation Detection in Energy Conversion Systems
9:40–9:55	Gabriel Jaime Osorio-Hernandez Selected Speaker	Data Driven Prediction of DC Current in an Inverter Free Photovoltaic Battery System for Telecommunication Antenna Applications
9:55–10:10	Jasmina Elmurodova Selected Speaker	A Machine Learning Regression Model for Early-Stage Prediction of Biogas Production
10:10–10:25	Hafsa Khayrane Selected Speaker	Integrating Electro-Thermal Dynamics into SOC Estimation through Internal Resistance and Thermal Loss Regularization
10:25–10:40	Oussama Khouili Selected Speaker	Benchmarking Deep Learning Techniques for Photovoltaic Output Prediction: A Case Study of PV Systems in China
10:40–10:55	Blessed Olalekan Oyebola Selected Speaker	AI-Driven Multi-Modal Integration for Structural Health Monitoring of Photovoltaic Systems: A Nigerian Context
10:55–11:10	Blessed Olalekan Oyebola Selected Speaker	Optimizing Remaining Useful Life Prediction in Photovoltaic Systems Using AI-Enhanced LSTM Models
11:10–11:25	Oumaima Echab Selected Speaker	An Optimized Hybrid Artificial Intelligence-based Control Strategy for Standalone Photovoltaic Systems under Complex Partial Shading Conditions
11:25–11:40	Dr. Tegar Septyan Hidayat Selected Speaker	IuditAR: A Pilot Study on Overcoming Indonesia's Household Energy Waste via AI-driven Game-As-Reality (GAR) Audits
11:40–11:55	Abhishek Bajirao Katkar Selected Speaker	A Hybrid Artificial Bee Colony with Adaptive Neighborhood Search and Gaussian Perturbation Integrated NSGA-II for Multi-Objective Probabilistic Optimal Power Flow Considering Solar, Wind, Electric Vehicles, and FACTS Devices
11:55–12:10	Sulyman Taofeeq Opeyemi Selected Speaker	Adaptive State of Energy Estimation for Lithium-Ion Batteries Using an Improved Sage–Husa Extended Kalman Filter

S5. Advanced Energy Materials**14:00 (CEST, Basel) | 09:00 (EDT, New York) | 21:00 (CST Asia, Beijing)**

CEST Time	Speaker	Title
14:00–14:10	Dr. Elisa Sani Session Chair	<i>Welcome & Opening Remarks</i>
14:10–14:35	Dr. Mattia Bartoli Keynote Speaker	
14:35–15:00	Dr. Roby Soni Keynote Speaker	Lithium–Sulfur Batteries: Solution is in the Electrolyte
15:00–15:15	Yue Xian Selected Speaker	Interfacial Engineering and Upscaling Strategy for Aluminum Foil Substrates Flexible Perovskite Solar Cells
15:15–15:30	Jakkapan Kumsi Selected Speaker	Experimental and computational insights into CO ₂ adsorption in biomass-derived activated carbons
15:30–15:45	Manel Mabrouk Selected Speaker	Theoretical study of hybrid architectures combining graphene substrate with single-molecule magnets
15:45–16:00	Yusuf Kepir Selected Speaker	Numerical Evaluation of Monolithic Aerogel as a Transparent Insulation Layer for Building-Integrated Natural Convection Solar Air Collectors

16:00–16:15	Claudiu Gorea Selected Speaker	Phase Change Materials in Energy Applications: Classification and Usual Evaluation Methods
16:15–16:30	Ayob Zanberi Selected Speaker	TiSiO ₄ as a Catalytic Dopant for Lowering the Decomposition Temperature and Improve Kinetics of AlH ₃ for Solid-State Hydrogen Storage
16:30–16:45	Abdisa Sisay Mekonnen Selected Speaker	Cryogenic Mechanical Properties of AISI 304 Stainless Steel for Hydrogen Storage
16:45–17:00	Nilay AĞAÇKESEN Selected Speaker	A Finite Element Framework for Assessing Diffusion Length–Thickness (L _d –d) Limitations in MA–FA Mixed Perovskite Semiconductor Absorber Layers for Solar Cells
17:00–17:15	Yacine Kouhlane Selected Speaker	Spectrally Resolved OCVD Investigation of Surface and Bulk Recombination in Silicon Photovoltaic Materials

14 May 2026 (Thursday)

S4. Smart Cities and Urban Management

9:00 (CEST, Basel) | 03:00 (EDT, New York) | 15:00 (CST Asia, Beijing)

CEST Time	Speaker	Title
9:00–9:10	Dr. Marco Pasetti Session Chair	<i>Welcome & Opening Remarks</i>
9:10–9:25	Mirela Panait Selected Speaker	Social responsibility of energy companies under the sign of the twin transition. The European perspective
9:25–9:40	Leandro Teófilo Pinto Dos Reis Selected Speaker	ISO-Based Smart City Assessment as an Urban Management Tool: Comparing the Connected Smart Cities Frameworks of 2024 and 2025
9:40–9:55	Cristian Mateo Hernandez Selected Speaker	<i>Energy-Aware Route Planning for Differential-Drive Mobile Robots in Polygonal Urban Environments via Feasibility-First Metaheuristic Optimization</i>
9:55–10:10	Miguel Iglesias Selected Speaker	AIoT-Driven Smart Public Lighting as a Cybernetic Infrastructure for Environmental and Climate Justice
10:10–10:25	Luis Fernando Grisales-Noreña Selected Speaker	Parallel Metaheuristic-Based Optimization for Electric Vehicle Charging Station Integration and Sizing in Distribution Systems
10:25–10:40	Mirela Panait Selected Speaker	Universities as key actors in the green transition ecosystem. Romanian perspective

S2. Energy Conversion (Heat and Mass Transfer, Combustion, Thermodynamics, Entropy & Exergy Analysis)

14:00 (CEST, Basel) | 09:00 (EDT, New York) | 21:00 (CST Asia, Beijing)

CEST Time	Speaker	Title
14:00–14:10	Prof. Tassos Stamatelos Prof. Efsthios Michaelides Session Chairs	<i>Welcome & Opening Remarks</i>
14:10–14:35	Dr. Andrew Dicks Keynote Speaker	
14:35–14:50	Christi K. Madsen Selected Speaker	Fresnel Lens-Based Concentrated Solar Thermal System for Compact High-Temperature Processing
14:50–15:05	Fatema Tarannum Selected Speaker	Graphene functionalization strategies for enhanced thermal management performance in polyetherimide composites
15:05–15:20	Vandana Kumari Jha Selected Speaker	Geometric Design Innovations for Enhanced Energy Recovery in Helical Configuration-based Thermal Systems
15:20–15:35	Pedro Gabana Selected Speaker	Study of emissions formation in a spark-ignition engine fuelled with natural-gas–hydrogen blends
15:35–15:50	Svetlana Boshnakova Selected Speaker	Heat Exchanger Optimization with Comparison of Plate-Joining Techniques
15:50–16:05	Christian Dewin Nery Selected Speaker	Influence of Torrefaction Temperature and Residence Time on the Physicochemical Properties and Structural Transformation of Market Waste-Derived Torrefied Solid Fuel
16:05–16:20	Helal Uddin Selected Speaker	Optimization of Heat and Mass Transport in Mechanical Devices for Hybrid Solar–Thermal Energy Harvesting
16:20–16:35	Aicha EDDMANI Selected Speaker	CFD-Based Evaluation of the Effect of Storage Material Size on Heat Transfer and Flow Characteristics in Packed Beds
16:35–16:50	Hayat El Baamrani Selected Speaker	Experimental Investigation of Heat Transfer and Evaporation Characteristics of a Falling Liquid Film on a Vertical Plate
17:00–17:15	Anthony Nathaniel Selected Speaker	3E (Energy, Exergy, and Environment) Analysis of Waste Heat Recovery Gas Engine Power Plant with Organic Rankine Cycle Model

15 May 2026 (Friday)**S7. Energy Economics and Policy (Thermo-Economics, Exergy Economics)****9:00 (CEST, Basel) | 03:00 (EDT, New York) | 15:00 (CST Asia, Beijing)**

CEST Time	Speaker	Title
9:00–9:10	Prof. Dr. Benjamin McLellan Session Chair	<i>Welcome & Opening Remarks</i>
9:10–9:25	Mulikat Abdulrahman Selected Speaker	Infrastructure Reliability as a Gatekeeper for Productive Electricity Use—Evidence from Rural Nigeria and Policy Implications
9:25–9:40	Chukwuemeka Valentine Okolo Selected Speaker	When Do Credit Prices Drive Decarbonization? Credit-Price Thresholds and EV Charging Infrastructure in Oregon's Clean Fuels Program
9:40–9:55	Sonia Rozbiewska Selected Speaker	Global Energy Security at Risk: Maritime Piracy and Supply Chain Disruptions in the Context of Middle East Conflict (2026)
9:55–10:10	Georgios Anagnostopoulos Selected Speaker	Renewable Energy Cooperatives in the Just Transition in Greece: Barriers and possibilities
10:10–10:25	Srikant Shaw Selected Speaker	Coping with Grid Failure: An Economic Analysis of Household Inverter Adoption as a Proxy for Future Storage Demand in Rural India
10:25–10:40	Suresh Baral Selected Speaker	Global Assessment of Low-Cost Green Hydrogen Production Potential Using Machine Learning Models
10:40–10:55	Bini Koffi Achille Bouo Selected Speaker	CO ₂ Emissions Mitigation Through Renewable Energy in West Africa: Evidence from Bilateral Green Finance
10:55–11:10	Michal Thlon Selected Speaker	Market Security Index (MSI): A pioneering framework for measuring and enhancing EU energy market resilience
11:10–11:25	Silmara Furtado da Silva Selected Speaker	A Thermo-Economic and Exergy-Based Analysis of Sustainable Aviation Fuel Production in Brazil: Policy, Efficiency, and Decarbonization Pathways
11:25–11:40	Victor José Olivero Selected Speaker	Mapping Energy Governance in the Global Energy Transition: An Evidence-Based Topic Modeling Approach
11:40–11:55	Gabriel Alberto Rosas Sánchez Selected Speaker	Distributed Generation in Mexico's Energy Transition: Regulatory Change, Institutional Tensions and Policy Implications

S1. Energy Sources (Fossil & Renewable)**14:00 (CEST, Basel) | 09:00 (EDT, New York) | 21:00 (CST Asia, Beijing)**

CEST Time	Speaker	Title
14:00–14:10	Prof. Dr. Adrian Ilinca Prof. Dr. Giovanni Esposito Session Chairs	<i>Welcome & Opening Remarks</i>
14:10–14:35	Dr. Md Ohirul Qays Keynote Speaker	Addressing System Strength Shortfall in Renewable Energy-Integrated Grid Systems
14:35–14:50	Shaik Nasrullah Shareef Selected Speaker	Hybrid Biomass Energy Systems for Rural Communities: A Case Study of Grenada County
14:50–15:05	Hassan Abdullahi Sheikhdon Selected Speaker	Design and Techno-Economic Analysis of a Resilient Hybrid Solar-Diesel Battery Microgrid for Rural Electrification in Conflict-Affected Regions: A Case Study in Somalia
15:05–15:20	Joseph-Kantole Basakay Selected Speaker	Bayesian Optimization-Based Performance Enhancement of Pneumatic-Hybrid Diesel Generators for Remote Power Systems
15:20–15:35	Carolina Amparo Santamarta Ballesteros Selected Speaker	Techno-Economic Analysis of Biomass Gasification for Decentralized Sustainable Aviation Fuel (SAF) Production
15:35–15:50	Eudes-Tshitshonu Kabeya Selected Speaker	From Firm Capacity to Flexible Adequacy: Rethinking Capacity Metrics for Renewable-Dominant Power Systems

15:50–16:05	Nkechi Miriam Nwaogaraku Selected Speaker	Sustainable Bioconversion of Biomass-Derived Butyric Acid to Butanol Using <i>Clostridium</i> Species: Metabolic Engineering, Process Optimization, and Environmental Implications
16:05–16:20	Pascal Kilunji Mwenge Selected Speaker	Biodiesel Production from Waste Cooking Oil Catalysed by a Calcium Oxide Heterogeneous Catalyst: Kinetics, Simulation, and Life Cycle Assessment
16:20–16:35	Rotimi Abiodun Afe Selected Speaker	Comparative Techno-Economic and Lifecycle Assessment of Diesel and Solar Storage Portfolios for Nigeria Towerco Low-Carbon Energy Supply in Weak Grid and Off-Grid Locations
16:35–16:50	Christian Agu Selected Speaker	Renewables for Resilience: Do Renewable Capacity Additions Improve Energy Security and Cut Emissions? Panel Evidence From 12 African Countries
16:50–17:05	Sana Abbas Selected Speaker	Unveiling the Role of Donor-Acceptor Attachment Sites in Molecular Design for High-Performance Organic Solar Cells: A Theoretical Study

Session 1. Energy Sources (Fossil & Renewable)

sciforum-166317: Modeling and Simulation of an Ultra-Low-Current Analog Electronic Load for Photovoltaic I–V Curve Extraction under Low-Irradiance Conditions

Yago Costa Oliveira *, Daniel Guzman del Rio, André Luiz Printes and Israel Gondres Torné

PPGEEL-Postgraduate Program in Electrical Engineering, State University of Amazonas (UEA), Manaus, 69050-020, Brazil

Photovoltaic (PV) characterization under low-irradiance conditions is critical for the development of ultra-low-power energy harvesting and Internet of Things (IoT) systems. In these conditions, PV sources operate in the microampere range, where conventional electronic loads and I–V curve tracers often lack sufficient resolution and stability. This work presents the modeling and simulation of a purely analog electronic load designed for ultra-low-current photovoltaic I–V curve extraction.

The proposed method is based on voltage-clamped operation. The electronic load regulates the terminal voltage of the photovoltaic source while the corresponding output current is measured, allowing direct extraction of the I–V relationship. A programmable voltage reference is assumed to define the operating point; in this study, this reference is represented by a ramp voltage signal, corresponding to a future implementation using a microcontroller digital-to-analog converter (DAC). This approach enables a continuous sweep from open-circuit voltage toward lower operating voltages while maintaining a fully analog control structure.

The methodology combines system-level and circuit-level simulations. The photovoltaic source is modeled in MATLAB using a single-diode equivalent model with series and shunt resistances, parameterized for low-irradiance operation. The electronic load is implemented as a closed-loop analog circuit and evaluated through circuit-level simulations. The MATLAB-based photovoltaic model is used as a reference to validate the extracted I–V curves and to assess voltage regulation accuracy, current resolution, and dynamic stability in the microampere range.

Simulation results indicate that the proposed voltage-clamped electronic load operates stably at ultra-low current levels and enables smooth and repeatable extraction of photovoltaic I–V curves under reduced illumination. The extracted curves closely match the MATLAB reference model, including open-circuit voltage, short-circuit current, and maximum power point behavior. No instability or significant oscillations are observed across the simulated operating range.

The results indicate that voltage-controlled analog electronic loading is a suitable approach for photovoltaic characterization in ultra-low-power scenarios. This study provides a solid basis for future hardware implementation and for extension into complete photovoltaic emulation platforms for energy harvesting and IoT applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170719: Design and Techno-Economic Analysis of a Resilient Hybrid Solar-Diesel Battery Microgrid for Rural Electrification in Conflict-Affected Regions: A Case Study in Somalia

Hassan Abdullahi Sheikhdon ^{1,*}, **Abdullahi Mohamed Sheikh Ali** ² and **Nur Mohamed Mohamud** ³

¹ Department of Energy Science and Engineering, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi, 110016

² Department of Civil and Environmental Engineering, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi, 110016

³ Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81300 Skudai, Johor, Malaysia

Reliable electricity supply remains limited in conflict-affected rural regions of Somalia, constraining socio-economic development and service delivery. This study designs and evaluates a hybrid photovoltaic–diesel generator–battery storage (PV–DG–BS) microgrid through techno-economic optimization, sensitivity analysis, resilience assessment, and environmental performance. Using HOMER Pro simulations supported by site data and a load-scaling approach, five systems designs were evaluated, combining conventional resources, particularly diesel, with renewable energy sources, particularly solar, alongside a battery storage solution. The study identified an optimal fixed architecture comprising 12,000 kW of PV, ≈ 38.3 MWh of battery storage, a 5,397-kW converter, and three of 2,000-kW diesel generators operated in a load-following mode. The optimal hybrid system produces ≈ 21.54 GWh/yr with a renewable fraction of $\approx 81.3\%$ indicating that the majority of annual energy is supplied by PV plus storage and achieves a competitive levelized cost of energy (LCOE ≈ 0.167 USD/kWh). Compared to a diesel-only baseline, annual diesel uses falls from ≈ 5.18 million L to ≈ 0.973 million L ($\approx 81.2\%$ reduction). Corresponding CO₂ emissions drop from 13,584,108 kg/yr to 2,550,864 kg/yr, saving $\approx 11,033$ tCO₂/yr. CO₂ intensity improves from 0.700 kgCO₂/kWh to 0.118 kgCO₂/kWh. One-at-a-time sensitivity runs show that LCOE is most sensitive to the discount rate and diesel price; PV and battery cost changes have a lesser impact within the tested bands. Resilience testing under realistic stress cases (solar -10% and -20% , load $+15\%$, single DG outage, and battery -20% capacity) shows the system maintains near-full reliability. Unmet load is effectively zero for all scenarios except the single-DG outage, which caused a very small unmet fraction ($\approx 0.0328\%$). Battery cycling (~ 203 cycles/yr) is consistent with daily peak-shaving use. The study concludes that the PV/DG/BS hybrid is technically feasible, environmentally safe, and economically robust under realistic assumptions; it recommends integrating wind and hydrogen-based storage to further increase the renewable fraction, investigating grid-connected and net-metering operations which may enhance energy availability and minimize curtailment, and evaluating socio-economic impacts.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170604: A Simulation Framework for Implementing a Detailed Kinetic Model for Dry Reforming of Methane.

Bruno Agún * and Alberto Abánades

Sustainable, Nuclear and Renewable Energy. Escuela Técnica Superior de Ingenieros Industriales (ETSI) - School of Industrial Engineering, Technical University of Madrid, Madrid, Calle de José Gutiérrez Abascal, 2, 28006, Spain

Dry Reforming of Methane (DRM) is a promising route for syngas production while valorizing and eliminating important greenhouse gases as CO₂ and CH₄. However, its high endothermicity demands efficient heat transfer at temperatures above 1073 K, and catalyst deactivation by coking remains a major challenge. In particular, we are analysing the use of liquid metal reaction media to avoid coking accumulation. Developing reliable process models for such reactor concepts requires the integration of detailed reaction kinetics with robust process simulation tools. This work presents a methodological framework for implementing complex, multi-step Langmuir-Hinshelwood (L-H) kinetic models. The framework is demonstrated through a case study on DRM coupled with the Reverse Water-Gas Shift (RWGS) reaction, tailored for a hypothetical liquid metal catalytic environment. A detailed 23-step surface mechanism is simplified by assuming the dissociation of adsorbed CH₄ and the surface reaction between adsorbed CO₂ and H as the Rate-Determining Steps (RDS) for DRM and RWGS, respectively. It incorporates the unique properties of liquid metals, such as weak adsorption and carbon dissolution into the bulk, to minimize coke formation terms. The derived rate equations are implemented in custom Python scripts to model an isothermal Plug-Flow Reactor (PFR). Using literature-derived kinetic parameters as a baseline. However, calculation runs into the lack of experimental data that allow its validation, which becomes critical aspect to be able to estimate the chemical kinetics of the reaction itself. As a result, a series of experiments are proposed to validate these design tools for DRM in liquid metal. The results highlight the framework's capability for preliminary performance assessment and sensitivity analysis. This study provides a foundational kinetic framework open-access workflow for incorporating advanced heterogeneous kinetics into process simulation, serving as a template for evaluating novel reactor designs where commercial simulator options are limited or cost-prohibitive.

The core contribution of this work is procedural and computational. It provides a clear, reproducible pathway from fundamental kinetic theory to executable process simulation. Key achievements of the framework include:

- The seamless integration of user-defined kinetic expressions within steady-state reactor models.
- The ability to model coupled reaction networks (DRM and RWGS) with proper thermodynamic consistency.
- The facilitation of sensitivity analyses, crucial for identifying critical parameters (e.g., adsorption constants) for future experimental campaigns.

Future work should focus on applying this framework to systems with available experimental data for full validation and the adjusted kinetic parameters for specific liquid metal alloys. Furthermore, model extension to adiabatic and multi-stage reactor configurations, coupled with techno-economic analysis, is essential to advance the industrial feasibility of this promising technology for sustainable syngas production. Critical technical milestones include the construction of fluid-mechanic demonstrators, the execution of high-temperature reaction experiments, and the development of specialized structural materials and carbon extraction systems capable of sustained high-temperature operation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166999: Bayesian Optimization-Based Performance Enhancement of Pneumatic-Hybrid Diesel Generators for Remote Power Systems

Joseph-Kantole Basakay *, Eudes-Tshitshonu Kabeya and Adrian Ilinca

Mechanical Engineering, École de technologie supérieure, Montréal, Canada

Diesel generator sets remain a primary source of electricity in many remote and isolated areas due to their robustness, dispatchability, and ease of deployment. But their high fuel consumption and emissions of pollutants pose economic challenges and environmental concerns, especially in regions with high fuel transportation costs. Improving the efficiency of diesel-based power generation is essential for enhancing the sustainability and reliability of off-grid energy systems.

Pneumatic hybridization of diesel engines is a promising method of enhancing brake thermal efficiency and specific power output. In this approach, compressed air is used to assist the intake process and modify in-cylinder thermodynamic conditions, potentially improving combustion efficiency while reducing fuel consumption and emissions.

This study proposes a data-efficient optimization framework combining Diesel-RK engine-cycle simulation with Bayesian optimization. The Diesel-RK model is treated as a computational black-box function that maps controllable engine operating variables to performance and emissions-related outputs. The optimization problem is formulated with multiple objectives, including maximizing brake thermal efficiency and minimizing brake-specific fuel consumption, while satisfying operational constraints, such as the required electrical power output and the allowable peak in-cylinder pressure.

Bayesian optimization is particularly suited to optimization problems involving computationally expensive black-box models such as Diesel-RK engine simulations. In contrast, widely used population-based metaheuristic algorithms, including genetic algorithms, particle swarm optimization, and differential evolution, typically rely on large populations of candidate solutions and repeated generations of objective function evaluations to converge toward optimal solutions. When each evaluation requires a detailed engine-cycle simulation, these methods can result in high computational costs. Bayesian optimization constructs a probabilistic surrogate model of the objective function using a Gaussian process. In addition, it guides the search using an acquisition function that balances exploration of the design space and exploitation of promising operating regions. This surrogate-based strategy allows for efficient identification of candidate optimal solutions while significantly reducing the number of expensive simulation evaluations.

The proposed framework aims to determine optimal operating conditions for pneumatic-hybrid diesel generators for remote power applications. The analysis will quantify the influence of pneumatic assistance on brake thermal efficiency, fuel consumption, and emissions indicators, including nitrogen oxides and soot formation. In addition, the study will evaluate the computational efficiency of Bayesian optimization relative to conventional metaheuristic methods, focusing on convergence behavior and the number of required simulation evaluations.

The proposed methodology provides a systematic framework for optimizing pneumatic-hybrid diesel generators used in remote and off-grid energy systems, aiming to improve fuel efficiency, reduce operating costs, and mitigate environmental impacts associated with diesel-based electricity generation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-155825: Biofuel Production from Agricultural Waste: Efficiency and Emissions Study

Goo Shao Kang

Faculty of Chemical Engineering and Energy Engineering, University of Technology Malaysia, Skudai, Johor Bahru , 81310, Malaysia

The increasing global energy demand and environmental concerns associated with conventional fossil fuels have accelerated scientific interest in renewable alternatives. Among the available renewable options, biofuels derived from agricultural waste present a promising pathway to reduce carbon emissions, enhance waste utilization, and support regional energy security. This study focuses on the production efficiency and emission characteristics of biofuel generated from agricultural residues, particularly lignocellulosic biomass such as rice husk, corn stover, palm oil residues, and sugarcane bagasse. The overarching aim is to assess how agricultural waste can be transformed into viable biofuels while maintaining economic and environmental sustainability.

Agricultural waste represents an abundant yet underutilised resource, especially in regions where farming activities dominate national economies. Large quantities of biomass are produced annually and typically subjected to open burning or natural decomposition, leading to methane release, particulate matter formation, and soil nutrient degradation. Converting these waste streams into biofuel offers dual benefits: waste reduction and renewable energy generation. However, key challenges remain in optimising conversion processes, improving energy yield, and minimising emissions during production and end-use combustion. This study examines these challenges by comparing three main conversion pathways—thermochemical, biochemical, and transesterification processes—and evaluating their associated performance indicators.

The experimental component involves conducting controlled pilot-scale production trials using selected agricultural residues. Each biomass sample undergoes pre-treatment and moisture control before being processed through gasification, pyrolysis, or anaerobic digestion, depending on the fuel type produced. Gasification mainly yields syngas, pyrolysis produces bio-oil and biochar, while anaerobic digestion generates biogas rich in methane. Parameters such as reaction temperature, catalyst type, particle size, and oxygen supply are modified to determine the conditions that provide maximum yield. Initial results demonstrate that catalytic pyrolysis using palm kernel shells yields higher bio-oil volume compared to rice husk due to its higher lignin content, which enhances thermal breakdown. Similarly, biogas generation rates from sugarcane bagasse indicate a methane composition exceeding 60%, making it a viable substitute for liquefied petroleum gas.

In addition to production efficiency, this research investigates the emission profile of the produced fuels. Combustion testing is carried out in controlled laboratory burners and small-scale internal combustion engines. Emission factors measured include carbon dioxide, carbon monoxide, nitrogen oxides, particulate matter, and unburned hydrocarbons. Preliminary findings reveal that biofuel combustion generally produces lower net CO₂ emissions compared to fossil diesel, due to the carbon neutrality principle of biomass. However, certain biofuels exhibit higher NO_x formation, mainly attributed to elevated combustion temperatures and nitrogen content in the feedstock. Bio-oil derived from pyrolysis shows slightly higher particulate emissions due to incomplete volatilisation, which indicates that post-treatment and upgrading processes may be required to meet strict air-quality regulations.

The study also evaluates lifecycle environmental benefits by comparing greenhouse gas emissions across fuel production, processing, transport, and combustion stages. Results suggest that agricultural waste-based biofuels can reduce total lifecycle emissions by up to 75% relative to fossil fuels, depending on conversion technology and local resource availability. Economic considerations are also explored. Cost modelling indicates that agricultural biomass fuels become financially competitive when feedstock is sourced locally, processing systems are modular, and government incentives support infrastructure development.

In conclusion, this research confirms that agricultural waste has strong potential to be a sustainable feedstock for renewable biofuel production. With growing agricultural output and rising waste generation, biofuel systems can offer decentralised energy solutions, reduce environmental pollution, and contribute to national decarbonisation efforts. Nonetheless, further refinement in conversion technologies, catalyst improvement, emissions mitigation, and fuel upgrading is required before large-scale implementation. The outcomes of this work provide valuable insight into the interplay between fuel efficiency and emission performance, helping researchers, policymakers, and industries build strategies for scaling up agricultural waste-based bioenergy systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-161015: Characterization of Almond (*Prunus amygdalus*) Biodiesel through GC/MS Analysis: A Fatty Acid Profile and Fuel Property Correlation Study

Tobi Adeyinka^{1,2}

¹ São Paulo State University (UNESP), Ilha Solteira, Brazil

² Federal University of Technology, Akure (FUTA), Nigeria

This study presents an extensive compositional characterization of biodiesel produced from sweet almond (*Prunus amygdalus* “dulcis”) seed oil, complementing earlier analyses of its physicochemical and fuel performance properties. While previous investigations evaluated parameters such as viscosity, density, flash point, acid value, and cold-flow behavior, the present work focuses on the detailed molecular composition of both the feedstock and its resulting biodiesel, with particular emphasis on the fatty acid (FA) and fatty acid methyl ester (FAME) profiles. Comprehensive knowledge of these molecular constituents is critical for predicting biodiesel stability, combustion efficiency, and compliance with established international standards. The biodiesel was synthesized via base-catalyzed transesterification using a heterogeneous calcium oxide (CaO) catalyst derived from locally available materials. Gas Chromatography–Mass Spectrometry (GC/MS) was used to identify and quantify the dominant fatty acids in the crude almond oil and the corresponding methyl esters formed after conversion. GC/MS analysis of the raw oil revealed a rich fatty acid composition dominated by oleic acid (20.78%), n-hexadecanoic acid (10.65%), and octadecadienoic acid (8.47%). The distribution reflects an oil rich in both monounsaturated and polyunsaturated fatty acids, a desirable characteristic for biodiesel production due to its potential to enhance key fuel properties. Following transesterification, these fatty acids were transformed into their respective methyl esters, with oleic acid methyl ester (20.91%) and octadecadienoic acid methyl ester (18.32%) identified as the most abundant FAMES. The predominance of these unsaturated esters strongly correlates with the biodiesel’s previously reported superior cold-flow characteristics, including a pour point of -9 °C and a cloud point of -3 °C. High monounsaturated ester content improves fluidity and contributes to oxidative stability, while polyunsaturated esters enhance low-temperature operability. This correlation underscores the significance of molecular-level profiling in assessing and predicting biodiesel performance. Overall, the findings confirm that the fatty acid composition of almond seed oil plays a crucial role in determining the quality of the resulting biodiesel and its ability to meet ASTM D6751 and EN 14214 specifications. The results validate sweet almond seed oil as a viable, sustainable, and technically promising non-conventional feedstock for biodiesel production in Nigeria. Its adoption could support cleaner energy alternatives, improve energy security, and contribute meaningfully to addressing the food–fuel dilemma.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171384: Comparative Techno-Economic and Lifecycle Assessment of Diesel and Solar Storage Portfolios for Nigeria Towerco Low-Carbon Energy Supply in Weak Grid and Off-Grid Locations

Rotimi Abiodun Afe

Department of Electrical and Electronics Engineering, Lead City University, Ibadan, Nigeria

Telecommunications tower infrastructure providers in Nigeria operate under weak grid and off-grid conditions, where diesel plays a prominent role as an energy source, affecting energy cost and supply reliability decisive for business continuity. This paper presents a comparative techno-economic and lifecycle assessment of two power portfolios for TowerCo sites, namely diesel-only baselines and diesel-solar-battery hybrid systems. The study is anchored on a five-year project horizon and a stringent 99.98% uptime requirement, translating reliability into explicit constraints on allowable downtime and energy that are not served. Using operational available datasets such as fuel logs, genset telematics, site solar potential, and outage history, we develop site models that capture heterogeneity in grid quality, logistics exposure, and load behaviour. For each model, we evaluate candidate portfolios through a reliability-constrained optimisation of ownership (CAPEX, fuel, Operations and Maintenance, replacements, and operational overhead) while meeting autonomous and operational limits. Environmental performance is measured through the lifecycle greenhouse gas intensity, with transparent treatment of component lifetimes and residual value within the five-year boundary. The results include the least cost sizing ranges for solar and storage by model, expected diesel displacement and runtime reduction, delivered-energy cost, and lifecycle emissions trade-offs under sensitivity to diesel price volatility, outage severity, solar yield uncertainty, and battery degradation. The proposed framework provides a scalable, data-driven basis for prioritising hybridisation investments across TowerCo portfolios and for benchmarking fossil-renewable supply strategies for firm, low-carbon energy delivery in emerging market telecommunications infrastructure. Results present minimum-expense PV and storage sizing strings by model, reflecting substantial diesel reduction, and generator run-hour. The hybrids decrease delivered energy cost (per kWh) and yield attractive 5-year NPV and return on investment versus diesel-only baselines, while providing significant lifecycle emission reductions. Sensitivity analysis confirms the economic viability of hybrids, from diesel price volatility to degree of outage, solar yield uncertainty, and different rates for battery degradation. The model provides a scalable, data-informed approach for TowerCos to prioritise investments in hybridisation throughout their fleets and creates a benchmark for transitioning power infrastructure in new and emerging markets to stable, low-carbon sources of energy.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166283: Design, Fabrication, and Experimental Validation of a Truncated Curved-Blade Rotor Based on Fibonacci Spiral Geometry for Vertical-Axis Wind Turbines

Emilio Augusto Alavrez Garcia^{1,*}, **Cristobal Patiño Carachure**², **José del Carmen Onofre López**², **Francisco Ismael Celis Rodríguez**¹, **Xochil Aguilar Osorio**¹ and **Isidro Javier Dominguez**¹

¹ Universidad Tecnológica de Campeche, Campeche, Mexico

² Universidad Autonoma del Carmen, Ciudad del Carmen, Campeche, Mexico

This study presents the **design, fabrication, and experimental validation** of a vertical-axis wind turbine (VAWT) rotor with **truncated curved blades**, whose geometry is rigorously based on the **Fibonacci spiral** and the **aspect ratio defined by the golden ratio**. The proposed configuration aims to enhance aerodynamic performance and energy conversion efficiency for **small-scale wind energy applications**, particularly in low to moderate wind speed regimes. The rotor was conceived as an alternative solution for decentralized generation systems and hybrid renewable energy configurations.

The aerodynamic behavior and operational performance of the proposed rotor were evaluated through a comprehensive experimental campaign that included **controlled wind tunnel testing at laboratory scale** and validation under **real operating conditions**. To systematically analyze the influence of design and operational parameters, a **full factorial experimental design** $N=3KN=3^4KN=3K$ was implemented, considering **two primary input factors** ($K=2$): the **number of blades** ($NA=2, 4$, and 6) and the **wind speed** (Vv) at three levels, namely **6.4 m/s (low)**, **7.6 m/s (medium)**, and **8.8 m/s (high)**. The experimental setup was conducted in a wind tunnel with a controllable velocity range from **2.5 to 10 m/s**, allowing precise regulation of the flow conditions.

The response variables analyzed included the available wind power (Pe), rotor mechanical power (Pr), tip-speed ratio (TSR), power coefficient (Cp), and rotational speed (rpm). Based on the experimental data, empirical mathematical models were developed to quantify the effect of the selected factors on power generation, aerodynamic efficiency, rotational dynamics, and TSR behavior. These models enabled a detailed assessment of performance trends and interactions between blade number and wind speed.

The experimental results reveal **power coefficient values ranging from 0.55 to 0.57**, indicating a high level of aerodynamic efficiency for a vertical-axis configuration. The **available wind power** varied between **0.588 and 1.586 kW**, while the **rotor mechanical power** ranged from **0.344 to 0.887 kW**. The **TSR values** were found between **0.64 and 0.85**, and the **rotational speeds** varied from **155.6 to 288.62 rpm**, depending on the operating conditions and blade configuration.

Overall, the obtained results demonstrate that the proposed Fibonacci-based rotor exhibits robust aerodynamic performance and stable operational behavior, positioning it as a viable and efficient alternative for mini wind energy systems and hybrid mini wind-solar generation schemes. The integration of Fibonacci spiral geometry and golden ratio proportions provides a promising design pathway for improving the performance of vertical-axis wind turbines in distributed renewable energy applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166178: Development and Functional Assessment of Modified Polymers for Enhanced Oil Recovery in Non-Producing Reservoirs

Abhishek Tyagi * and Akhil Agrawal

Department of Microbiology, School of Life Sciences, Central University of Rajasthan, 305817, Ajmer, India

The recovery of residual oil from mature and non-producing reservoirs remains a major challenge owing to unfavourable mobility ratios and persistent rock fluid interactions. Although polymer flooding is a developed chemical enhanced oil recovery (cEOR) technique, the long-term performance of both synthetic and natural polymers is often limited by thermal degradation, salinity sensitivity, and shear-induced instability under reservoir conditions. These limitations highlight the development of polymer systems with modified molecular structures capable of enhancing mobility control and interfacial interactions. In this study, a chemically modified guar gum-based biopolymer was developed to overcome the limitations of conventional polymer flooding. The polymer structure was modified through a chemo-selective approach involving graft copolymerization, esterification, gel modification, crosslinking, and nanocomposite functionalization to achieve improved rheological stability and interfacial performance. Structural modification was confirmed by spectroscopic characterization, and the polymer system was systematically evaluated under reservoir-simulated conditions. Rheological investigations showed a significant enhancement in dynamic viscosity compared to native guar gum, along with stable pseudoplastic behaviour over a temperature range of 30–70 °C, showing improved resistance to gravitational flow and enhanced sweep efficiency. Interfacial studies showed a significant reduction in oil–water interfacial tension to 27 dyne/cm, accompanied by a decrease in surface tension, facilitating improved oil mobilization. Wettability alteration experiments on oil-aged carbonate rocks showed a clear transition from oil-wet to water-wet conditions. These findings were confirmed by flotation and qualitative wettability tests, including flotation and two-phase separation experiments, where polymer-treated carbonate powders migrated to the aqueous phase. The modified polymer also exhibited enhanced emulsifying activity with the formation of finer and more stable oil water droplets. The displacement efficiency of the developed polymer was further validated through oil reservoir simulating bioreactor (ORSB) flooding experiments conducted at 70 °C. Polymer flooding resulted in an additional oil recovery of more than 10% original oil in place (OOIP). The enhanced recovery performance results from the synergistic effects of viscosity enhancement, viscoelastic flow behaviour, interfacial tension reduction, wettability alteration, and stable emulsion formation. Overall, this study demonstrates that rational chemo-selective modification of natural polymers provides a sustainable and cost-effective pathway for developing high-performance EOR agents. The developed biopolymer system shows strong potential for deployment in mature and non-producing reservoirs under harsh reservoir conditions.

“Next-Generation Biopolymer Systems for Sustainable and Energy-Efficient Oil Recovery”



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171263: Development and Performance Evaluation of a Low Cost Manual Charcoal Briquetting System for Sustainable Rural Energy Applications

Ali Ahmad ¹, Hafiz Muhammad Safdar Khan ^{1,*}, Imran Shauket ¹, Kashif Mehmood ²,
Rao Husnain Arshad ² and Mohsin Noor ¹

¹ Department of Structures and Environmental Engineering, Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad 38000, Pakistan

² Department of Irrigation and Drainage, Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad 38000, Pakistan

Abstract

Introduction

The open burning of agricultural residues and lack of access to affordable energy remains a major challenge in the rural areas of the developing countries. One million tons of crop residue like rice husk, wheat straw and cotton stalks are wasted each year, contributing to excessive air pollution, greenhouse gases and wasted bioenergy. Briquetting of charcoal is a potential waste-to-energy conversion platform where low density agricultural byproducts can be converted into more clean and high energy density solid fuels to be used in decentralized rural energy use. This paper is aimed at analyzing the design, development and performance analysis of a low cost manually operated charcoal briquetting system, which is targeted towards the smallholder farmers with special attention being on the fuel quality, system productivity and its environmental performance.

Methods

The constructed system comprises of drum kiln to carbonize biomass, a size reduction unit to prepare charcoal and manually operated compaction press, which is made of locally available materials. Agricultural waste is burned in the presence of limited oxygen and reduced to fine charcoal dust and then mixed with other natural binders like starch and molasses. The briquettes obtained are tested in terms of bulk density, compressive strength, moisture content, calorific value, burning time and smoke emission. The controlled burning tests that are used to evaluate combustion performance and emission properties are conducted by use of the portable Testo-350 gas analyzer to compare between briquettes and the traditional biomass fuels.

Results

The system yields 25-35 kg/hr of charcoal briquettes with bulk densities of 650-820 kg /m³ and calorific values of 18-24 MJ/kg. The briquettes have a lifespan of 30-45 percent longer and much lower smoke emissions as compared to raw biomass fuels. According to the availability of crop residues in the region and the potential of their utilization as briquettes, the system suggests that 30-40 percent of agricultural residues can be diverted against open field burning. Moreover, the household fuel expenses will decrease by 25-35 percent. These findings demonstrate that biomass briquettes can be used as a dependable renewable solid fuel which can partially substitute the conventional fuels like firewood and coal in decentralized rural energy systems.

Conclusions

In general, the subject of manual charcoal briquetting has been demonstrated to be a technically and economically viable to rural energy solution. At the same time, it can serve to manage crop residues and domestic energy demands in households. The research shows the significance of emission controlled carbonization equipment and standardized production of briquette to enhance energy efficiency, minimize environmental pollution, and promote the use of briquette by rural populations.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166362: Energy Transitions and Health Equity: Case Studies From Developing Economies

Abdullahi Suleiman Umar

Department of Applied Science, School of General and Applied Sciences, Shehu Idris College of Health Sciences and Technology, Makarfi, Kaduna State, 812103, Nigeria

Introduction

Energy transitions in developing economies lie at the intersection of social justice, public health, and climate action. Over 80% of the world's 2.3 billion people without access to clean cooking solutions live in Sub-Saharan Africa, where continued reliance on traditional biomass fuels such as wood, charcoal, and agricultural residues contributes to more than 800,000 premature deaths annually, disproportionately affecting women and children. This study examines the relationship between energy transitions and health equity in developing economies, with particular attention to Bangladesh, South Asia, and Sub-Saharan Africa. It explores how the adoption of clean energy influences health outcomes, household medical costs, and gender equity. For low- and middle-income countries, transitioning from fossil-based and traditional biomass energy systems to renewable and clean energy sources presents both opportunities to reduce health disparities and challenges related to affordability, infrastructure, and policy implementation.

Methods

A systematic review methodology was employed, integrating qualitative assessments of policy interventions with quantitative analysis of empirical studies published between 2020 and 2025. Peer-reviewed literature focusing on household energy transitions in China, Bangladesh, Kenya, and broader Sub-Saharan African contexts was analyzed. Data sources included longitudinal household surveys, geospatial modeling studies, and difference-in-differences (DID) analyses. Key outcome measures were: (1) household medical expenditures before and after clean energy adoption; (2) health outcomes measured through respiratory disease incidence, mortality rates, and disability-adjusted life years; (3) gender-specific impacts on time use, income generation, and household decision-making; and (4) rural-urban disparities in energy access and health equity. Case studies were selected based on geographical diversity, empirical rigor, and representation of diverse clean energy technologies, including liquefied petroleum gas (LPG), solar home systems, biogas digesters, improved cookstoves, and micro-hydropower. The analysis also incorporated policy framework evaluations, infrastructure requirements, and cost-benefit considerations to identify scalable and context-specific solutions.

Results

The findings demonstrate that clean energy transitions yield significant health and economic benefits, with notable heterogeneity across populations. In China, household adoption of clean energy was associated with a 16.1% reduction in medical expenditures, with stronger effects observed among rural households, individuals with lower educational attainment, and medium-sized families. These reductions were mediated by improvements in income and health status. In Bangladesh, more than 6 million solar home systems had been installed by 2021, generating 489 MW of electricity and substantially expanding energy access. However, high upfront costs and infrastructure limitations constrained broader impacts, with renewables accounting for only 3.5% of total energy consumption.

Sub-Saharan Africa faces the most severe challenges: in 2022, approximately 990 million people lacked access to clean cooking, a figure increasing annually due to population growth outpacing infrastructure expansion. Geospatial analyses indicate that traditional biomass yields the lowest social net benefits, reflecting significant market failures. Gender impacts were particularly pronounced, as women in rural areas spend an average of 20 hours per week collecting firewood—time that could otherwise be allocated to education or income-generating activities. Clean cooking initiatives, such as biogas programs in East Africa, benefited approximately 0.5 million people and enabled participating women to save \$150–\$300 annually in

fuel costs. Health gains extended beyond reductions in mortality to lower incidences of chronic obstructive pulmonary disease, lung cancer, and ischemic heart disease. Projections suggest that universal access to clean cooking could avert 2.5 million premature deaths globally by 2030.

Conclusion

Energy transitions in developing economies offer substantial potential to advance health equity, gender equality, and climate objectives, particularly for vulnerable populations such as women, low-income households, and rural communities. Clean energy adoption reduces household medical costs, improves health outcomes, and redistributes time and economic opportunities more equitably. Nonetheless, achieving universal access requires addressing persistent barriers, including inadequate infrastructure, affordability constraints, and limited financing mechanisms. The global annual financing gap of approximately \$8 billion represents a small fraction of existing energy subsidies, underscoring that political commitment rather than resource scarcity remains the principal obstacle. Successful transitions demand gender-inclusive policies, innovative financing, strengthened local governance, and context-specific strategies grounded in energy justice. As climate change is projected to affect billions of people in coming decades, accelerating clean energy access constitutes essential infrastructure for sustainable development, public health protection, and social equity.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-155121: Enhanced Electrochemical Performance of Protonic Ceramic Fuel Cells via Controlled Ni Exsolution at the Anode

Abid Ullah^{1,*}, Muhammad Humayun² and Muhammad Waqar³

¹ Department of Advanced Energy and System Engineering, University of Science and Technology, Daejeon, 34113, South Korea

² Department of Basic Science, University of Engineering and Technology, Peshawar, 25000, Pakistan

³ Department of Chemistry, Malakand University, Malakand, 18800, Pakistan

Nickel (Ni) exsolution from perovskite oxide lattices has emerged as a highly effective strategy to develop active, stable, and coking-resistant anodes for protonic ceramic fuel cells (PCFCs). Conventional Ni-based anodes, although widely employed due to their excellent catalytic activity toward the hydrogen oxidation reaction (HOR), suffer from several critical challenges under typical operating conditions. These include severe degradation caused by Ni particle agglomeration, delamination from the ceramic backbone, and carbon deposition when exposed to hydrocarbon fuels. Such structural and chemical instabilities significantly limit the long-term durability and performance of PCFCs. To address these limitations, the present study explores the *in situ* exsolution of Ni nanoparticles from doped perovskite oxide anodes as a means to achieve strong metal-support interaction and enhanced catalytic robustness. During controlled reduction, Ni cations migrate from the perovskite lattice to the surface, nucleating as uniformly distributed nanoscale particles that are partially embedded, or “socketed,” into the oxide framework. This anchored configuration ensures excellent thermal and mechanical stability, preventing particle coarsening and detachment even under prolonged operation. The resulting exsolved Ni-oxide interface provides abundant active sites for electrochemical reactions and facilitates rapid charge and proton transfer at the electrode-electrolyte boundary. In this work, the exsolution behavior of Ni from doped perovskite anodes was systematically investigated under various reduction temperatures and atmospheres to tune nanoparticle size, distribution, and density. Comprehensive structural and microstructural characterizations using X-ray diffraction (XRD), scanning and transmission electron microscopy (SEM and TEM), and X-ray photoelectron spectroscopy (XPS) confirmed the formation of finely dispersed, metallic Ni nanoparticles anchored firmly to the perovskite surface. Electrochemical analyses, including current-voltage (I-V) characteristics and electrochemical impedance spectroscopy (EIS), demonstrated that the Ni-exsolved anodes exhibited substantially lower polarization resistance and higher peak power density than their conventional Ni-impregnated counterparts. The enhanced electrochemical performance is attributed to the synergistic effect between the exsolved Ni nanoparticles and the perovskite lattice, which collectively promote efficient HOR kinetics, proton conduction, and electronic transport. Moreover, redox cycling experiments revealed remarkable reversibility of the exsolution process, with Ni nanoparticles re-dissolving and re-exsolving without loss of performance or structural integrity. This self-regenerative capability contributes to long-term operational stability and resistance to fuel impurities, such as carbonaceous species, thereby mitigating coking and degradation. Overall, this study highlights Ni exsolution as a transformative approach for the rational design of advanced PCFC anodes that combine high catalytic activity, structural resilience, and long-term stability. The findings provide fundamental insights into the relationship between exsolution chemistry, microstructural evolution, and electrochemical functionality. By leveraging the unique properties of exsolved metal-oxide interfaces, this work contributes to the development of next-generation, high-efficiency, and sustainable PCFC systems for clean energy conversion and storage applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-167028: From Firm Capacity to Flexible Adequacy: Rethinking Capacity Metrics for Renewable-Dominant Power Systems

Eudes-Tshitshonu Kabeya *, Joseph-Kantole Basakayi and Adrian Ilinca

Mechanical Engineering, École de technologie supérieure, Montréal, Canada

The rapid transition toward power systems with high shares of renewable energy raises fundamental questions about how system adequacy, reliability, and resource value should be assessed in a decarbonized electricity sector. While renewable sources such as wind and solar photovoltaics provide clear environmental benefits, their variability, weather dependence, and limited controllability challenge conventional approaches to capacity planning and adequacy assessment. These challenges are further intensified by increasing electrification, sector coupling, and the growing presence of distributed and hybrid energy resources.

Classical resource adequacy frameworks were originally developed for power systems dominated by dispatchable thermal generation. Under assumptions of independent forced outages and statistically stationary demand, probabilistic metrics such as Loss of Load Probability (LOLP), Loss of Load Expectation (LOLE), Expected Unserved Energy (EUE), and Effective Load Carrying Capability (ELCC) have long been used to quantify system reliability. However, the increasing penetration of variable renewable energy introduces weather-driven variability, correlated generation patterns, and climate-related non-stationarity, challenging these foundational assumptions.

This systematic review evaluates whether classical probabilistic adequacy metrics remain structurally valid under high renewable penetration and examines how modelling approaches are evolving to represent correlated renewable variability, storage dynamics, and climate uncertainty. Following PRISMA 2020 guidelines, literature searches were conducted in Scopus, Web of Science, IEEE Xplore, and ScienceDirect for peer-reviewed studies published between 2000 and 2025. Preliminary screening identified 300 records, of which 30 full-text articles were selected for detailed analysis.

Early results indicate that while traditional adequacy metrics remain widely used, their implementation increasingly relies on chronological Monte Carlo simulation and weather-correlated modeling. Significant methodological heterogeneity persists, particularly in ELCC calculation, the representation of multi-day renewable droughts, and the definitions of reliability standards. These findings suggest that adequacy metrics remain relevant but require adapted modeling frameworks for renewable-dominant systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-167305: Hybrid Biomass Energy Systems for Rural Communities: A Case Study of Grenada County

Shaik Nasrullah Shareef^{1,*}, Veera Gnaneswar Gude² and Mohammad Marufuzzaman³

¹ Purdue University Northwest Water Institute, 2540 169th St. Schneider Avenue Building, Hammond, Indiana 46323

² Purdue University Northwest Water Institute, Purdue University Northwest, Hammond, IN 46323, USA

³ Industrial and systems engineering, Mississippi State University, Mississippi State, MS 39762

Renewable energy systems are increasingly critical for achieving decarbonization and long-term energy security, particularly in rural regions with abundant local resources. While solar and wind technologies have become cost-competitive, their intermittency limits reliability when deployed independently. Biomass, by contrast, offers dispatchable renewable power but faces economic challenges related to feedstock logistics. This study evaluates a biomass-led hybrid renewable energy system (HRES) for Grenada County, Mississippi, integrating biomass (feedstock includes tree species, including softwoods such as loblolly and shortleaf pine, and hardwoods such as white and red oak, ash, beech, sweetgum, cottonwood, poplar, hickory, and others within a 45-mile radius considering transport costs), solar photovoltaic (PV), and wind resources to enhance system reliability and reduce environmental impacts. System performance and optimization were assessed using the System Advisor Model (SAM) and the Hybrid Optimization of Multiple Energy Resources (HOMER). The proposed configuration comprises approximately 80% biomass, 10% solar PV, and the remaining share from wind, producing a total annual electricity output of about 423 GWh sufficient to meet regional demand which exceeds domestic, industrial and other energy demands of the county. The subsystem levelized cost of energy (LCOE) was estimated at 12.10 cents/kWh for biomass, 4.07 cents/kWh for solar PV, and 8.62 cents/kWh for wind, with the overall hybrid cost influenced primarily by biomass feedstock transportation and storage. Environmental impact assessment (LCA) based on U.S. EPA eGRID and IPCC factors indicates that the hybrid system achieves a weighted emission intensity of approximately 28.4 kg CO₂-eq/MWh, representing a reduction of over 94% compared to the regional grid. When scaled to annual generation, this corresponds to roughly 197,000 metric tons of avoided CO₂-equivalent emissions per year, alongside 80–95% reductions in acidification and eutrophication impacts. The results demonstrate that biomass-anchored hybrid systems can provide a reliable, low-carbon pathway for rural energy development, with further cost reductions achievable through targeted policy incentives and financing support. Overall, the findings from this study substantiate the system's value proposition as context-responsive rather than universally optimal: regions with comparable resource conditions and similar rural development objectives may adapt the framework, provided that ecological limits, institutional capacity, and feedstock governance are explicitly addressed.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165606: Hybrid Neuro-Fuzzy Controllers for Robust Maximum Power Point Tracking under Variable Environmental Conditions

Casimiro Agostinho^{1,*} and **Fabio Meneghetti Ugulino de Araujo**²

¹ Department of Control and Automation, Federal University of Rio Grande do Norte (UFRN), Natal, 59078-970, Brazil

² Department of Control and Automation, Federal University of Rio Grande do Norte, Natal, Lagoa Nova 59078-900, Brazil

I.Introduction

Global energy security positions solar energy as a strategic alternative, although the efficiency of photovoltaic systems is constrained by the non-linear nature of I-V curves under environmental variations. MPPT techniques are essential for optimizing this operation. However, conventional methods, such as P&O, fail under transient regimes. This work proposes the ANFIS model as a robust solution, integrating Artificial Neural Networks and Fuzzy Logic to provide dynamic adaptation without the need for complex mathematical modeling.

II.Methodology

An experimental database of 17,193 real-world irradiance samples, collected from a university plant, was utilized. The system was sized using Yingli polycrystalline modules (245 W, 15.1% efficiency) and simulated within the MATLAB/Simulink environment. The model was trained with 80% of the data and validated with the remaining 20%, exploring four scenarios that varied the number of membership functions (5 and 8) and training epochs (100 and 150). The ideal configuration was defined by the lowest prediction error and the highest coefficient of determination (R^2).

III.Results

Simulations confirmed the high tracking capability of the ANFIS controller. It was observed that increasing the training to 150 epochs significantly optimized the stability of the estimated power. Despite initial oscillations typical of the transient regime, the voltage () and current () curves converged rapidly. Scenario B_2 (8 functions, 150 epochs) exhibited superior performance, achieving an R^2 of 0.91 and the lowest Mean Squared Error (MSE) of 0.6895.

IV.Conclusions

The ANFIS model proved highly effective in extracting the maximum power point under real-world disturbances. The integration of climatic and electrical variables resulted in rapid responses and low oscillation around the MPP, validating the technique as a robust tool for the optimization of photovoltaic systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166247: Optimization of a Novel Cu⁺-Based Perovskite Chloride Absorber for Improved Photovoltaic Efficiency Targeting 23%

Moiz Abdul *, Mohammed Saleh Alshaikh and Ahmed N. M. Alahmadi

Faculty of Electrical Engineering, Umm Al Qura University, Makkah 21955, Saudi Arabia

Perovskite solar cells have evolved as a revolutionary photovoltaic technology in just over a decade, with power conversion efficiencies that have been proven to be higher than 26%. The exceptional performance of these materials can be attributed to the exceptional optoelectronic properties of ABX₃-structured materials. These properties include the long diffusion lengths of charge carriers and high absorption coefficients. A substantial amount of research has been conducted on non-toxic, all-inorganic alternatives as a result of concerns with the long-term stability of high-performance formulations and the toxicity of lead.

This computational study aims to employ SCAPS-1D device modelling to predict novel lead-free photovoltaic absorbers utilising copper(I) perovskite chlorides (CuMCl₃, where M = Fe, Cr, Zn) with a target power conversion efficiency (PCE) of 23%. CuMCl₃ compounds are selected due to their lower total energies compared to caesium-based alternatives and their direct, tuneable bandgaps ranging from 1.4 to 1.6 eV, which closely approach the optimal Shockley-Queisser limit for single-junction cells. These compounds exhibit enhanced projected electron and hole mobilities by diminishing their carrier effective masses in comparison to CsPbCl₃. The A-site cation not only contributes to structural stability but also, due to its distinctive hybridisation of Cu⁺ and MCl₆ orbitals, plays an active role in the electronic structure, influencing electrical characteristics.

Detailed SCAPS-1D simulations of a conventional n-i-p architecture (FTO/TiO₂/CuFeCl₃/Spiro-OMeTAD/Au) demonstrated that CuFeCl₃ had an exceptional capability characterised by a bandgap of 1.45 eV. Through the precise optimisation of layer thickness, doping density, and interface characteristics, a simulated device achieved a peak power conversion efficiency of 23.2%. The performance of the device is characterised by an open-circuit voltage (VOC) of 1.12 V, a short-circuit current density (JSC) of 26.8 mA/cm², and a fill factor of 77.4%. A key benefit is the improved volatile organic compound (VOC), which signifies a minimal voltage deficit and implies a decrease in non-radiative recombination. Notwithstanding defect densities of 10⁴ cm⁻³, the material demonstrated exceptional defect tolerance inside the absorber bulk, maintaining an efficiency above 20%. The performance exhibited significant sensitivity to the quality of the interface. To limit recombination losses, it is crucial that the defect concentrations at the interfaces of the charge transport layer remain below 10 cm⁻².

The results indicate that Cu⁺-based perovskites have considerable promise as next-generation, lead-free photovoltaic materials, accomplished by optimising the all-inorganic composition for improved optoelectronic properties. The research offers a definitive theoretical framework and performance standards for experimental synthesis. Nevertheless, considerable obstacles remain, including the experimental stability of Cu⁺ inside the perovskite lattice to prevent oxidation and the reduction of moderate near-infrared absorption, which requires rather thick active layers. Addressing these issues via sophisticated manufacturing and interface engineering will be essential for converting this promising theoretical prediction into a high-performance, stable, and environmentally friendly solar cell technology.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165385: Photovoltaic Power Prediction Using a Hybrid Method Combining FFT and ANN

Fatima Wardi^{1*}, Oussama Khouili², Hafsa Khayrane¹, Mohamed Louzazni¹ and Mohamed Hanine²

¹ Science Engineer Laboratory for Energy, National School of Applied Sciences, Chouaib Doukkali University of El jadida, Morocco

² information technology laboratory, National School of Applied Sciences, Chouaib Doukkali University of El jadida, Morocco

A crucial element in the worldwide shift towards cleaner energy, renewable sources present a lasting alternative to traditional energy, significantly reducing carbon emissions and mitigating climate change. Solar energy, in particular, stands out as a highly advantageous resource, fostering technological progress, economic growth, and energy self-sufficiency. However, in order to accurately predict power generation, reliable and robust predictive models are required for improving accuracy and model performance in real-world practical solar applications. Sophisticated forecasting techniques must be developed due to the inherent intermittency of solar radiation and the growing demand for renewable energy. This study proposes a hybrid method for solar power prediction that combines Artificial Neural Networks (ANN) and the Fast Fourier Transform (FFT). The dataset used comprises 30 days of measurements, with 15 sampled values of global irradiance, ambient temperature (AT), and module temperature (MT) per day. To extract dominant periodic components, daily power profiles are first converted into the frequency domain using the FFT. In order to minimize noise while maintaining the crucial daily patterns of solar production, a frequency filtering procedure is then used to retain important low-frequency components. The input vector of the ANN model is then created by combining these extracted frequency features with meteorological data. The nonlinear relationship between environmental factors and photovoltaic power output is captured by the ANN through supervised learning. Statistical indicators such as RMSE (0.092), MAE (0.067), and the coefficient of determination ($R^2 = 99.44\%$) are used to evaluate the model using independent test data. An improvement over a traditional ANN model is demonstrated by a comparative analysis ($R^2 = 98.67\%$). Nevertheless, because of the comparatively small dataset and the lack of thorough testing under various operating conditions, the validation of the suggested approach is still restricted despite these encouraging results. To properly illustrate the robustness and generalization potential of the suggested approach, more research on bigger and more diverse datasets is required.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165244: Process Integration Strategies for High-Purity CO₂ Recovery from Acid Gas Mixtures in Gas Chemical Complexes

Bekzod Eshkulov

Transport and Civil Engineering Faculty, Karshi State Technical University, Karshi city, 180119, Uzbekistan

CO₂-rich streams generated by acid gas removal units in gas chemical complexes are usually treated as waste, despite their potential value as a technical product. However, conventional separation techniques are frequently only intended for gas purification, which leads to high energy consumption and poor CO₂ recovery purity. This study investigates process integration strategies to convert traditional acid gas treatment units into carbon capture systems that generate value in order to recover high-purity CO₂ from acid gas mixtures originating from natural gas processing. With a focus on reducing regeneration energy and increasing overall system efficiency, the suggested framework assesses the integration of absorption-based CO₂ separation with downstream conditioning, regeneration, and recycling stages. The analysis highlights the role of hybrid chemical loops in improving CO₂ selectivity while concurrently lowering solvent degradation, corrosion risks, and utility demand. It takes into account both traditional solvent-based systems and alkaline-assisted capture routes. The relationship between separation units and current plant utilities such as steam, electricity, and waste heat streams is given particular consideration because these factors are crucial in determining overall energy performance. To find critical integration points where heat recovery, material recycling, and process coupling can greatly increase separation efficiency and energy, and mass balance evaluations are used. Reusing low-grade heat from upstream units, optimising solvent regeneration, and carefully conditioning captured CO₂ to satisfy purity standards for technical and industrial applications are some of these integration opportunities. The findings show that, in comparison to traditional stand-alone configurations, integrated separation schemes can achieve high CO₂ purity appropriate for downstream use while lowering the specific energy consumption of acid gas treatment. Overall, the results show that upgrading current gas purification infrastructure into integrated carbon capture and utilisation platforms is feasible through process-level optimisation. By facilitating circular carbon approaches within gas chemical complexes and promoting more efficient use of fossil-based energy resources, such strategies aid in the shift towards more sustainable and energy-efficient industrial systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166724: Recent Advances in Perovskite Solar Cells: Materials, Stability, and Integration Strategies

Partha Protim Borthakur

Department of Mechanical Engineering, Dibrugarh University, Dibrugarh 786004, Assam, India

Introduction

Perovskite solar cells (PSCs) represent a transformative development in photovoltaics due to their high power conversion efficiencies (PCEs), solution-processable fabrication, and low material cost. Since their inception, PSCs have witnessed a dramatic improvement in PCE from 3.8% in 2009 to over 27% in certified single-junction devices, with perovskite–silicon tandem cells now exceeding 33.9% efficiency. Despite this progress, challenges such as poor long-term stability, lead toxicity, and scalability hinder their commercial deployment.

Methodology

This study synthesizes recent advancements in materials engineering, device architecture, and integration techniques. The materials analyzed include mixed-cation and halide perovskites (e.g., $\text{Cs}_x(\text{FA}_{0.4}\text{MA}_{0.6})_{1-x}\text{PbI}_{2.8}\text{Br}_{0.2}$), lead-free alternatives (e.g., Cs_2TiBr_6), and 2D/3D hybrid structures. Evaluation methods span experimental fabrication outcomes, theoretical simulations, and comparative analyses of transport layers (e.g., ZnO , CuSbS_2 , MBene) and encapsulation techniques (e.g., polymeric coatings, self-healing systems).

Results

The incorporation of dimensional and compositional engineering strategies—such as 2D Dion–Jacobson capping layers, covalent organic frameworks (COFs), and transition metal dichalcogenides (TMDs)—has led to marked improvements in stability and charge transport. Tandem and bifacial architectures have enabled PCEs exceeding 30%, while simulation studies indicate the potential for >33% with anti-reflective coatings. Lead-free compositions like Cs_2TiBr_6 have achieved simulated PCEs near 27%, demonstrating comparable promise without toxicity concerns. Advanced hole/electron transport layers, including SnO_2 -MBene and C60 -LiF- SnO_2 combinations, have significantly reduced charge recombination losses. Scalable manufacturing processes, such as blade coating and vapor-phase deposition, are facilitating the transition toward flexible and building-integrated photovoltaics (BIPVs). Encapsulation strategies have improved operational durability under moisture and UV exposure, while self-healing materials extend functional lifespan.

Conclusion

PSCs have reached the forefront of next-generation solar technology, achieving record-breaking efficiencies and notable breakthroughs in material science. However, further innovation is required to overcome issues of long-term environmental stability, reproducibility in large-scale fabrication, and lead toxicity. Continued interdisciplinary research into lead-free compositions, interface engineering, and scalable device processing will be crucial to enable the successful commercialization of PSCs. The integration of perovskites into tandem, flexible, and multifunctional platforms represents the next frontier in photovoltaic evolution.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166193: Renewables for Resilience: Do Renewable Capacity Additions Improve Energy Security and Cut Emissions? Panel Evidence From 12 African Countries

Chinasa Ebere Urama ¹, Chukwuemeka Valentine Okolo ², Afamefuna Angus eze ¹, Christian Agu ^{1*} and Shedrach Adzugbele Agbutun ³

¹ Department of Economics, Faculty of the Social Sciences, University of Nigeria, Nsukka, Nigeria

² Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, United States

³ Miva Open University Abuja, Nigeria

Rising carbon emissions and energy insecurity have become part of the major issues affecting the development of African economies. Renewable capacity additions, that is, renewable energy generation, through renewable energy sources, such as hydropower, solar power, wind power, and geothermal power, play a vital role in ensuring energy efficiency and are clean and environmentally friendly. The increasing deployment of renewable energy in African countries raises some serious questions about its role in strengthening energy security and reducing carbon emissions, even though they are widely recognised as pathways to resilience. However, there is a paucity of empirical evidence with robust causal implications to ascertain this claim in the case of Africa. This study is therefore aimed at investigating the impacts of renewable capacity additions—solar, wind, hydro, and geothermal—on improving energy security and reducing emissions in Africa. The study will make use of the panel ARDL estimation technique to analyse data across 12 African countries from 2000 to 2024. In order to ascertain the validity of the results obtained, the study will also employ the use of the fixed-effects estimation technique to serve as a robustness check. Energy security will be proxied by indicators like fossil fuel import dependence, electricity access rates, and frequency of supply disruptions. Carbon intensity and emissions will be used to capture environmental outcomes. The expected outcome of this study is such that renewable capacity additions will propel energy security in Africa both in the short and long run. Policy-wise, the findings from this study are expected to strengthen the argument that renewable energy is also a resilience-enhancing tool for African economies. By investigating the direct impacts of renewable capacity additions in improving energy security and reducing emissions in Africa, this study is crucial and holds potential for high-impact policy recommendations, actionable insights, and scholarly contributions that are crucial for the region's renewable energy generation trajectory.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166256: Safeguarding livelihoods through renewable energy innovations

Charity Tsatsi

National Transmission Company South Africa, Johannesburg, South Africa

Introduction:

South Africa's energy supply remains heavily reliant on coal, which provides about three-quarters of the country's national electricity and sustains nearly 90,000 jobs in coal-dependent provinces, such as Mpumalanga. While this reliance has historically ensured energy security and economic activity, it has also placed South Africa among the world's leading carbon emitters, undermining climate commitments and contributing to environmental degradation and public health risks. At the same time, renewable energy initiatives, notably the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), have added over six gigawatts of solar and wind power to the grid, now supplying roughly a quarter of electricity. However, the transition is constrained by challenges such as grid integration, funding shortages, and uneven policy enforcement.

Problem Statement: The central problem, which is South Africa's dependence on coal, creates a dual crisis: (1) escalating carbon emissions and climate vulnerability, and (2) socio-economic risks for communities reliant on coal mining and power generation. A rapid coal phase-out without safeguards could devastate livelihoods, while a slow transition undermines environmental and health objectives. The adverse impact is felt both globally (through emissions) and locally (through job insecurity, pollution, and unreliable electricity supply). The problem to be solved is how to balance emission reduction with social protection and energy reliability.

Why the Problem Must Be Solved: Failure to act deepens climate risks, worsens air quality, and jeopardizes South Africa's international commitments under frameworks such as the Paris Agreement. At the same time, inaction prolongs economic dependence on a declining industry, leaving coal communities vulnerable to unemployment and poverty. Solving this problem is essential to secure a sustainable, inclusive energy future that protects both people and the planet.

Research Methodology: This study will adopt a mixed-methods approach. Quantitative analysis will assess energy production, emissions data, and job trends across fossil and renewable sectors. Qualitative research, including policy analysis, stakeholder interviews, and case studies of REIPPPP projects, will explore governance challenges, community perspectives, and opportunities for just transition strategies. Comparative analysis with international energy transitions will provide lessons adaptable to South Africa's context.

Collaborators: The research will engage with government agencies (e.g., Department of Mineral Resources and Energy, Eskom), renewable energy developers, labor unions representing coal workers, and civil society organizations advocating for environmental justice. Academic institutions and international partners (such as climate finance bodies and technical experts from the International Renewable Energy Agency) will provide additional expertise and comparative insights.

By integrating technical, social, and policy dimensions, this research aims to propose pathways for a just and inclusive energy transition that safeguards livelihoods while advancing renewable innovation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-159718: Solar-Powered Hydrogen Production Enabled by a Robust and Efficient MoS₂/Ti₃C₂ Heterojunction Catalyst

Govinda raj Muniyandi

Departamento de Química, Universidad Técnica Federico Santa María, Av. España 1680, Valparaíso, Chile

The development of highly efficient and economically viable solar-driven catalysts for hydrogen (H₂) production is of paramount importance in the pursuit of sustainable and clean energy alternatives to fossil fuels. Among the materials explored for this purpose, transition metal dichalcogenides (TMDs) and two-dimensional (2D) materials have gained significant attention due to their unique structural, electronic, and surface properties, which make them promising candidates for photocatalytic applications. In particular, MXenes such as Ti₃C₂ stand out for their metallic conductivity, high surface area, hydrophilicity, and versatile functionalization possibilities. In this study, a series of MoS₂/Ti₃C₂ (X) heterostructured nanocomposites (where X = 1, 3, 5, 7, and 9 wt.%) were successfully synthesized via a simple one-step hydrothermal method. The synthesized materials were thoroughly characterized using state-of-the-art analytical and spectroscopic techniques to investigate their composition, morphology, crystallinity, and optical features. Photocatalytic hydrogen evolution tests were performed in a methanol–water sacrificial solution under visible-light irradiation to evaluate their activity. Among all samples, the MoS₂/Ti₃C₂ 5% composite demonstrated the highest hydrogen evolution rate, outperforming pure Ti₃C₂, pure MoS₂, and the other composites in the series. The superior photocatalytic performance of the MoS₂/Ti₃C₂ 5% heterojunction is attributed to the synergistic interaction between the MoS₂ nanosheets and Ti₃C₂ MXene layers, which facilitates more efficient interfacial charge transfer. The formation of a well-matched heterojunction promotes rapid electron migration while suppressing recombination of photogenerated electron–hole pairs, resulting in enhanced photocatalytic activity. Electrochemical impedance spectroscopy (EIS) and photoluminescence (PL) analyses further support this conclusion by revealing improved charge separation efficiency and lower recombination rates in the optimized composite. Overall, this work provides compelling evidence that 2D MoS₂/Ti₃C₂ hybrid structures serve as high-performance, durable, and cost-effective photocatalysts for solar-driven hydrogen production. The results not only highlight the potential of MXene-based heterostructures in renewable energy applications but also offer valuable design insights for developing next-generation hybrid photocatalysts for efficient solar energy conversion.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170219: Sustainable Bioconversion of Biomass-Derived Butyric Acid to Butanol Using *Clostridium* Species: Metabolic Engineering, Process Optimization, and Environmental Implications

Nkechi Miriam Nwaogaraku^{1,*}, Abdulrahman Itopa Suleiman² and Mustapha Omenesa Idris³

¹ Department of Biology, University of Wisconsin, Oshkosh, 54901, USA

² School of Applied Sciences, Department of Science Laboratory Technology, Kogi State Polytechnic, P.M.B 1101, Lokoja, Kogi State, Nigeria Directorate of Research and Innovation, Kogi State Polytechnic, P.M.B 1101, Lokoja, Nigeria

³ Interdisciplinary Research Centre for Membranes and Water Security, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

Interest in biobutanol as a top-rated biofuel and industrial solvent has increased due to its high energy density, low water-absorbing properties, and compatibility with existing fuel infrastructure systems. Converting butyric acid derived from biomass to butanol using species of *Clostridium* presents a promising approach for recycling carbon and valorising waste. Despite advances, challenges persist due to low conversion efficiency, product inhibition, and metabolic limitations, hindering large-scale implementation. This research examines the microbial conversion of butyric acid into butanol by solventogenic *Clostridium* species in a controlled anaerobic fermentation process. The process was optimized by altering pH levels, initial butyric acid concentrations, availability of electron donors, and the duration of fermentation. Metabolic flux was redirected towards solventogenesis by controlling redox balance and selectively supplementing nutrients. Substrate consumption and product formation were quantified using analytical techniques such as gas chromatography and high-performance liquid chromatography. Significant improvements to fermentation conditions led to a substantial increase in butanol production, resulting in high butanol selectivity and a decrease in the formation of by-products. The fermentation of butyric acid utilized a two-step process. The first stage process of upgrading is esterification, where the butyric acid is reacted with an alcohol. Butyric acid is separated from methanol in the presence of an acid catalyst to form methyl butyrate and water. The second step is hydrogenolysis of the butyrate ester in the presence of Hydrogen and a metal catalyst. The ester C-O bond is broken by hydrogenolysis, and the intermediates are hydrogenated to obtain biobutanol, and the corresponding alcohol utilized in the esterification is reusable. Reaction temperatures are normally between 180 and 260°C at high hydrogen pressures. This process reduced fermentation time and enhanced carbon efficiency relative to conventional acetone-butanol-ethanol (ABE) fermentation. The results show that *Clostridium* sp. can effectively re-uptake butyric acid and convert it into butanol, which suggests a strong potential for combining acidogenic and solventogenic bioprocessing methods. The conversion of butyric acid to butanol by *Clostridium* sp. constitutes a feasible and environmentally friendly biotechnological process for the production of sophisticated biofuels. This approach underpins circular bioeconomy principles by integrating waste-derived volatile fatty acids with renewable fuel production. Advances in metabolic engineering and process integration could make biobutanol production more scalable and economically viable.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-158612: Techno-Economic Analysis of Biomass Gasification for Decentralized Sustainable Aviation Fuel (SAF) Production

Carolina Amparo Santamarta Ballesteros *, Pablo Rodríguez Álvarez, Enrique García-Franco, David León Ruíz, Marcelo Fabian Ortega and David Bolonio Martín

Escuela Técnica Superior de Ingenieros de Minas y Energía, Universidad Politécnica de Madrid (UPM), Madrid, Spain

Introduction

The decarbonization of the aviation sector requires the deployment of renewable energy pathways capable of minimizing greenhouse-gas emissions while maintaining fuel quality and energy density. Sustainable Aviation Fuel (SAF) derived from biomass gasification and Fischer-Tropsch (FT) synthesis represents a viable route to achieve net-zero aviation. In Spain, the large availability of agricultural and forestry residues allows for decentralized production schemes located close to biomass sources.

Santamarta et al. (2025, Resources) proposed a conceptual decentralized SAF model based on residual biomass gasification but did not include detailed process validation. This study extends that framework by developing a rigorous Aspen Plus® simulation of the gasification stage and performing a techno-economic analysis to quantify the performance, syngas composition, and investment cost of a 5 MWth modular plant integrated into the decentralized SAF system.

Methods

The modeled process represents a downdraft gasifier using mixed vine-pruning and forestry residues with steam and oxygen as gasifying agents. The process flow consists of five main Aspen Plus® blocks:

RYIELD – biomass decomposition into elemental constituents (C, H, O, N, S, H₂O, ash)RGIBBS – global equilibrium for oxidation and reduction reactionsRCSTR – reforming and Water-Gas Shift (WGS) reactor for H₂/CO adjustmentCOOLER – controlled heat recovery and gas cooling to 350 °CCSEP – removal of solids and condensates.

To avoid full thermodynamic equilibration of the WGS reaction, the RCSTR was operated with a limited conversion, representing its kinetic limitation in real downdraft gasifiers and yielding a more realistic H₂/CO ratio close to 2.

Thermodynamic properties were calculated using the Redlich-Kwong-Soave (RKS) equation of state. Complete equilibrium was assumed in the main gasification zone, with total heat losses below 5%. Sensitivity analyses on temperature (850–1000 °C), equivalence ratio (ER = 0.25–0.35), and steam-to-biomass ratio (S/B = 1.0–2.5) were performed to optimize gas yield and composition. The target H₂/CO ratio (1.8–2.2) was selected for compatibility with FT synthesis.

Results

The optimum operating point was found at 950 °C, ER = 0.30, and S/B = 2.0, producing a clean syngas with 24.6 % H₂, 35.4 % CO, 33.7 % CO₂, and 4.9 % CH₄, resulting in an H₂/CO ratio of 1.98, cold-gas efficiency (CGE) of 49.3 %, and carbon conversion of 85 %. The lower heating value (LHV) reached 11 MJ·Nm⁻³, consistent with high-performance O₂ + H₂O gasification systems. Limiting the WGS extent reduced CO₂ formation (≈ 29 %) and improved agreement with pilot-scale data.

The techno-economic analysis, based on cost correlations integrated in Aspen Plus®, yielded a total CAPEX of 12 million euros for the 5 MWth modular unit. The gasifier accounted for 3.5 M€ (≈ 29 %) of the investment, followed by gas cleaning (21 %) and auxiliary systems (18 %). These results validate the assumptions used by Santamarta et al. (2025) and demonstrate the technical and economic feasibility of modular SAF production plants in Spain.

Conclusions

The Aspen Plus® model provides both technical and economic validation of the decentralized SAF concept. The combination of steam-oxygen gasification and partial WGS

conversion delivers a syngas suitable for direct Fischer-Tropsch synthesis ($H_2/CO \approx 2$, $LHV \approx 11 \text{ MJ}\cdot\text{Nm}^{-3}$) with realistic process behavior.

The derived CAPEX of 12 M€ per 5 MWth unit supports the economic viability of a distributed network of small gasifiers capable of valorizing local biomass while minimizing transport and emissions. This integrated simulation-economic framework bridges the gap between conceptual design and industrial deployment, strengthening the basis for SAF production within the European renewable-energy transition.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170900: Thermo-Fuel Characterization of Bio-Composite Charcoal Briquettes Derived from Argo-Forest Wastes

Muhammd Hamid Mehmood *, Hafiz Muhammad Safdar Khan and Imran Shauket

Department of Structures and Environmental Engineering, Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad 38000, Pakistan

Biomass materials can serve as a good alternative source of renewable energy that will help decrease reliance on fossil fuels and will help decrease environmental pollution. Charcoal specifically burns more efficiently and generates less smoke emissions than raw biomass, leading to minimal greenhouse gas emissions. The biomass to charcoal briquettes provide a combined solution to energy insecurity, waste management, and environmental sustainability. This study examines the fuel and environmental characteristics of charcoal briquettes made using rice straw, sugarcane leaves, sawdust, maize cobs, and forest residues. It sought to assess their relevance as clean solid fuels in domestic and small-scale energy usages. The agricultural and forest residues were subjected to controlled carbonization and then briquette formation was carried out through low compaction pressure (no more than 7 MPa) and starch as a natural binder. All the experimental analyses were carried out in accordance with the standard procedures and generally accepted tests. Proximate analysis showed a percentage of water content, volatile matter, ash content, and fixed carbon. The resulting briquettes also showed a calorific value ranging between 16.6 and 22 MJ kg⁻¹, which means that the energy density of these briquettes is favorable and is comparable to those of solid fuels in common use. A comparative evaluation against the locally available coal revealed that the resulting charcoal briquettes had much lower concentrations of nitrogen and sulfur, and this implied that there was less promise of harmful emissions like NO_x and SO_x during combustion. All these attributes affirm the environmental benefits of charcoal produced through biomass against traditional coal fuels. Moreover, briquettes made of biocomposites of agricultural residues had a better fuel consistency and burning efficacy than the ones made up of single constituents. The results indicate that biocomposite charcoal briquettes show promise as an environmentally friendly and sustainable substitute of firewood and coal. This strategy is the way to offer a viable avenue of transforming agricultural wastes into clean energy sources that will serve the decentralized power facilities and help achieve the sustainable energy transition and resource efficiency.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-163264: Unveiling the Role of Donor–Acceptor Attachment Sites in Molecular Design for High-Performance Organic Solar Cells: A Theoretical Study

Sana Abbas^{1,*}, **Usman Ali**² and **Abdessamad Tounsi**¹

¹ LGEEI, Faculty of Science and Technology, Sultan Moulay Slimane University, Beni-Mellal, Morocco

² Department of Physics, University of Rome Tor Vergata, Rome, Italy

Organic solar cells (OSCs) based on π -conjugated small molecules are attracting growing interest as lightweight, flexible, and solution-processable photovoltaic technologies compatible with sustainable energy strategies. Within this class of materials, acceptor–donor–acceptor (A–D–A) chromophores have emerged as a particularly versatile platform, where subtle modifications of donor–acceptor connectivity can substantially alter energy levels, optical gaps, and charge-transport descriptors. Understanding how these intramolecular design choices control key electronic and photophysical properties is therefore essential for the rational development of next-generation OSC active layers.

In this contribution, we present a systematic theoretical investigation of a family of A–D–A small molecules constructed from an electron-rich pentathiophene (PTP) core and electron-deficient trimethylxanthine (TMX) terminal units. By varying only the attachment sites of the two TMX fragments around the PTP ring, four symmetry-distinct isomers are generated within a single chemical platform, allowing us to isolate the effect of donor–acceptor connection pattern without changing the underlying building blocks. Ground-state geometries and electronic structures are obtained through density functional theory (DFT), while excited-state properties are explored using time-dependent DFT (TD-DFT) in an implicit solvent environment. The workflow includes the calculation of frontier orbital energies, density-of-states profiles, chemical reactivity indices, and exciton binding energies, together with simulated absorption and emission spectra and an analysis of charge-transfer character.

Charge-transport descriptors are evaluated within the non-adiabatic Marcus hopping framework from intramolecular reorganization energies, Gibbs free energy differences, and effective electronic couplings extracted from frontier-orbital splittings. In addition, a semi-empirical photovoltaic model is employed to estimate open-circuit voltage, light-harvesting efficiency, fill factor, and normalized power-conversion descriptors based on the computed energetics and oscillator strengths.

The presentation will focus on how this integrated DFT/TD-DFT and Marcus theory framework links donor–acceptor attachment sites to changes in electronic structure, optical response, and charge-transport metrics across the four PTP/TMX isomers. Emphasis will be placed on extracting general structure–property relationships and qualitative design rules that can inform the future synthesis and device integration of A–D–A chromophores for organic solar cells, rather than on reproducing specific experimental devices or quantitative efficiencies.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Session 2. Energy Conversion (Heat and Mass Transfer, Combustion, Thermodynamics, Entropy & Exergy Analysis)

sciforum-162733: Optimization of Heat and Mass Transport in Mechanical Devices for Hybrid Solar–Thermal Energy Harvesting

Helal Uddin ^{1,*} and Qodirova Lola Zafar Qazi ²

¹ Department of Mechanical Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200, Bangladesh

² Department of English language teaching, Millat Umid University, Namangan, Uzbekistan

Hybrid solar–thermal energy harvesting—Solar–thermal hybrid energy harvesting systems are a vital development in renewable energy technology, in that they have the ability to produce electrical power and potentially useful thermal energy simultaneously in the same footprint. The conflicting performances of these mechanical apparatus can be highly limited by inefficient heat transfer and ineffective transport of the working mass of liquids and gases, resulting in photovoltaic thermal degradation and high-level exergy loss. The goal of the proposed study is to optimize the heat and mass transport processes that occur in a hybrid solar–thermal mechanical system to make the most out of energy recovery and to guarantee long-term system performance reliability. The governing equations of continuity, momentum, and energy conservation were written in the form of three-dimensional numerical modeling based on the finite volume method (FVM). The genetic algorithm used was the Multi-Objective Genetic Algorithm (MOGA), which was applied to obtain the optimum geometry parameters, that is, analysis of the effects of variable cross-section microchannels on the attributes of the flow and thermal boundary layer disruption. According to the optimization results, at a Reynolds number of 2000, the suggested microchannel geometry raised the average Nusselt number by 43.5% when compared to a smooth channel configuration. As a result, the photovoltaic component's effective operating temperature dropped by 12.6°C, corresponding to a 9.3% increase in relative electrical efficiency. The hybrid system's highest thermal efficiency, net energy gain (76.8%), satisfied the acceptable 16.3% increase in pumping power requirements due to friction penalties. The results of the experiment indicate with no doubt that the optimization of the mass transport processes is a critical component of the facilitation of the high-quality thermal regulation. The results of the experiment indicate without doubt that the optimization of the mass transport processes is a critical component of the facilitation of high-quality thermal regulation. This optimization policy has presented a technically effective channel for the creation of high-grade, high-efficiency industrial solar collector equipment and has laid strong groundwork regarding the development of renewable energy technology that is sustainable and poly-generational.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166202: 3E (Energy, Exergy, and Environment) Analysis of Waste Heat Recovery Gas Engine Power Plant with Organic Rankine Cycle Model

Anthony Nathaniel, Hifni Mukhtar Ariyadi *, Rico Rian Avero, Khasani, M. Agung Bramantya and Willie Prasadha

Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Indonesia

Introduction

The rapid growth of electricity demand in Indonesia has led to the extensive operation of gas engine power plants (PLTMG) due to their flexibility and relatively high efficiency. Nevertheless, a significant fraction of the fuel energy, typically around 25–30%, is rejected to the environment as exhaust gas waste heat. The exhaust gas temperature of gas engines commonly ranges from 350 to 450°C, indicating a considerable potential for waste heat recovery (WHR). Organic Rankine Cycle (ORC) technology has been widely recognized as an effective solution for converting low- to medium-temperature waste heat into useful electrical power.

Previous studies have demonstrated the feasibility of ORC integration with internal combustion engines. However, most investigations focus on generic operating conditions or rely on simplified thermodynamic models. Moreover, studies that simultaneously integrate energy, exergy, and environmental (3E) analyses using real operational data remain limited, particularly for gas engine power plants. Therefore, this study aims to evaluate the energetic, exergetic, and environmental performance of an ORC system integrated with an existing PLTMG using a comprehensive thermodynamic simulation framework.

Materials and Methods

A thermodynamic model of the ORC system was developed using Aspen HYSYS, which enables accurate representation of multiphase flows and heat exchanger behavior. Real operational data from a gas engine power plant were used as boundary conditions, including exhaust gas temperature and mass flow rate. The ORC configuration consists of an evaporator, turbine, condenser, and pump operating under steady-state conditions.

Six working fluids were investigated: R600 (butane), R600a (isobutane), R601 (pentane), R601a (isopentane), R134a, and R744 (CO₂). All simulations were conducted at a constant working fluid mass flow rate of 10 kg/s. The system performance was evaluated using energy and exergy analyses based on the First and Second Laws of Thermodynamics. Environmental performance was assessed by estimating fuel savings and the corresponding reduction in CO₂ emissions resulting from the additional power generated by the ORC system.

Results and Discussion

The simulation results indicate that the selection of working fluid has a pronounced impact on ORC performance. The turbine power output varies significantly among the investigated fluids, ranging from 139.5 kW for R744 (CO₂) to 1331 kW for R601 (pentane). Hydrocarbon-based working fluids generally exhibit superior performance due to better thermodynamic matching with the exhaust gas heat source.

The highest thermal efficiency of the ORC system is achieved using R601, reaching 21.89%, followed by R601a with 19.29%. In contrast, R134a and R744 demonstrate relatively low thermal efficiencies of 6.56% and 3.30%, respectively. From an exergetic perspective, R600 (butane) provides the highest exergy efficiency at 17.36%, indicating lower irreversibilities during energy conversion processes.

In terms of environmental performance, the integration of the ORC system results in a substantial reduction in fuel consumption and associated CO₂ emissions. The maximum CO₂ reduction is obtained with R601, reaching approximately 0.19 kg CO₂ per Nm³ of natural gas, while

R744 exhibits the lowest reduction at around 0.02 kg CO₂ per Nm³. These findings confirm that higher turbine power output directly translates into greater fuel savings and emission reductions.

The novelty of this study lies in the application of a comprehensive 3E analysis using Aspen HYSYS combined with real operational data from a gas engine power plant in Indonesia, as well as the systematic comparison of hydrocarbon and CO₂-based working fluids under identical operating conditions.

Conclusions

This study demonstrates that ORC-based waste heat recovery is a technically feasible and effective approach for enhancing the performance of gas engine power plants. The results show that ORC integration can generate additional net power ranging from approximately 140 kW to 1331 kW, depending on the selected working fluid. Among the investigated fluids, R601 (pentane) provides the best overall performance in terms of thermal efficiency and CO₂ emission reduction, while R600 (butane) achieves the highest exergy efficiency. Although CO₂ (R744) offers advantages in terms of safety and environmental compatibility, its thermodynamic performance is comparatively lower under the investigated conditions. Overall, the findings highlight the critical role of working fluid selection and demonstrate the effectiveness of a 3E-based evaluation framework for ORC applications in gas engine power plants.

References

1. Bari, S., & Hossain, S. N. (2013). Waste heat recovery from the exhaust of a diesel engine using Organic Rankine Cycle. *Applied Thermal Engineering*, 61, 355–363.
2. Nadaf, S. A., & Gangavati, P. B. (2014). A review on waste heat recovery and utilization from diesel engines. *Renewable and Sustainable Energy Reviews*, 29, 1–12.
3. Quoilin, S., Van Den Broek, M., Declaye, S., Dewallef, P., & Lemort, V. (2013). Techno-economic survey of Organic Rankine Cycle (ORC) systems. *Renewable and Sustainable Energy Reviews*, 22, 168–186.
4. Guo, Y., Wang, J., & Dai, Y. (2011). Thermodynamic analysis of a supercritical CO₂ Rankine cycle for low-grade heat recovery. *Energy*, 36, 327–335.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171462: Graphene functionalization strategies for enhanced thermal management performance in polyetherimide composites

Fatema Tarannum * and Keisha Walters

Chemical Engineering, University of Arkansas, 4183 Bell Engineering Center 1 University of Arkansas Fayetteville, Arkansas 72701

Efficient thermal management has become increasingly important as modern electronic devices continue to shrink in size while operating at higher power densities, leading to elevated heat fluxes and localized overheating. Polymer composites offer an attractive platform for thermal management due to their low density, processability, and cost effectiveness; however, their inherently low thermal conductivity limits performance. Incorporation of graphene- and graphite-based fillers has emerged as a promising strategy to enhance heat dissipation, yet achieving high thermal conductivity in polymer composites remains challenging due to interfacial thermal resistance, filler agglomeration, and degradation of graphene's lattice during chemical modification. Consequently, optimizing both polymer-filler interfacial interactions and preservation of intrinsic phonon transport pathways is essential. In this work, the influence of graphene functionalization strategies and synthesis routes on thermal transport was systematically investigated in polyetherimide (PEI) composites. Several graphene-based fillers, including pristine graphene nanoplatelets (GnPs) and thermally expanded graphite (EG), were examined to elucidate how chemical modification and structural integrity govern heat conduction in polymer matrices. Edge-oxidized graphene (EGO) was prepared using a controlled edge-selective oxidation approach that preserved the sp^2 -bonded basal plane while introducing oxygen-containing functional groups primarily at the sheet edges. This selective functionalization enhanced polymer-filler interfacial bonding without significantly disrupting phonon transport, resulting in an 18% increase in thermal conductivity at 10 wt% filler loading compared to pristine GnP/PEI composites. In contrast, basal-plane-oxidized graphene (BGO), produced using the Hummers method, introduced oxygen functionalities directly onto the basal plane, leading to increased defect density and lattice distortion. These structural disruptions significantly impeded phonon propagation, causing a 57% reduction in thermal conductivity relative to pristine graphene-filled composites. Raman mapping, X-ray photoelectron spectroscopy (XPS), and Fourier transform infrared spectroscopy (FTIR) confirmed preferential edge functionalization in EGO and extensive basal-plane disorder in BGO, underscoring the importance of oxidation site control. To further enhance long-range phonon transport, EG was incorporated into PEI via a solvent-casting technique. EG, obtained by thermal expansion of graphite intercalation compounds, forms a three-dimensional interconnected network of continuous graphene sheets with minimal interlayer contact resistance. Preservation of the worm-like porous EG structure during solvent casting enabled formation of an interpenetrating polymer-graphite network conducive to efficient phonon transport. As a result, thermal conductivity increased nearly linearly with EG loading, reaching 7.3 W/(mK) at 10 wt%, a substantial enhancement compared to pristine PEI (≈ 0.23 W/(mK)). The effect of intercalation chemistry on EG microstructure and performance was further evaluated using two expansion routes: H_2SO_4/H_2O_2 and $H_2SO_4/NaClO_3$. EG synthesized via the H_2O_2 route exhibited superior structural integrity, predominantly edge-localized oxidation, and enhanced graphitic continuity, resulting in thermal conductivities as high as 9.5 W/(mK) at 10 wt%. In contrast, EG produced using $NaClO_3$ showed greater basal-plane damage and reduced network continuity, yielding a lower thermal conductivity of 5.3 W/(mK). Raman ID/IG ratios, XPS oxygen speciation, and X-ray diffraction analysis corroborated these structural differences. Overall, this study demonstrates that controlling oxidation location, minimizing basal-plane damage, and preserving long-range graphitic networks are critical for achieving high thermal conductivity in polymer-graphene composites, providing key design principles for scalable thermal interface materials and advanced heat-spreading technologies.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170858: Heat Exchanger Optimization with Comparison of Plate-Joining Techniques

Svetlana Boshnakova

Center of Competence “Intelligent Mechatronic, Eco- and Energy-Saving Systems and Technologies”, Technical University Sofia, branch Plovdiv, 4000 Plovdiv, Bulgaria

Introduction: For the process fluid from the distillation column, a temperature reduction is needed, and originally an air-cooled heat exchanger has been used. In order to increase the energy efficiency, a plate heat exchanger is designed, manufactured, and put into operation as a substitute in this position. Several attempts to obtain the best applicable materials and welding technology for the plates have been made. The best solution has lasted eight years. In order to optimize performance and service life, two heat exchangers of the same construction and materials but with different joining methods of the plates are compared.

Method: Material for the construction of the air-cooled heat exchanger is X6CrNiTi18-10 (EN 10088-2). The initial plate heat exchanger is made of X2CrNiMo17-12-2 (EN 10088-2) and has a service life of five years. Its substitute is made from super austenitic stainless steel Avecta SMO 254 X1NiCrMoCuN20-18-7 (EN 10088-4), but it fails within a year due to defects in the large area of laser-welded seams. Detailed consideration of all operating conditions is performed, as well as corrosion evaluation. Comparison is made between the two applicable types of plate's welding processes—Tungsten Inert Gas (TIG) and Laser welding. The resulting structure and manufacturing technology are investigated. Possible post-weld treatment is proposed in order to reduce the remaining residual stresses. Consideration is made for heat utilization, and subsequently, a new material is proposed: NiCr23Mo16Cu (Hastelloy® C-2000®). After detecting leaking, the defective plates' edges are examined with visual and penetrant testing. Positive material identification is carried out. Microhardness of the base metal and welding zone is performed, together with microstructure analysis.

Results: The heat exchanger is operating on gasoline/crude oil with process inlet $T^\circ = 135 - 152^\circ\text{C}$ and process outlet $T^\circ = 78 - 95^\circ\text{C}$. For the crude oil, we have an ambient inlet temperature and an outlet of around 100°C . pH is 6 ± 0.5 , with an operating pressure of gasoline 5,4 bar and crude oil 12,5 bar. The overhead vapors of gasoline are directed to the plate heat exchanger. A comparison is done for two different welding methods/regimes for samples of the plates in order to simulate and detect the initial conditions that led to the defects. Both have used PA positions, autogenous weld without edge preparation for a thickness of 1.2 mm. TIG welding was performed at 50 A and 10 V, with a tungsten electrode diameter of 1.6 mm. Laser parameters were as follows: power 1800 W, speed of application 25 mm/s, distance to workpiece 120 mm, with Ar 100% gas at a flow rate of 4 l/min. For the TIG welding, the achieved values of microhardness in the welded zone are 200 - 220 HV1, and in the heat-affected zone, they were 191-208 HV1. Laser welding measurements yield, correspondingly, 230 - 246 HV1 and 174 - 193 HV1. For the laser method, the received hardness values are above the permissible limit and over 1.4 times higher than those shown by the base metal. It is vital to perform treatment after welding, which shows that in the welding zone the hardness value falls to 190-192 HV1.

Conclusion: The aim of the investigation is to define and propose the best mechanically reliable heat exchanger option for a critical refinery position. Resulting is that either additional filler material has to be specified for the welding or mandatory treatment for stress relief has to be applied in order to retain the corrosion resistance and operational life of the equipment.

Funding: The author acknowledges support from project BG16RFPR002-1.014-0005.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166313: CFD-Based Evaluation of the Effect of Storage Material Size on Heat Transfer and Flow Characteristics in Packed Beds

Aicha Eddemani *, Hayat El Baamrani, Ahmed Aharoune, Lahcen Bouirden and Ahmed Ihlal

Thermodynamic and Energetics Laboratory, Faculty of Science, Ibn Zohr University, BP8106, 80006 Agadir, Morocco

Packed rock-bed thermal energy storage (TES) systems represent a robust and economically attractive solution for large-scale solar energy storage, enabling enhanced efficiency, dispatchability, and operational flexibility of solar thermal power plants. This study presents an in-depth computational fluid dynamics (CFD) investigation of an air-rock packed-bed TES system, in which air is used as the heat transfer fluid (HTF). A two-phase local thermal non-equilibrium (LTNE) model is implemented within a porous media framework, with distinct energy conservation equations solved for the fluid and solid phases and interphase convective heat transfer explicitly modeled through appropriate closure correlations. The governing mass, momentum, and energy equations are numerically solved using a finite-volume approach and rigorously validated against experimental measurements reported in the literature. A systematic parametric study is performed to evaluate the influence of rock particle diameter on flow distribution, interphase heat transfer coefficients, pressure drop, thermocline evolution, and global storage performance during charging and discharging processes. The results demonstrate that particle size exerts a first-order control on the coupled thermal-hydraulic behavior of the packed bed. Specifically, smaller particle diameters significantly increase the specific surface area and enhance interphase convective heat transfer, resulting in steeper axial temperature gradients, thinner and more stable thermoclines, faster thermal front propagation, and improved utilization of the storage volume. These effects lead to higher energy storage capacity, increased charging effectiveness, and improved thermal efficiency; however, they are accompanied by a marked increase in pressure losses and pumping power requirements due to reduced bed permeability and higher flow resistance. In contrast, larger particle diameters promote higher bed permeability and more uniform velocity fields, thereby substantially reducing pressure drop and pumping energy consumption, but they exhibit lower heat transfer coefficients, delayed solid-phase thermal response, increased thermal dispersion, and broader temperature fronts, which degrade thermal stratification and limit effective energy recovery. The analysis further reveals that the optimal particle size represents a compromise between maximizing thermal performance and minimizing hydraulic losses, and that this trade-off becomes increasingly critical at higher operating temperatures and mass flow rates. Overall, the results provide detailed physical insight into the role of particle size in thermal and hydraulic performance and offer valuable CFD-based guidelines for the optimal design and scaling of packed-bed thermal energy storage systems for solar thermal applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-167477: Determination of the Maximum Figure of Merit of Alloy Silicon-Germanium and Thermoelectric Materials Containing Them

Irakli Nakhutsrishvili

Department of Optically Controlled Anisotropic Systems, Institute of Cybernetics of Georgian Technical University, Tbilisi, 0186, Georgia

We investigated the dependence of the maximum figure of merit of SiGe alloy on the material parameter B . We used $\text{Si}_x\text{Ge}_{1-x}$ samples with N- and P-type conductivity and different component compositions. For comparison, we calculated $(ZT)_{\max} - B$ dependences for SiGe, as well as for materials containing them according to the data available in the literature. For both types $\text{Si}_x\text{Ge}_{1-x}$ the dependence $(ZT)_{\max} - B$ forms a regular network together with the data for thermoelectrics containing SiGe and separately for Si or Ge. It is similar to the dependence $(ZT)_{\max} - B^*$ (generalized parameter) of thermoelectric materials. The temperature dependence of the electronic quality factor is also considered, which provides information on the presence of additional effects. For p- and n- $\text{Si}_x\text{Ge}_{1-x}$, these dependencies initially indicate the presence of additional scattering, and then band convergence and the bipolar effect are added.

Introduction

In this work, we used the dependence of the maximum figure of merit ($ZT = \sigma S^2 T / k$; σ —specific electrical conductivity; S —Seebeck coefficient; T —absolute temperature; and k —total thermal conductivity) of SiGe alloy on the material parameter $B = B_E / k_L$ ($B_E = \sigma S^2 / B_S$ is electronic quality factor, $B_S \cong$ is the scaled power factor, $S_r \cong 1.16 \cdot 10^4$ is the reduced Seebeck coefficient), and k_L is the lattice component of thermal conductivity. We used $\text{Si}_x\text{Ge}_{1-x}$ samples with p- and n-type conductivity and different component compositions. For comparison, we calculated $(ZT)_{\max} - B$ dependences for SiGe, as well as for materials containing them according to the data available in the literature [1,2].

Method

We used $\text{Si}_x\text{Ge}_{1-x}$ samples with different component compositions ($x = 0.7, 0.72, 0.76, 0.8$, and 0.83). Boron was used as a dopant to obtain p-type conductivity, and phosphorus was used for n-type conductivity. The initial charge carrier concentration was $3.2 \cdot 10^{26} \text{ m}^{-3}$. It was determined by measuring the Hall constant at room temperature. The studies were conducted at temperatures of 30–1150 °C: the upper limit was limited by the melting point of the alloy. The measurement error for S was ~3%, and for resistivity ρ ($=\sigma^{-1}$), ~5%. Thermal conductivity was also measured with an error of no more than ~7%. The methodology for **sample** preparation is described in **previous works** [3,4].

Results

In addition to our samples, parameter B was also calculated for $\text{Ge}_{0.9}\text{Bi}_{0.1}\text{Te}$, nano-SiGe, $\text{Si}+2\%\text{P}$, $\text{Si}_{0.88}\text{P}_{0.02}$, $\text{Si}_{80}\text{Ge}_{20}+2\%\text{P}$, $\text{Si}_{0.58}\text{Ge}_{0.42}$, $\text{GeTe}+1\%\text{Sb}$, $\text{GeTe}+3\%\text{Sb}$, nanocrystalline Si, $\text{Ge}_{0.98}\text{In}_{0.02}\text{Te}$, $\text{SiGe}+3\%\text{SrTiO}_3$, $(\text{Si}_{0.8}\text{Ge}_{0.2})_{0.98}\text{P}_{0.02}(\text{SiC})_{0.03}$, $\text{Cu}_{26}\text{Cr}_2\text{Ge}_6\text{S}_{32}$, $(\text{Si}_{0.8}\text{Ge}_{0.2})_{0.98}\text{P}_{0.02}(\text{SiC})_{0.015}$, $\text{Cu}_{26}\text{CrWGe}_6\text{S}_{32}$, $(\text{MnSi}_{1.7}/\text{Ge})_6$, $\text{SiGe}+5\%\text{Mg}_2\text{Si}$, GeTe , $\text{Ge}_{0.98}\text{Ta}_{0.02}\text{Te}$, $\text{Ge}_{0.92}\text{Ta}_{0.02}\text{Sb}_{0.06}\text{Te}$, SiGe , $\text{Si}_{95}\text{Ge}_5\text{P}_2$, $\text{Bi}_{0.06}\text{In}_{0.01}\text{Cd}_{0.02}\text{Te}$, $\text{Ge}_{0.888}\text{Sb}_{0.1}\text{In}_{0.012}\text{Te}$, $\text{Si}_{0.99}\text{P}_{0.01}$, $\text{GeTe}+0.1\%\text{C}_{60}$, $\text{Ge}_{0.89}\text{Sb}_{0.1}\text{In}_{0.01}\text{Te}$, $\text{GeTe}+5\%\text{Bi}$, $\text{Ge}_{0.995}\text{W}_{0.005}\text{Te}$, $\text{Ge}_{0.893}\text{Sb}_{0.1}\text{In}_{0.007}\text{Te}$, $\text{Ge}_{0.93}\text{In}_{0.01}\text{Bi}_{0.06}\text{Te}$, $\text{Ge}_{0.91}\text{Sb}_{0.09}\text{Te}$, $\text{Ge}_{0.92}\text{Sb}_{0.08}\text{Te}$, $\text{GeTe}+0.2\%\text{C}_{60}$, nanostructured $\text{Si}_{80}\text{Ge}_{20}$, $\text{WSi}_2+\text{Si}_x\text{Ge}_{1-x}$, and others.

For both types of $\text{Si}_x\text{Ge}_{1-x}$, the dependence $(ZT)_{\max} - B$ forms a regular network together with the data for thermoelectrics containing SiGe and separately for Si or Ge. This dependence is similar to the dependence $(ZT)_{\max} - B^*$ (generalized parameter [5]) of thermoelectric materials.

We note that the issue of maximizing the figure of merit for $\text{Si}_x\text{Ge}_{1-x}$ was also considered by us in previous work [6]. There, the following empirical formulas were obtained: $(ZT)_{\max} \cong 3.2B + 0.05$, $(ZT)_{\max} \cong 0.39x + 0.28$ and $\lg(ZT)_{\max} \cong -0.4\lg\sigma' + 6.2$, where σ' is the universal electrical conductivity ($\sigma' = (q/k_B)^2 \sigma / B_E = (q/k_B)^2 B_S / S^2$). The dependence $(ZT)_{\max} - B$ differs from the dependence obtained in this work, since only our samples were considered there.

Conclusion

We investigated the dependence of the maximum figure of merit of SiGe alloy on the material parameter B . We used $\text{Si}_x\text{Ge}_{1-x}$ samples with p- and n-type conductivity and different component compositions. For comparison, we calculated $(ZT)_{\max}-B$ dependences for SiGe, as well as for materials containing them according to the data available in the literature. For both types of $\text{Si}_x\text{Ge}_{1-x}$, the dependence $(ZT)_{\max}-B$ forms a regular network together with the data for thermoelectrics containing SiGe and separately for Si or Ge. For p- and n- $\text{Si}_x\text{Ge}_{1-x}$, the temperature dependences of the electron quality factor initially indicate the presence of additional scattering, and then band convergence and the bipolar effect are added.

References

1. Wang J., Yin Y., Che Ch., Cui M. *Energies*, 2025, 18, 2122.
2. Sun F.-H., Li H., Tan J. et al. *Materiomics*, 2024, 218-233.
3. Bokuchava G., Barbakadze K., Nakhutsrishvili I. *Material Sci. & Engin.*, 2023, 7, 54-57.
4. Bokuchava G., Barbakadze K., Nakhutsrishvili I. *Bull. Georg. Acad. Sci.*, 2023, 17, 33-37.
5. Liu W., Han Z., Ji J. et al. *Materials Today Phys.*, 2022, 31, 100989.
6. Nakhutsrishvili I., Adamia, Kakhniashvili G. *Materials Sci. Res. and Rev.*, 2023, 6, 918-922.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-154281: Evaluation of Geothermal Temperatures on the Exergy and Thermo-Economic Performance of a Subcritical Dual-Pressure Evaporation Organic Rankine Cycle

Omid Rowshanaie * and Hooman Rowshanaie

Assistant Professor, Department of Biotechnology, Fatemiyeh Institute of Higher Education, Shiraz, Fars Province, Iran

Introduction: The dual-pressure evaporation Organic Rankine Cycle (ORC) consists of two evaporation and compression processes, which yield a better temperature match during evaporation and lower exergy loss than a single-pressure evaporation ORC, resulting in the highest exergy efficiency and maximum net power output.

Methodology: In this study, an assessment process is designed and simulated by AspenPlus (V12) on the dual-pressure evaporation ORC to determine the maximum and assessed net power output, overall exergy efficiency, and thermo-economic parameters, including the Specific Purchased Equipment Cost (SPEC), Net Earning (NE), and Payback Period (PBP). Therefore, we evaluate to make a comparison between R245fa as an old but high-performance refrigerant working fluid with R1336mzz(Z) as a substitute and environmentally friendly refrigerant working fluid with low Global Warming Potential (GWP), Ozon Depletion Potential (ODP), and very low lifetime in the atmosphere in pure and different mole fraction of zeotropic mixtures based on effect of different geothermal water temperatures as a heat source (100, 125, 150, 175, and 200 °C).

Results: The results reveal that, based on the design and simulation of a new assessment process for the dual-pressure evaporation ORC under subcritical conditions at 0.05 bar below the critical pressure of the working fluids, geothermal water temperature is considered a fundamental key parameter in this assessment process. We increased the geothermal water temperatures and discuss the results from two perspectives: thermodynamic and thermo-economic. Regarding the thermodynamic results, the maximum net power output and overall exergy efficiency increase significantly due to the increased heat duty in the evaporators and a better temperature match between pure and zeotropic working fluid mixtures and geothermal water during both high- and low-pressure evaporation. In this case, among pure working fluids, the maximum net power output for R1336mzz(Z) showed 12.05%, 15.55%, 21.09%, 8.84%, and 5.12% improvements compared with R245fa at 100, 125, 150 °C, 175 °C, and 200 °C, respectively, because of higher evaporator heat duty and higher thermal conductivity. Furthermore, for all mole fractions of binary zeotropic mixtures of working fluids, based on this newly designed assessment process, the R1336mzz(Z)/R245fa (0.8/0.2) reveals a maximum improvement of 23.86%, corresponding to 2049 kW, which is the highest maximum net power output among all pure and zeotropic mixtures at a geothermal water temperature of 150 °C. Also, these results are reflected in the overall exergy efficiency of pure R1336mzz(Z) at all five geothermal water temperatures, with 5.01%, 6.22%, 10.11%, 4.03%, and 3.74%, improvements. R1336mzz(Z)/R245fa (0.8/0.2) illustrates a 17.99% improvement at 150 °C and reaches 88.95% as the highest exergy efficiency compared with all pure and zeotropic mixtures. These results are due to the lower irreversibility arising from lower viscosity and a higher reduced temperature of the geothermal water output. According to the thermo-economic results, the SPEC, as an indication of economic efficiency for pure working fluids, shows a reduction of 18.05-24.08% for R1336mzz(Z) across all geothermal water temperatures compared with R245fa due to its higher maximum net power output. For all mole fractions of binary zeotropic mixtures of working fluids, R1336mzz(Z)/R245fa (0.8/0.2) shows a 26.43% reduction in SPEC at 150 °C compared with all pure and zeotropic mixtures. To support this, the higher heat duty during evaporation processes indicates a greater required heat exchanger area. On the other hand, the lower high and low pressures in the compression processes of R1336mzz(Z) have a positive effect on SPEC. However, among the other thermo-economic results, the NE for R1336mzz(Z) is slightly higher than that for R245fa, owing to the

higher maximum net power output, and this increase in NE has a positive effect on PBP. Based on the designed assessment process, PBP was reduced to its minimum value, reaching 13.21 years, for R1336mzz(Z)/R245fa (0.8/0.2). Finally, in terms of environmental analysis results, R1336mzz(Z)/R245fa (0.8/0.2) was selected at a geothermal water temperature of 150 °C, with a GWP of 207.6, compared with R245fa with 1030 GWP.

Conclusion: Overall, according to the designed and simulated assessment process for the dual-pressure evaporation ORC, the substantial improvement in overall exergy efficiency for R1336mzz(Z)/R245fa (0.8/0.2) indicates lower irreversibility during evaporation and a smaller temperature reduction of the geothermal water output. Likewise, the lowest SPEC and PBP of R1336mzz(Z)/R245fa (0.8/0.2), as the optimal composition compared with all pure and zeotropic mixtures, are attributed to its higher maximum net power output resulting from higher thermal conductivity and lower viscosity. Therefore, the newly designed and simulated assessment process identified R1336mzz(Z)/R245fa (0.8/0.2) as the best binary zeotropic mixture to substitute R245fa.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166305: Experimental Investigation of Heat Transfer and Evaporation Characteristics of a Falling Liquid Film on a Vertical Plate

Hayat El Baamrani^{1,*}, Abdelaziz Yagour², Aicha Eddemani¹, Ahmed Aharoune¹ and Abdallah Boukhris¹

¹ Thermodynamics and Energetics Laboratory, Faculty of Science, Ibn Zohr University, BP8106, 80006 Agadir, Morocco

² Electronic, signal processing and physical modeling Laboratory, Faculty of Science, Ibn Zohr University, BP8106, 80006 Agadir, Morocco

Falling film evaporation over heated vertical surfaces is a well-established heat and mass transfer mechanism with applications in evaporators, thermal management systems, desalination units, and chemical process equipment. While numerous experimental and numerical studies have addressed this configuration, further high-resolution experimental data remain necessary to improve the understanding of local thermal behavior and to support the validation of predictive models. The present work provides a detailed experimental investigation of heat transfer and evaporation characteristics of a falling water film flowing over a vertically oriented plate subjected to a uniform heat flux.

The experimental setup is based on a metallic vertical plate of practical dimensions, uniformly heated by a copper heating element coated with a silicone layer to ensure homogeneous heat flux distribution. A distinctive feature of this study lies in the high spatial resolution of surface temperature measurements, achieved using an array of 32 negative temperature coefficient (NTC) thermistors distributed along the plate. This measurement approach enables precise monitoring of local temperature variations associated with film thinning, flow development, and evaporation processes. The system is carefully insulated, and heat losses from the rear surface and plate edges are minimized to ensure that the supplied thermal power is predominantly transferred to the liquid film.

Experiments are conducted for a range of liquid mass flow rates and imposed heat flux densities representative of practical operating conditions. The results demonstrate that increasing the imposed heat flux density significantly intensifies the evaporation process. In particular, at an imposed heat flux density of $q = 2200 \text{ W}\cdot\text{m}^{-2}$, the evaporation efficiency of the system reaches 54% for a liquid mass flow rate of $\Gamma_0 = 2 \text{ kg}\cdot\text{h}^{-1}\cdot\text{m}^{-1}$, while it decreases to 39% when the mass flow rate is increased to $\Gamma_0 = 3 \text{ kg}\cdot\text{h}^{-1}\cdot\text{m}^{-1}$. These quantitative results clearly indicate that lower mass flow rates promote thinner liquid films, leading to enhanced heat transfer and higher evaporation efficiency. Furthermore, the combined effect of low mass flow rates and high heat flux densities results in a substantial improvement of the overall thermal and evaporative performance of the system.

The originality of this work resides in the combination of a well-controlled uniform heat flux boundary condition with high-resolution surface temperature measurements over a plate of practical dimensions, providing reliable experimental data that remain limited in the existing literature. The findings offer new insights into local heat transfer and evaporation mechanisms in falling film flows and provide valuable reference data for the design, optimization, and validation of thermal systems and numerical models involving falling film evaporation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166330: Fresnel Lens-Based Concentrated Solar Thermal System for Compact High-Temperature Processing

Christi K. Madsen

Department of Electrical and Computer Engineering, College of Engineering, Texas A&M University, College Station, TX 77859, USA

High-temperature thermal storage and material processing applications demand efficient solar energy conversion with minimal thermal losses. Traditional concentrated solar power (CSP) receiver designs suffer from relatively large surface areas with significant convective and radiative losses, limiting practical operating temperatures and system scalability. This work presents a novel concentrated solar thermal (CST) architecture integrating a one-meter diameter PMMA Fresnel lens with an optical light pipe-based receiver, designed to achieve high concentration ratios while minimizing receiver surface area and associated thermal losses.

The system design is for high concentration ratios, in the order of $1000\times$, enabling large focal flux densities in the order of MW/m^2 and receiver temperatures exceeding 1000°C . The Fresnel lens, with a 1000 mm diameter aperture and over 80% optical efficiency, focuses incident solar radiation onto a compact coupling area (20 mm diameter), substantially reducing surface area-dependent thermal losses compared to lower-concentration systems, such as traditional parabolic troughs, and providing advantages over receiver designs susceptible to high convective and radiation losses.

The light pipe functions as an integrated thermal transport and energy storage medium, enabling enhanced energy conversion and control for both instantaneous thermal processes (material heating, melting, sintering) and sensible/latent heat storage for thermal buffering. The compact receiver geometry facilitates integration with high-temperature thermal storage materials, creating a unified thermal processing and storage system.

Performance analysis includes optical characterization of the Fresnel lens and light pipe coupling, as well as thermocouple-based temperature measurements to verify receiver heat transfer. Preliminary experimental results demonstrate the feasibility of achieving high temperature processing or storage under optimal operating conditions, with potential for further improvement through receiver optimization and system refinement.

This architecture offers significant scalability advantages through modular lens arrays and cost reduction potential via polymer Fresnel lens mass production, positioning it as a viable pathway for small-to-medium scale CSP applications where compact, high-temperature performance is commercially critical.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170888: Geometric Design Innovations for Enhanced Energy Recovery in Helical Configuration-based Thermal Systems

Vandana Kumari Jha^{1,*} and Soubhik Kumar Bhaumik²

¹ Department of Chemical Engineering, KTH Royal Institute of Technology, Stockholm 114 28, Sweden

² Department of Chemical Engineering, IIT (ISM) Dhanbad, Dhanbad 826004, India

Introduction

Energy recovery systems, such as heat sinks, heat exchangers, and condensers, are very important in improving the overall process efficiency of different thermal energy systems. Among these devices, many operate under low to moderate Reynolds number, where thermal performance becomes limited due to weak mixing, boundary-layer growth, and reduction of temperature gradients. Several conventional performance enhancement techniques are incorporated, such as active mixing, surface treatments, inserts, etc. However, these strategies increase system complexity, pressure drop, or energy consumption, thereby offsetting the benefits.

In this context, simple geometric design innovations prove crucial in enhancing heat transfer using passive modes [1]. Helical-geometries can be employed to improve fluid mixing and heat transfer owing to their curvature-driven secondary flow features (Dean vortices) [2]. Despite their simplicity and inherent compactness, certain aspects are less-explored, **particularly how specific geometric modulations can be systematically mapped to different dominant thermal resistances across applications**. Furthermore, these geometries offer potential as transferable, **general-purpose design guidelines rather than case-specific enhancements**, for various energy systems. **Present work synthesizes and reinterprets isolated helical-geometry studies applied to three representative applications: (i) heat sink, (ii) cross-flow heat exchanger, and (iii) conical coil condenser, to establish a unified design framework based on spatial tuning of curvature-induced feature**. The aim of this work is to demonstrate a common passive geometric principle that can be achieved by adjusting geometric parameters, and leveraged across different energy systems to achieve scalable, and mechanism-informed performance enhancement.

Methods

The study is based on validated CFD simulations, which are carried out for three distinct thermal systems employing helical geometries. In all cases, steady-state, laminar flow conditions are considered, which **representative of compact thermal energy systems**. Working fluids and boundary conditions were selected to demonstrate **application-relevant** operating conditions relevant for each application. For heat sink configuration, helical fins were employed to enhance coolant-side heat removal, and relate flow intensification with thermal performance [3]. In cross-flow heat exchanger, interaction between internal helical flow and external cross-flow was examined to evaluate heat transfer rate and efficiency [4]. For condenser, both simple helical and conical helical coils of equal tube length were analysed, to investigate the influence of cone angle on secondary flow development and heat extraction along the flow path. In all cases, the analysis mainly focuses on flow fields, temperature fields, and **non-dimensional** heat transfer metrics. Improvements in heat transfer were found to be **primarily** the effect of curvature-induced secondary flow intensification.

Results

All the systems showed a common underlying enhancement mechanism, that is governed by helical geometry, even though there are differences in applications. Centrifugal forces generated due to curvature lead to the formation of secondary flow structures, which result in the enhanced transverse mixing and disruption of thermal boundary layers. In the heat sink configuration, swirl-induced natural convection results in reduced surface temperature non-uniformity and enhanced fin efficiency by 10-15%. Cross-flow heat exchanger demonstrates improved ***Nu* (1.4 to 2.5 times)**

and heat exchanger efficiency upto 90% due to flow intensification and tortuosity. In condenser system, geometric modification through conical design led to progressive intensification of secondary flow, which compensates for decreasing temperature gradients **resulting in an overall heat extraction enhancement of ~14%**. Cross-comparison of these applications shows that, although the dominant thermal limitations are different, as poor mixing in heat sinks, boundary-layer growth in heat exchangers, and temperature gradient decay in condensers, helical design principle **consistently mitigates these limitations through a common passive mechanism** [5], and highlights the versatility of helical-geometry-based enhancements.

Conclusions

Implementation of helical configurations serve as an effective and broadly applicable design strategy for enhancing thermal energy recovery. By intensifying secondary flow, simple helical geometries are shown to improve heat transfer, in a passive manner, without increasing complexity and energy consumption. This analysis, covering heat sink, cross-flow heat exchanger, and condenser emphasizes the potential of geometry-driven design innovations in a unified, **cross-application framework**. The findings provide generalized **and transferable** design insights that can be used for the development of next-generation passive energy devices for **compact** industrial and environmental applications.

References

1. M.A. Rahman, Review on heat transfer augmentation in helically coiled tube heat exchanger, *International Journal of Thermofluids* 24 (2024). <https://doi.org/10.1016/j.ijft.2024.100937>.
2. J.O.D.B. Lira, H.G. Riella, N. Padoin, C. Soares, Fluid dynamics and mass transfer in curved reactors: A CFD study on Dean flow effects, *J. Environ. Chem. Eng.* 10 (2022). <https://doi.org/10.1016/j.jece.2022.108304>.
3. V.K. Jha, S.K. Bhaumik, Enhanced heat dissipation in helically finned heat sink through swirl effects in free convection, *Int. J. Heat Mass Transf.* 138 (2019) 889–902. <https://doi.org/10.1016/j.jheatmasstransfer.2019.04.099>.
4. V.K. Jha, S.K. Bhaumik, Enhanced cooling in compact helical tube cross-flow heat exchanger through higher area density and flow tortuosity, *Int. J. Heat Mass Transf.* 150 (2020) 119270. <https://doi.org/10.1016/j.jheatmasstransfer.2019.119270>.
5. V.K. Jha, K. Banerjee, S.K. Bhaumik, Enhanced thermal stability of novel helical-finned jacketed stirred tank heater, *Appl. Therm. Eng.* 184 (2021). <https://doi.org/10.1016/j.applthermaleng.2020.116250>.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164493: Influence of Torrefaction Temperature and Residence Time on the Physicochemical Properties and Structural Transformation of Market Waste-Derived Torrefied Solid Fuel

Christian Dewin Nery *, Rex Demafelis, Anna Elaine Matanguihan, Rowena Carpio and Bernadette Magadia

Department of Chemical Engineering, University of the Philippines Los Baños, 4031, Philippines

Global energy-related carbon dioxide (CO₂) emissions reached approximately 37.4 Gt in 2023, reflecting continued dependence on fossil fuels. In the Philippines, coal accounted for about 62% of total electricity generation in 2023, highlighting the need for renewable and lower-carbon fuel alternatives. At the same time, increasing urbanization has intensified municipal solid waste generation, which now exceeds 35,000 tons per day, with fruit and vegetable residues (FVR) comprising a substantial biodegradable fraction. This study investigated the effects of torrefaction temperature and residence time on the physicochemical properties, fuel quality, and structural transformation of FVR to assess its suitability as a torrefied solid fuel.

Torrefaction experiments were conducted using a full factorial 2² design under an inert nitrogen atmosphere at two temperatures (200°C and 300°C) and two residence times (30 and 90 min), with three replicates per condition. Prior to treatment, the feedstock was air-dried, oven-dried, and milled to particle sizes ranging from 0.25 to 2.00 mm. Product performance was evaluated through mass yield determination, proximate analysis, higher heating value (HHV), fuel ratio, visual colorimetric analysis, Fourier Transform Infrared (FTIR) spectroscopy, and Analysis of Variance (ANOVA).

ANOVA identified temperature as the dominant factor affecting torrefaction behavior and product quality. Samples treated at 200°C exhibited high mass yields of 94.92%–96.83%, indicating limited devolatilization, whereas torrefaction at 300°C reduced mass yield to 46.40%–52.74%. Despite lower product recovery, higher torrefaction severity improved fuel characteristics. HHV increased from 9060–9246 Btu/lb at 200°C and 30 min to 10,918–11,560 Btu/lb at 300°C and 90 min. Volatile matter decreased from 73.90%–76.50% to 39.70%–44.30%, while fixed carbon increased from 17.10%–20.40% to 41.60%–48.00%. Ash content increased from 5.70%–6.32% to 12.30%–14.20%, and fuel ratio rose from 0.2235–0.2760 to 0.9391–1.2091, indicating enhanced carbonization and improved solid fuel behavior. FTIR analysis further showed a reduction in hydroxyl and aliphatic C–H functional groups and a stronger aromatic C=C band near 1600 cm⁻¹, confirming the formation of a more aromatic and chemically stable carbonaceous structure. These changes were accompanied by progressive darkening from light brown feedstock to nearly black torrefied solids.

The results show that lower torrefaction severity favors mass retention, whereas higher severity improves fuel quality and structural stability, supporting the potential use of market waste-derived torrefied solids for renewable energy applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-153355: Physics-Guided Machine Learning Framework for Exergy Efficiency Prediction in Renewable Energy Systems

Aswin Karakadakattil

Mechanical Engineering, Independent researcher, Kasaragod 671314, India

Exergy analysis provides a thermodynamically rigorous measure of energy quality by explicitly accounting for irreversibilities, entropy generation, and the true useful work potential of energy conversion systems. Although widely used for performance assessment of renewable energy technologies, exergy evaluation is typically conducted through system-specific thermodynamic modeling or detailed numerical simulations. Such approaches, while accurate, are computationally intensive and often tailored to individual configurations, limiting scalability and rapid optimization across diverse renewable platforms. In contrast, machine learning methods have been increasingly adopted for renewable energy forecasting and performance prediction; however, most existing studies focus primarily on energy efficiency and rely on purely data-driven architectures that lack thermodynamic consistency and physical interpretability. This work presents a physics-guided machine learning framework for predicting exergy efficiency across solar thermal, wind, and biomass-based systems. A feedforward neural network architecture comprising three hidden layers with ReLU activation functions is trained on a curated dataset assembled from published case studies and publicly available performance data. Input variables include key operational and thermodynamic parameters relevant to each system type, enabling cross-technology applicability within a unified modeling structure. To ensure physical consistency, constraints derived from the first and second laws of thermodynamics are incorporated directly into the loss function as penalty terms. These regularization components enforce non-negative entropy generation and maintain consistency between exergy destruction, input exergy, and exergy efficiency definitions during training. Model performance is evaluated using five-fold cross-validation and standard regression metrics, including root mean square error (RMSE), mean absolute error (MAE), and coefficient of determination (R^2). The proposed framework achieves an average R^2 of 0.93 and an MAE of 0.037 in exergy efficiency prediction. Compared with a conventional neural network baseline, the physics-guided model demonstrates improved predictive stability and a lower incidence of physically inconsistent outputs, particularly under off-design operating conditions. Unlike prior system-specific exergy prediction approaches, this study proposes a unified physics-guided framework applicable across multiple renewable technologies. The findings indicate that embedding thermodynamic constraints within the learning process enhances robustness and interpretability while preserving computational efficiency, providing a scalable alternative to purely simulation-based exergy assessment for renewable energy optimization and sustainability analysis.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-167555: Study of emissions formation in a spark-ignition engine fuelled with natural-gas–hydrogen blends

Pedro Gabana^{1,*}, Izan Martínez¹, Luis André Álamo¹ and Alexis Cova-Bonillo²

¹ Department of Energy and Fluid Mechanics Engineering, University of Valladolid, Paseo del Cauce 59, E-47011 Valladolid, Spain

² Department of Mechanical Engineering, School of Engineering, University of Birmingham, Birmingham B15 2TT, UK

Decarbonising the automotive sector requires powertrains capable of delivering cleaner and more efficient energy conversion processes. Low-carbon gaseous fuels such as natural gas and hydrogen represent promising alternatives for spark-ignition engines, as they facilitate more sustainable combustion while maintaining operational feasibility. Hydrogen, in particular, enables CO₂-free combustion and can achieve net-zero lifecycle emissions when produced from renewable sources. However, its inherently high reactivity and flame speed pose operational challenges, including an increased risk of backfiring, difficulties in controlling the combustion rate, and a higher propensity for engine knock, especially in stoichiometric mixtures. Blending hydrogen with natural gas can mitigate these limitations by reducing mixture reactivity and improving combustion stability, while preserving the low-carbon characteristics of both fuels.

Despite their potential to lower CO₂ emissions, the combustion of natural-gas–hydrogen mixtures may still generate pollutants such as CO, NO_x and unburned hydrocarbons. Controlling these emissions requires a detailed understanding of how the combustion process governs pollutant formation, especially under varying fuel compositions and operating conditions. Furthermore, cleaner in-cylinder conversion processes can simplify the design and improve the performance of after-treatment systems, which must be tailored to the specific characteristics of hydrogen-assisted combustion. However, the literature still lacks comprehensive studies describing the interplay between combustion dynamics and pollutant formation when using hydrogen–natural-gas blends.

The main objective of this work is to characterise the combustion process in relation to the formation of CO and NO_x emissions in a spark-ignition engine operating with various hydrogen–natural-gas mixtures. Experimental tests were carried out at three engine speeds (1000, 1750 and 2000 rpm), varying both the fuel–air equivalence ratio and the hydrogen fraction in the mixture. The engine was evaluated under three fuelling strategies: pure natural gas ($\phi = 0.7$ – 1.0), pure hydrogen ($\phi = 0.3$ – 0.7) and binary mixtures of natural gas and hydrogen. The experimental data were processed using a two-zone thermodynamic diagnostic model and a kinetic diagnostic model, enabling a detailed analysis of both the combustion process and the formation of pollutant emissions.

The results show that, although adding hydrogen reduces overall carbon emissions, CO formation persists under stoichiometric conditions when the engine operates on natural gas. Increasing the hydrogen fraction leads to higher NO formation, primarily due to the faster energy release associated with hydrogen's high laminar flame speed. Conversely, when the engine runs on 100% hydrogen, the use of lean mixtures with equivalence ratios below 0.5 almost completely suppresses NO emissions while maintaining stable engine operation. These findings provide valuable insight into the relationship between combustion evolution and pollutant formation, supporting the development of cleaner, more efficient energy-conversion systems based on hydrogen-enriched gaseous fuels.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166156: Synergistic Thermophysical Modulation and Emission Abatement in Compression Ignition Engines via Coconut Shell-Derived Nanobiochar Augmentation of Ternary Diesel-Biodiesel-Bioethanol Blends

Anne Sherina Trisha Dulogildo¹, Sie Kwang Kim¹, Cyra Nicole Sangabol¹, Maria Angelika Delza Santos¹, Hannah Imelda Sartorio¹, Rugi Vicente Rubi^{1,2}, Allan Soriano³, Nathaniel Dugos³ and Rich Jhon Paul Latiza^{1,2,*}

¹ Chemical Engineering Department, College of Engineering, Adamson University, 900 San Marcelino St. Ermita Manila, Philippines

² Adamson University Laboratory of Biomass, Energy and Nanotechnology (ALBEN), Adamson University, 900 San Marcelino St., Ermita, 1000, Manila, Philippines

³ Department of Chemical Engineering, Gokongwei College of Engineering, De La Salle University, Manila, Philippines

The global automotive and logistics sectors currently face an escalating environmental crisis driven by the prolific discharge of particulate matter and greenhouse gases from conventional diesel-powered internal combustion engines. While the industry has pivoted toward renewable alternatives such as biodiesel and bioethanol, these oxygenated fuels often present inherent limitations regarding oxidative stability, lower energy density, and phase separation when utilized in ternary blends. To address these physicochemical deficiencies, this study investigates the synthesis and application of a novel ternary blend consisting of conventional diesel, biodiesel, and bioethanol (70:20:10) (DBE), augmented with coconut shell-derived nanobiochar (CNS) as a high-surface-area heterogeneous catalyst. The research specifically explores the impact of varying CNS nanobiochar concentrations—0, 20, 30, and 40 ppm—on the holistic fuel profile to determine an optimal formulation for modern compression ignition systems. The experimental methodology involved a rigorous series of laboratory analyses conducted in strict accordance with ASTM standards, including ASTM D445 for kinematic viscosity and ASTM D93 for flash point. Critical physicochemical parameters, including density, fire point, corrosiveness, and calorific value, were evaluated using specialized analytical instrumentation. The results revealed that while density and corrosiveness remained relatively stable across the various dosages, viscosity and thermal stability metrics exhibited significant sensitivity to nanobiochar loading. Notably, the 20 ppm CNS concentration emerged as the most effective variant, demonstrating the lowest kinematic viscosity at 5.6 mm²/s and superior safety characteristics with a flash point of 58°C, alongside a calorific value of 29.18 MJ/kg. In engine performance evaluations, the 20 ppm DBE-CNS blend significantly enhanced Brake Thermal Efficiency (BTE) and optimized Specific Fuel Consumption (SFC) compared to the unblended diesel baseline. The catalytic effect of the nanobiochar facilitated a micro-explosion phenomenon during combustion, leading to cleaner burning and a measurable reduction in hazardous pollutants, including carbon monoxide (CO), nitrogen oxides (NO_x), and carbon dioxide (CO₂). The study concludes that micro-dosages of coconut shell nanobiochar serve as a viable mechanism for upgrading renewable fuel blends, though further research is recommended to explore long-term effects on fuel injector durability and tribological wear.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166027: Thermodynamic Analysis of Extractive Heterogeneous Azeotropic Distillation with Water Auto-Entrainer

Jonathan Wavomba Mtogo^{1,*}, Péter Mizsey² and Agnes Szanyi³

¹ Chemical Engineering Division, Kenya Industrial Research and Development Institute, P.O. Box 30650 – 00100 Nairobi

² Institute of Chemistry, University of Miskolc, Egyetemváros, H-3515 Miskolc

³ Higher Education and Industrial Cooperation Centre, University of Miskolc, Egyetemváros, H-3515 Miskolc, Hungary

Extractive Heterogeneous Azeotropic Distillation (EHAD) is a separation technique designed for non-ideal mixtures exhibiting azeotropic behaviour, capable of achieving separations that are difficult or impossible to achieve with conventional distillation. Unlike conventional extractive distillation, which typically requires external entrainers, the distinguishing feature of this study is the exclusive use of water as an auto-entrainer, eliminating the need for additional chemicals, simplifying operational procedures, and enhancing the sustainability of the process. A defining characteristic of EHAD is the relatively small temperature difference between the top and bottom of the distillation column. This narrow thermal profile governs heat and mass transfer, directly influences entropy generation, and affects overall thermodynamic efficiency, while providing a suitable basis for energy integration and process intensification.

The applicability and performance of EHAD are investigated through a case study involving the separation and recycling of a quaternary mixture of water, ethanol, ethyl acetate, and methyl ethyl ketone from the waste stream of a printing firm, representing a complex system with multiple azeotropes. A rigorous process simulation is conducted using Aspen modelling software in conjunction with detailed entropy generation and exergy analyses to evaluate thermodynamic performance, identify inefficiencies within the configurations, and quantify losses throughout the process. Process-intensification strategies, including heat integration and heat-pump coupling, are explored to reduce energy consumption and minimize thermodynamic irreversibilities. Entropy generation analysis is used to determine dominant sources of energy degradation, while exergy analysis quantifies thermodynamic losses and allows for the calculation of exergy efficiency across different configurations.

Results indicate that energy integration reduces the total energy demand by approximately 57% compared to non-integrated operation, significantly lowering both entropy generation and exergy destruction. The overall exergy efficiency of the integrated EHAD process reaches 35%, demonstrating the thermodynamic advantages of the approach. The findings highlight that using water as an auto-entrainer enables EHAD to achieve energy-efficient, thermodynamically optimized separation of complex azeotropic mixtures, offering strong potential for sustainable industrial applications in the chemical and pharmaceutical sectors.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Session 3. Energy and Environment. Sustainable Transition

sciforum-166443: Policy Signals and Transition Outcomes: Examining the Influence of Energy Policy on Fossil Fuel Production in Australia

Niranjika Wijesooriya

School of Physics, The University of Sydney, Australia

Energy policy is widely regarded as a primary mechanism for enabling and accelerating energy transitions. Through regulatory frameworks, market interventions, and strategic signalling, policy is expected to shape investment decisions, reorient organisational strategies, and progressively shift energy systems away from carbon-intensive production. Yet, in fossil fuel-dependent economies, the extent to which energy policy materially influences organisational transition trajectories remains an open empirical question. This paper examines how energy policy has shaped, constrained, or enabled transition outcomes within a major fossil fuel organisation, using Woodside Energy as a case study within the Australian energy system.

The study focuses on the period from 2015 to 2025, a decade characterised by intensifying climate commitments, evolving energy security concerns, and the increasing prominence of gas as a so-called “transition fuel” in Australian policy discourse. During this period, successive federal and state governments introduced a range of climate, energy, and gas market policies intended to reduce emissions while maintaining supply reliability and export competitiveness. This paper maps these policy developments against changes in Woodside's energy mix, specifically examining trends in oil and gas production, project approvals, and investment priorities over time.

Adopting a qualitative longitudinal research design, the analysis draws on publicly available corporate disclosures, including annual reports, sustainability and climate reports, and investor communications, alongside legislative instruments, policy statements, and media coverage. Document analysis is used to trace how policy signals are interpreted, negotiated, and incorporated within corporate strategy, while production data provides a material indicator of transition outcomes. Rather than treating policy as a static constraint, the study conceptualises policy as an evolving and often contested influence that interacts with organisational agency, market conditions, and institutional logics.

The findings suggest that energy policy has exerted an uneven influence on transition outcomes. While policy frameworks have increasingly articulated decarbonisation goals, they have simultaneously reinforced the strategic role of gas in Australia's transition narrative. This duality appears to have enabled the retention and, in some cases, expansion of gas-related investments, even as organisations publicly align with transition objectives. The persistence of oil and gas production over the decade indicates that policy influence has been more effective in reshaping organisational discourse and justification strategies than in driving substantive changes in the energy mix.

By empirically examining the relationship between policy signals and organisational production outcomes, this paper contributes to transition studies by highlighting the limits of policy-driven change in the absence of clear phase-down or phase-out mechanisms. It underscores the importance of policy coherence, credibility, and enforceability in shaping transition pathways and cautions against over-reliance on transitional narratives that may delay structural change. The paper offers insights for policymakers seeking to design energy policies that more effectively translate transition ambition into measurable transformation within fossil fuel-intensive organisations.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166309: Assessing Transient Thermal Models for Photovoltaic Modules Using High-Time-Resolution Outdoor Measurements

Bitian Jiang * and Christi Madsen

Department of Electrical and Computer Engineering, Texas A&M University, Texas, USA

Accurate characterization of photovoltaic (PV) module temperature is essential for evaluating performance under real outdoor operating conditions. The widely used Faiman thermal model assumes steady-state behavior and neglects short-term temperature dynamics caused by rapid changes in irradiance, wind, and ambient conditions. As a result, temperature predictions based on steady-state assumptions can deviate from actual module behavior during rapidly changing environmental conditions. Recent studies have proposed transient extensions to such models by introducing thermal mass terms, highlighting the need for experimental validation under realistic outdoor operating conditions.

This work presents a measurement-focused study aimed at resolving transient temperature and irradiance effects on PV module efficiency using high time-resolution outdoor data. An outdoor measurement system is developed to simultaneously record module temperature, ambient conditions, irradiance, and electrical output under naturally varying environmental conditions. Attention is given to the transient response of different temperature sensing methods, including contact thermocouples and infrared-based measurements, and their influence on time-dependent thermal analysis and parameter interpretation.

Controlled experimental scenarios are designed to isolate key transient effects, including temperature response to ambient changes without irradiance, irradiance-driven heating near thermal equilibrium, and cooling behavior under shaded conditions while ambient conditions remain unchanged. These measurement configurations enable the identification of temperature lag and sensor response characteristics that can introduce non-negligible deviations in inferred thermal behavior when transient effects are neglected or insufficiently resolved.

The resulting time-dependent data are used to evaluate effective heat transfer behavior and to compare the performance and limitations of steady-state and transient thermal models. The analysis demonstrates clear differences between steady-state assumptions and observed transient behavior, particularly during periods of rapidly changing irradiance and ambient conditions. These differences are found to depend strongly on measurement methods, sensor response characteristics, and operating regime, underscoring the importance of sensor selection and temporal resolution in outdoor PV thermal studies.

Overall, this measurement-driven perspective provides experimental insight into the applicability of transient thermal models for PV systems under realistic outdoor operating conditions and offers practical guidance for improving temperature measurement strategies and system-level performance evaluation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171312: Explaining the Intention to adopt Photovoltaic Systems in Small businesses: Evidence from an emerging economy

Alejandro Silva Cortés^{1,*}, **Eliana Maria Villa Enciso**¹, **Luis Daniel Benitez Vázquez**², **Jorge L. Gallego**³, **Rodolfo Casadiego-Alzate**⁴, **Heidy Rodriguez Ramos**⁵ and **Fernando Aricapa**⁶

¹ Management Sciences Research Group, Department of Economics and Management Sciences, Instituto Tecnológico Metropolitano, Medellín 050034, Colombia

² Technology Management Student, Instituto Tecnológico Metropolitano, Medellín 050034, Colombia

³ Biodiversity Biotechnology and Bioengineering Research Group GRINBIO, Department of Engineering, University of Medellín, Medellín 050026, Colombia

⁴ Department of Marketing, Institución Universitaria Politécnico Granacolobiano, Medellín 050034, Colombia

⁵ Escola Superior de Propaganda e Marketing (ESPM) São Paulo, Brasil

⁶ 1. GISAH Research Group, Environmental Engineering Program, Universidad Tecnológica de Bolívar Campus Tecnológico, km 1 vía Turbaco Cartagena, Cartagena de Indias 130011, Colombia 2. GIA Research Group, Department of Engineering, Fundación Universitaria

The adoption of photovoltaic (PV) systems by micro and small enterprises (MSEs) continues to represent a major challenge in emerging economies, even though the economic, environmental, and energy-security benefits of solar technologies are widely recognized. In contexts such as Colombia, where MSEs account for a substantial share of economic activity and electricity demand, the diffusion of distributed solar energy remains limited. This situation highlights the need to better understand the factors that shape adoption decisions beyond purely technical or financial considerations, particularly those related to individual perceptions, organizational conditions, and the broader institutional environment. This study investigates the determinants of MSEs' intention to adopt photovoltaic systems by integrating the Technology Acceptance Model (TAM) and the Technology–Organization–Environment (TOE) framework into a unified explanatory model. This integrated approach allows for a comprehensive assessment of both individual-level cognitive factors and organizational and environmental influences affecting technology adoption. Data were collected from micro and small enterprises operating across diverse economic sectors, ensuring heterogeneity in organizational characteristics and energy use profiles. The proposed model was empirically tested using partial least squares structural equation modeling (PLS-SEM), a method well suited for exploratory analysis and prediction-oriented research.

The analytical procedure followed several stages, including the validation of the measurement model, the estimation of direct and indirect relationships through bootstrapping, and predictive performance assessment using root mean square error (RMSE) and Stone–Geisser's Q^2 . Additionally, importance–performance map analysis (IPMA) was applied to identify the most relevant constructs for managerial and policy intervention. The results reveal that TAM-related variables, perceived usefulness, perceived ease of use, and attitude toward photovoltaic systems, are the strongest predictors of adoption intention, explaining a substantial proportion of its variance. In contrast, organizational and environmental factors, such as management support, regulatory incentives, and energy cost pressure, show mainly indirect or comparatively weaker effects. Overall, the findings suggest that photovoltaic adoption among MSEs is driven primarily by individual cognitive and evaluative processes rather than external pressures. This underscores the importance of user-oriented system design, simplified financing mechanisms, and targeted capacity-building strategies aimed at enhancing perceptions of usefulness and ease of use, thereby accelerating the energy transition in small businesses.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171131: Innovation in the Energy Sector

Daniella Kamisaki Camilato * and Uheslei Fagundes da Silva

Department of Production Engineering, Federal Center for Technological Education Celso Suckow da Fonseca (CEFET/RJ), Rio de Janeiro, 20271-110, Brazil

Introduction:

Energy represents the primary catalyst for economic and social development. Demographic growth and industrial progress demand an uninterrupted increase in generation capacity. The Brazilian electric sector operates a matrix based on renewable sources, but the system faces continuous market pressures to reduce carbon emissions and expand its reach. Innovation acts as the main tool to guarantee this sustainable progress. This study executes an audit on the national energy sector, analyzing the structural tension between the high physical generation potential and the institutional restrictions. The research maps the transition from the fossil model to clean operation matrices, highlighting the barriers that prevent the solidification of renewable energy proposals.

Methods:

The methodological approach employs a systematic bibliographic review, complemented by the strict metric analysis of databases. The researchers extracted industrial deposit data from the National Institute of Industrial Property (INPI) and the European Patent Office (Espacenet). The extraction aims to quantify the technological protection efforts of universities and research centers. The work evaluated the competitive position of the country through the Global Innovation Index (GII) between the editions of 2013 and 2022. The financial balance documented the capital flow of the Sectoral Fund for Electricity (CT-Energia), managed by the Financier of Studies and Projects (FINEP). Monti (2015) defends the urgency of renewable technologies, and Barbieri (2020) attests the superiority of the inventive model of developed nations.

Results:

The compilation of statistical data exposes a strong disconnection between the geographical vocation and the destination of financial promotion. The volume of patent registration for renewable sources reached the exact mark of 106 requests in the year of 2019. The Northeast region hosts the main wind and solar generation complexes in the national territory. The production of technical knowledge is confined to the academic institutions of the South and Southeast regions. The official report of the Global Innovation Index allocated the country in the 54th general position during the year of 2022. The knowledge creation indicator exhibited an ascending evolution, but the generation infrastructure and the innovation linkages remain immobilized in the lower positions of the table. The budgetary fluctuation justifies the failure of this technological integration. The CT-Energia fund has faced gradual liquidity cuts since 2015. The 2022 budget approved an injection of R\$ 113.6 million, but the projection for 2023 retracted the cash to only R\$ 9.83 million. The energy modernization edicts receive slices inferior to 2% of the total revenue of the development fund.

Conclusion:

The renewal of the electric system dictates the rules of the productive capacity advance and social inclusion. The structural base of the state sustains a diversified matrix under the regulation of inspection agencies. The conversion of laboratory inventions into practical products requires the mathematical stabilization of the public fund. The government inspection needs to ensure the uninterrupted transfer of the net revenue of the concessionaires to the researchers. The Ministry of Mines and Energy and the National Electric Energy Agency (ANEEL) must use these indicators to reorganize the tax allocation of energy distributors. Corporate managers must foster the creation of direct consortiums with local universities. The full progress of the green matrix occurs when the legislation aligns the university talent with the problems of the generating plants. The formulation of a new energy policy obliges the agile and decentralized release of the research capital. This action guides the decision-making of the sector stakeholders to optimize costs and democratize access.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171179: Meat industry waste as raw materials for renewable gases production

Elena Duque Rivera *, Álvaro Muñoz, Juan Jerónimo, Fátima de la Fuente, Encarnación Cruz and Nuria García-Mancha

Scientific Development Unit, National Hydrogen Center, Puertollano, 13500, Spain

Introduction

In Castilla-La Mancha, the meat processing industry generated approximately half of the 104,431 tonnes of agro-industrial waste in 2019 (Castilla-La Mancha, 2024). These are highly biodegradable, making them ideal for methane production through anaerobic digestion (Rodríguez-Abalde et al., 2019). However, the hydrolysis of these lipids and proteins can inhibit this process (Rodríguez-Méndez et al., 2017) due to the release of ammonia and long-chain fatty acids (Rodríguez-Abalde et al., 2017). To avoid this, various strategies can be employed, such as co-digestion or a two-stage anaerobic digestion process. In the latter case, the hydrolysis and acidogenesis stages would occur first, obtaining H_2 , volatile fatty acids (VFAs), and ammonium (NH_4^+). NH_4^+ is produced through ammonification under anaerobic conditions where protein hydrolysis occurs (Deng et al., 2024). Therefore, developing strategies to intensify the anaerobic digestion process, such as thermal pretreatment at different temperatures, will promote the formation of renewable gases (H_2 and CH_4), as well as NH_3 , which is considered an energy vector and a carrier of H_2 .

In this study, batch tests were performed to investigate the potential of producing renewable gases (H_2 , NH_3 , and CH_4) from meat processing waste. This will support the development of future strategies to intensify the anaerobic digestion process.

Material and Methods

Three different concentrations (12.5%, 25% and 50%) of the selected waste (manure, blood, wastewater, and sludge from the company wastewater treatment plant (WWTP)) were used to assess the potential of producing renewable gases. Tests were conducted according to Hollinger et al. (2016) and Carrillo-Reyes et al. (2020) for evaluating CH_4 and H_2 generation, respectively.

Results and Discussion

As shown in the analysis, blood and manure have a high COD. Blood also has a high NH_4^+ content. As the concentration of the wastewater and sludge increases, CH_4 production increases. In the case of wastewater, CH_4 production is too low due to the presence of recalcitrant and/or toxic compounds that are detrimental to methanogenic archaea. However, increasing the organic load of the sludge multiplies CH_4 generation by almost fivefold, from 50 to 217 mL CH_4 . However, when blood is added, CH_4 production decreases as blood concentration increases, due to the accumulation of volatile fatty acids (VFAs), as evidenced by the detection of H_2 . Furthermore, the high N- NH_4^+ content in blood may also contribute to the inhibition of archaea. In the case of manure, the maximum amount of CH_4 was produced when the waste concentration was 25%, resulting in an improvement in CH_4 production from 95 to 146 mL CH_4 . Higher concentrations would lead to inhibitory processes, possibly related to an overload of organic matter. NH_4^+ concentration was analysed throughout the trials, increasing along the different tests, highlighting the transformation of organic nitrogen into ammoniacal nitrogen. Nevertheless, an inhibitory concentration of NH_4^+ (>1.5 g/L; Deng et al., 2024) was only achieved when blood was used. On the other hand, no H_2 production was observed during the biochemical H_2 test due to the unacclimatised inoculum used and the need for an initial waste pre-treatment. Future work includes waste pretreatment, co-digestion, co-fermentation, and using acclimated sludge to obtain H_2 .

Conclusions

Anaerobic digestion is a suitable method of treating waste to produce renewable gases (CH_4 , H_2 , and NH_3). The results obtained showed that WWTP sludge and manure were the most suitable materials for CH_4 production, while blood had high potential for NH_3 generation. However,

intensification strategies such as co-digestion and two-stage anaerobic digestion are needed to optimise the production of these gases.

References

1. Carrillo-Reyes, J., Buitrón, G., Moreno-Andrade, I., Tapia-Rodríguez, A. C., Palomo-Briones, R., Razo-Flores, E., ... & Zaiat, M. (2020). Standardized protocol for determination of biohydrogen potential. *MethodsX*, 7, 100754.
2. Castilla-La Mancha. (2024). Plan de prevención y gestión de residuos de Castilla-La Mancha 2030.
3. Deng, Z., Sierra, J. M., Ferreira, A. L. M., Cerqueda-Garcia, D., Spanjers, H., & van Lier, J. B. (2024). Effect of operational parameters on the performance of an anaerobic sequencing batch reactor (AnSBR) treating protein-rich wastewater. *Environmental Science and Ecotechnology*, 17, 100296.
4. Holliger, C., Alves, M., Andrade, D., Angelidaki, I., Astals, S., Baier, U., Bougrier, C., Buffière, P., Carballa, M., & De Wilde, V. (2016). Towards a standardization of biomethane potential tests. *Water Science and Technology*, 74(11), 2515–2522.
5. Rodríguez-Abalde, Á., Flotats, X., & Fernández, B. (2017). Optimization of the anaerobic co-digestion of pasteurized slaughterhouse waste, pig slurry and glycerine. *Waste Management*, 61, 521–528.
6. Rodríguez-Abalde, Á., Guivernau, M., Prenafeta-Boldú, F. X., Flotats, X., & Fernández, B. (2019). Characterization of microbial community dynamics during the anaerobic co-digestion of thermally pre-treated slaughterhouse wastes with glycerin addition. *Bioprocess and Biosystems Engineering*, 42, 1175–1184.
7. Rodríguez-Méndez, R., Le Bihan, Y., Béline, F., & Lessard, P. (2017). Long chain fatty acids (LCFA) evolution for inhibition forecasting during anaerobic treatment of lipid-rich wastes: Case of milk-fed veal slaughterhouse waste. *Waste Management*, 67, 51–58.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-167257: Process Stability and Biomethane Production in Food Waste Anaerobic Digestion with Functional Compost-Based Additives

Arly Arienda Morico^{1,*}, Jeffrey Lavarias¹ and Antonio Barroga²

¹ Department of Agricultural and Biosystems Engineering, College of Engineering, Central Luzon State University, Science City of Muñoz 3120, Nueva Ecija, Philippines

² Department of Animal Science, College of Agriculture, Central Luzon State University, Science City of Muñoz 3120, Nueva Ecija, Philippines

Anaerobic digestion (AD) is a widely implemented biotechnological process for treating organic wastes, such as food waste, providing the dual advantages of renewable energy production and nutrient recovery. Nonetheless, the heterogeneous composition of food wastes—characterized by high moisture content, lipids, salts, and nitrogenous compounds—often results in process instability and suboptimal biomethane yields. The use of multifunctional additives offers a promising avenue to enhance buffering capacity, microbial activity, and overall system stability. This investigation examined the effects of a compost-based additive (CBA) containing 25 functional compound agents (FCAs), including bacteria and fungi involved in organic matter decomposition, enzymatic activity, nitrogen fixation, methane production, and sulfate and ammonia reduction, on the AD of food waste. Batch AD experiments were performed under mesophilic conditions ($37 \pm 1^\circ\text{C}$) over a 20-day digestion period. The influence of CBA supplementation on biomethane production and key stability parameters, including pH, alkalinity, total volatile fatty acids (TVFAs), FOS/TAC ratio, and electrical conductivity (EC), was systematically evaluated. Results showed that CBA supplementation significantly improved process stability by increasing alkalinity and overall buffering capacity, which facilitated more effective TVFA degradation. The CBA-amended reactor achieved a TVFA degradation efficiency of 78.55%, nearly double that of the control (36.10%) ($p < 0.01$). Although pH is directly influenced by TVFA concentration, no statistically significant differences in pH were observed between treatments ($p > 0.05$), indicating that the enhanced alkalinity effectively maintained stable conditions. Furthermore, the EC in the CBA-treated reactor decreased by 19.7% relative to its initial value, while the FOS/TAC ratio declined to 0.10 by the end of the digestion period, indicating enhanced metabolic balance and a markedly reduced risk of acidification. These stability enhancements translated into improved performance, with the CBA-treated reactor attaining a maximum cumulative biomethane yield of $291.80 \pm 6.09 \text{ mL g}^{-1} \text{ VS}$, representing a 10.51% increase over food waste digestion without additives. In conclusion, this study demonstrates that CBA can enhance process stability and biomethane production from food waste, highlighting its potential to support sustainable, low-carbon energy generation through the AD process.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166392: The Influence of Microbial Diversity on the Energy Efficiency of Anaerobic Digestion of Biodegradable Waste

Maria Crina Isac

Department of Biology, Faculty of Biology, Alexandru Ioan Cuza University of Iași, Iași, 700506, Romania

Anaerobic digestion represents a relevant biological technology for the energy recovery of biodegradable waste and for reducing environmental impact, contributing to the transition toward sustainable and circular energy systems. The efficiency of this process is closely correlated with the structure, composition, and diversity of microbial communities involved in the sequential stages of hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Each microbial group plays a specific and essential role: hydrolytic bacteria break down complex polymers into simpler molecules, acidogenic bacteria convert these molecules into volatile fatty acids, acetogenic bacteria produce acetate, hydrogen, and carbon dioxide, and methanogenic archaea finalize the process by generating methane-rich biogas. The present paper examines the relationship between microbial diversity and the energy efficiency of anaerobic digestion, considering and synthesizing data, trends, and conclusions reported in the scientific literature. The main microbial groups involved in the process are analyzed, including hydrolytic and acetogenic bacteria as well as methanogenic archaea, highlighting the biological mechanisms and interactions that influence process stability, energy yield, and system resilience under variable operational conditions. In addition, trends identified in recent studies regarding the impact of microbial diversity on biomass-to-energy conversion and on the reduction of greenhouse gas emissions associated with biodegradable waste management are discussed, emphasizing the importance of microbial community composition for sustainable energy production. The analysis indicates that higher microbial diversity is associated with increased energy efficiency, more stable biogas production, reduced accumulation of intermediate metabolites, and enhanced resilience of the anaerobic digestion process in response to fluctuations in feedstock composition or environmental conditions. In this context, integrating microbial and biological considerations into the design, monitoring, and operation of anaerobic digestion facilities can significantly contribute to optimizing energy performance, improving process reliability, and promoting environmentally sustainable solutions for the management of organic waste. This perspective underscores the central role of microbiology in advancing renewable energy technologies and supporting the broader goals of sustainable development and environmental protection.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170704: A Blockchain-Supported LCA Framework to Strengthen Environmental and Social Governance in Renewable Energy Projects

Cesar Enrique Polo Castro ¹, Alexander Armando Bustamante ^{1,*}, John Alexander Taborda ¹ and Laura Alejandra Chia Pinto ²

¹ Facultad de Ingeniería, Universidad del Magdalena, Calle 29H3 No 22 - 01, 470004, Santa Marta D.T.C.H., Colombia

² Vicepresidencia Técnica, Agencia Nacional de Hidrocarburos (ANH), Avenida Calle 26 N° 59 - 65 Piso 2, Bogotá, Colombia

The accelerated deployment of wind and solar energy is a cornerstone of global decarbonization strategies, yet it has intensified challenges related to the transparency, credibility, and governance of environmental and social impact assessments, particularly in emerging and Global South contexts. Life Cycle Assessment (LCA) is widely established as a robust methodological framework for evaluating environmental impacts across the full life cycle of energy systems; however, practical applications often rely on fragmented datasets, static evaluations, and limited verification mechanisms, which can undermine trust among regulators, communities, and project developers. These limitations are especially critical in renewable energy projects, where cumulative effects, social impacts, and governance considerations are central to enabling a just energy transition. In this context, this study proposes a blockchain-supported LCA framework that enhances data integrity, traceability, and accountability while preserving the scientific foundations of life cycle thinking.

Methodologically, the framework positions LCA as the analytical backbone, aligned with ISO-compliant life cycle principles, and integrates blockchain strictly as a technological enabler for data governance rather than as an end in itself. The approach combines a structured environmental LCA with a selected set of social indicators inspired by Social Life Cycle Assessment (S-LCA) practice, focusing on dimensions particularly relevant to renewable energy projects in emerging contexts, such as community engagement, labor conditions, land-use interactions, grievance mechanisms, and compliance with social commitments across project phases. These indicators are operationalized through a digital architecture capable of capturing, structuring, and processing heterogeneous data streams derived from monitoring systems, project documentation, and stakeholder inputs. A permissioned blockchain layer records cryptographic hashes and metadata associated with datasets, indicators, and assessment outputs, enabling immutability, version control, and verifiability while maintaining data privacy and operational flexibility. Within this setup, authorized stakeholders—such as project developers, regulators, and academic partners—can write and validate records, while broader audiences can access verified information through read-only interfaces, supporting transparency and accountability. The framework is operationalized through a functional digital platform developed under the IMPACT Energy.CO initiative, designed to interlink LCA workflows, data management modules, and blockchain services in a coherent and scalable manner.

The results demonstrate both conceptual and applied contributions. Conceptually, the framework clarifies how blockchain can be systematically embedded within LCA workflows to address long-standing issues of transparency, accountability, and trust without compromising methodological rigor or comparability. Functionally, the platform implementation shows that life cycle indicators, monitoring records, and governance-related events can be registered in a tamper-resistant manner, enabling independent verification of assessment outputs across project phases. The integration of blockchain enhances data integrity and traceability, while the LCA engine ensures analytical consistency and supports evidence-based decision-making, regulatory review, and multi-stakeholder oversight in renewable energy projects.

Overall, this work advances a novel, blockchain-supported LCA framework that strengthens the environmental and social governance of renewable energy systems and contributes to the operationalization of a just energy transition. While the approach is broadly applicable to emerging and Global South contexts, its practical feasibility is illustrated through a case study in Colombia,

where wind and solar projects face complex environmental, social, and institutional challenges. The proposed framework offers a scalable and replicable pathway for bridging science, policy, and practice by embedding trustworthy, life -cycle-based evidence into renewable energy planning and governance worldwide.

This research was made possible through the support of the Agencia Nacional de Hidrocarburos (ANH), Vicepresidencia Técnica, within the framework of Contracts 478 and 515 of 2025 executed between the ANH and the Universidad del Magdalena. The authors gratefully acknowledge this institutional cooperation, which enabled the development of the IMPACT Energy.CO platform and the advancement of applied research aimed at improving the assessment, transparency, and governance of environmental and social impacts in renewable energy projects in Colombia.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-169401: A Comparative Assessment of Nanostructured Adsorbents for Direct Air Capture

Md. Nurjaman Ridoy * and Tahzib Ibrahim Protik

Department of Environmental Research, Nano Research Centre, Sylhet, 3114, Bangladesh

Direct air capture (DAC) is increasingly recognized as a critical component of net-zero emission strategies, as it enables the direct removal of CO₂ from ambient air. While carbon capture, utilization, and storage technologies are relatively mature for point sources, the ultra-low concentration of atmospheric CO₂ presents fundamental challenges for DAC, leading to high energy demand and elevated costs that currently constrain large-scale deployment. Recent advances in nanotechnology have enabled the development of nanostructured adsorbents with high surface areas, tunable pore architectures, and tailored surface chemistries capable of enhancing CO₂ capture under ultra-dilute conditions. In this study, a unified comparative evaluation framework is established to assess the performance of key classes of nanostructured adsorbents under DAC-relevant conditions. The analysis focuses on critical performance metrics, including CO₂ adsorption capacity, regeneration energy requirements, moisture tolerance, and cyclic stability. Representative material classes examined include MOFs, LDHs, porous carbons, graphene-based materials, and bio-derived nanostructures. Comparative assessment indicates that amine-functionalized LDH nanosheets exhibit rapid CO₂ uptake and stable performance over repeated adsorption-desorption cycles. At the same time, polyamidoamine-dendrimer-functionalized nanosilica demonstrates enhanced capture efficiency under both dry and humid conditions with relatively low-temperature regeneration. In parallel, charged-sorbent systems incorporating ions within activated carbon pores have emerged as a promising strategy, enabling fast CO₂ capture and electrically driven regeneration. Despite advances, substantial challenges remain. Reported techno-economic assessments frequently estimate capture costs in the approximate range of USD 300–1000 per ton of CO₂, depending on system configuration and scale, with associated energy penalties. Additional limitations include sensitivity to moisture, structural degradation during long-term cycling, and challenges related to scalable synthesis and deployment. No single adsorbent class currently satisfies all performance, cost, and scalability requirements. The comparative framework presented here highlights key trade-offs among material classes and underscores the need for integrated material- and system-level optimization to advance scalable, low-carbon DAC technologies.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171412: A Research Maturity Assessment and Indicator Framework for IoT-Driven Energy Efficiency and CO₂ Mitigation in Hospitality

Manuel Adrián Domínguez Couturier *, Oscar Frausto Martínez and Julisa Guadalupe Cabrera Borraz

Ciencias Multidisciplinarias Campus Cozumel, Universidad Autónoma del Estado de Quintana Roo, Cozumel, 77600, México

A substantial share of the hotel sector's consumption and carbon footprint is in air conditioning (HVAC), lighting, and occupancy-related operational dynamics. In the context of the global energy transition goals, rising energy costs, and increasing pressure to reduce greenhouse gas emissions, improving energy efficiency in hotel rooms has become a strategic priority. In recent years, Internet of Things (IoT) technologies and building automation systems have been increasingly proposed as key enablers for optimizing energy use and mitigating CO₂ emissions in building interiors. Despite the rapid growth of scientific publications in this field, there remains a lack of consolidated evidence on performance indicators, technological architectures, empirical robustness, and real-world applicability, particularly in the hospitality sector. This study aims to systematically analyze international research on IoT-based energy efficiency in hotel rooms by identifying energy and environmental indicators used to evaluate performance, examining the reported benefits and limitations of intelligent systems, and assessing the overall maturity of the research field from a universal implementation perspective. A systematic literature review was conducted in accordance with the PRISMA guidelines. One guiding research question informs the selection criteria: which achievements are associated with the use of IoT tools in the hotel sector? After applying the predefined inclusion and exclusion criteria, a final corpus of 60 peer-reviewed scientific articles has been selected. To ensure a structured and replicable synthesis, a hierarchical analytical framework composed of seven research questions was developed and organized into four analytical levels: (A) What is studied (technologies and system definitions), (B) how it is studied (experimental design and measurement approaches), (C) what is demonstrated (energy and CO₂-related outcomes and limitations), (D) for what purpose it is applied (implementation strategies and decision support). Each article was evaluated using an ordinal scoring scale ranging from 1 (not relevant) to 4 (in-depth analysis with precise empirical results), resulting in a 60 × 7 analytical matrix. Quantitative synthesis was performed using frequency analysis, average depth scores, and consistency measures. Additionally, a research maturity index was developed to assess the developmental stage of IoT-based energy-efficiency research. The results indicate that most studies focus on HVAC and lighting systems, with occupancy smart meters, environmental sensors, smart thermostats, and centralized energy management platforms being the most frequently analyzed technologies. Energy consumption (kWh), HVAC operating time, and indoor temperature are the most reported indicators, while carbon footprint metrics are less consistently quantified. Although a large proportion of studies report energy savings associated with IoT-based control strategies, only a limited subset provides robust empirical evidence derived from experimental or quasi-experimental designs under real operating conditions. Human and operational factors, such as occupant behavior and system overrides, are repeatedly identified as significant constraints on actual energy performance, but there is a lack of empirical evidence. The research maturity index reveals that, while IoT-based energy-efficiency research is generally progressing toward consolidation, its application to hotel rooms remains largely exploratory, with persistent gaps in indicator standardization, scalability, and replicability. Within this investigation, an indicator system has been proposed, built with all the systems that have been mentioned in most articles, to contribute to further implementations of future research. From an operational perspective, these results have direct implications for hotel management. IoT systems not only reduce energy consumption but also enable predictive maintenance strategies, improve the guest experience through automated climate control, and generate valuable data for daily operations, including indoor temperature and humidity, daily guest

presence times, and AC activation times, among others. The hotel industry operates with narrow margins and is subject to increasing corporate sustainability goals; therefore, systems capable of dynamically responding to actual occupancy and optimizing HVAC performance represent a competitive advantage. However, the lack of consolidated evidence hinders informed decision-making, making further studies in real-world operating environments essential to transforming these potential benefits into standard industry practices. This study concludes that IoT-based intelligent systems have substantial potential to improve energy efficiency and mitigate CO₂ emissions from the hospitality sector. However, advancing toward scalable and replicable energy solutions requires greater methodological rigor, standardized energy performance indicators, and pilot-scale experimental implementations conducted in real hotel environments. By systematically synthesizing existing evidence and identifying critical technical and methodological gaps, this research provides a robust foundation for future experimental studies. It supports the development of data-driven energy management strategies aligned with the objectives of sustainable, low-carbon building operations.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166411: Agrivoltaics as a Catalyst for Sustainable Energy Transition, Rural Electrification, and Environmental Sustainability in Developing Regions

Deepthi Narayana Swamy^{1,2,3}

¹ Master of Science - Energy Management from Meinders School of Business, of Oklahoma City University, Oklahoma, United States of America - 73106

² Master of Science - Power Engineering from Stevens Institute of Technology, Hoboken, New Jersey, United States of America - 07030

³ Bachelor of Electrical & Electronics Engineering - Dayananda Sagar College of Engineering, Bengaluru, India - 560111

ABSTRACT:

Introduction: Transitioning to green energy for a greener environment requires moving away from fossil fuels. Agrivoltaics seems like a promising solution for a sustainable transition, aligning with current energy and environmental trends to reduce carbon emissions. Agrivoltaics has gained significant momentum in recent years. Agrivoltaics is the concept of dual use of the same land: solar panels generate solar energy on the agricultural land, and crops are cultivated beneath them. This generates two sources of income for the farmers. This concept is being widely welcomed across the world. It is a novel approach to addressing the severe challenges posed by climate change.

Methods: This study aimed to obtain solutions to enhance agrivoltaics resilience through a satellite monitoring system. With current technological advancements, we have a range of tools and platforms to detect issues in the agrivoltaics system, including crop health, soil fertility, and atmospheric conditions. All these can be identified at the early stages and trying to resolve these issues through various measures may help to increase yield. Through traceability solutions, it helps determine the flow of energy and farm products across the supply chains. In addition, fleet management system tools help optimize the performance of agricultural and energy equipment. Above all, carbon impacts and carbon footprinting can be monitored more frequently to reduce the levels of carbon before it enters the atmosphere. With these support systems in place, installing solar panels on agricultural land could drive a more sustainable transition in the energy industry. Agrivoltaics can be considered a tool for resilience in climate transition, thereby advancing a sustainable transition.

Results: Power and energy yield help determine the efficiency of agricultural field output. This depends on the placement of different panels in the agricultural field. Crop yields are also significantly determined by the transparency of the lighting rays through panels placed in the field. Additionally, agrivoltaics strongly supports rural electrification in developing nations, where agriculture is the main source of income. With proper government support and subsidies, the agricultural sector could be covered with solar panels. There is another major benefit to the agricultural sector: water conservation through refined irrigation practices, achieved by installing solar panels above the crops. This significantly helps in water conservation. Pesticide use can be reduced by adopting agrivoltaics in the field, thereby improving crop quality. This parallel even helps in reducing groundwater contamination. Hence, Agrivoltaics can drive ecological and sustainable power transitions without compromising agricultural productivity and solar energy generation.

Conclusion: Agrivoltaics appears to be a promising solution for addressing the challenges we face in the food, water, and energy sectors. But the success rate also depends on the regional supportiveness for solar radiation availability and crop suitability. The concept of agrivoltaics enhances land-use efficiency and modifies the microclimate by reducing soil and air temperatures in the surrounding area. The major benefits of generating solar energy in reducing

greenhouse gas emissions are achieved in parallel with crop cultivation. Hence, supporting the sustainable energy transition.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-163292: AI-Driven Multi-City Optimization of Glazing and Shading Systems for Building Energy Use and Operational Carbon Reduction Across Global Climate Zones

Khuloud Ali and Ghayth Tintawi *

Research and Development Division, IMAGINE Studios, Rio de Janeiro, RJ 22780-084, Brazil

Buildings account for a substantial share of global energy consumption and operational carbon emissions, and a significantly high value of this impact is formed long before mechanical systems are specified. The building envelope, particularly glazing and shading design, controls how solar radiation and heat exchange, along with daylight, are managed across different climates. Despite this, façade optimization research has largely been conducted within isolated climatic contexts, producing results that are difficult to transfer beyond their original location. This fragmentation leaves designers without robust and comparative guidance for climate-responsive façade decisions.

Rather than focusing on a single city or environmental condition, this study aimed to develop and evaluate an AI-driven, multi-city optimization methodology for glazing and shading systems capable of operating across diverse global climate zones.

A standardized prototype-based simulation methodology was adopted to ensure consistency across all analyses. The building model was developed in DesignBuilder, with EnergyPlus performing the underlying energy calculations. The prototype was tested in representative cities corresponding to major Köppen climate classifications, including hot-arid, hot-humid, Mediterranean, temperate, and cold climates. An AI-driven optimization workflow was then used to change the ratios of glazing to walls, the fixed external shading configurations, and the building's orientation. Performance was assessed using annual energy use intensity, heating and cooling demand, and operational carbon emissions, enabling direct comparison of façade strategies under contrasting climatic conditions.

The analysis showed that façade performance varied significantly across different climatic conditions. AI-optimized solutions consistently outperformed baseline configurations and achieved measurable reductions in energy use and associated operational carbon emissions. Climates that were mostly cool were the most sensitive to shading depth and glazing proportion. Climates that were mixed or mostly warm had more complex interactions between solar gains and thermal losses. No single glazing or shading configuration emerged as optimal across all climates, highlighting the limitations of uniform façade design practices.

In conclusion, these findings support a shift away from standardized façade solutions toward façade possibilities that respond directly to the climate in which they are built. This is achieved by framing façade design as an adaptive problem rather than a fixed solution; this study contributes a transferable, AI-assisted methodology suitable for early stage decisions. The approach provides a scalable foundation for future research on more complex building typologies and advanced façade systems. It also provides climate-responsive pathways toward operational carbon reduction.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-163136: An Energy Management Optimization Method for Arctic Space Environment Monitoring Buoys Based on Deep Reinforcement Learning

Hui Zhu^{1,2,3,*}, Bingrui Li², Yan Chen¹, Yinke Dou¹, Yi Tian^{1,2,4}, Yahao Li^{1,2,5}, Huiguang Li⁶ and Zepeng Gao^{1,2}

¹ School of Electrical and Power Engineering, Taiyuan University of Technology, Taiyuan 030000, China

² Key Laboratory of Polar Science, Ministry of Natural Resources, China Polar Research Center (Chinese Academy of Polar Sciences), Shanghai 200000, China

³ Ulanqab Power Supply Branch, Inner Mongolia Electric Power (Group) Co., Ltd., Ulanqab 012000, China

⁴ Chengde Power Supply Company, State Grid Jibei Electric Power Co., Ltd., Chengde 067000, China

⁵ DC Branch, State Grid Henan Electric Power Company, Zhengzhou 450000, China

⁶ Alashan Power Supply Branch, Inner Mongolia Electric Power (Group) Co., Ltd., Alashan 750306, China

To address the long-term operational challenges of space environment monitoring buoys under extreme Arctic conditions—characterized by polar day-night alternations, ultra-low temperatures (often dropping below -40°C), strong winds, and highly variable renewable energy availability—this paper proposes an energy management optimization method based on deep reinforcement learning (DRL) algorithms. A comprehensive buoy system model is constructed, integrating renewable energy (photovoltaic panels and wind turbines) and lithium-ion battery power supply units, lead-acid battery energy storage units, and multi-sensor load units (including ionospheric detectors, geomagnetic instruments, high-precision attitude sensors, temperature and humidity sensors, and satellite communication modules). Critically, the model incorporates Arctic-specific environmental constraints, particularly low-temperature-induced battery efficiency degradation patterns that can reduce energy storage performance by 30–50% in extreme cold, as well as dynamic fluctuations in solar irradiance (zero during polar nights) and wind speed (frequent gusts exceeding 25 m/s). To balance operational stability and energy efficiency, a scientific reward function is designed to minimize unsupplied energy while strictly ensuring the functional integrity of multi-sensor monitoring tasks, with penalty terms for both energy surplus (wasted renewable generation) and deficit (compromised sensing operations). Using the Twin Delay Deep Deterministic Policy Gradient (TD3) algorithm on the MATLAB simulation platform, comparative experiments are conducted to verify the effectiveness of two energy storage configurations: a photovoltaic-lithium battery-lead-acid battery system and a hybrid photovoltaic-wind-lithium battery-lead-acid battery system for long-term Arctic observation. Based on 180 days of real Arctic environmental data (irradiance, wind speed, temperature) sourced from the NSF Data Center, the results demonstrate that the proposed method dynamically optimizes charging/discharging strategies of energy storage systems and power allocation of supply units in real time. It not only reduces lithium battery power demand by 87.5% (from 61.44 kWh to 7.685 kWh) compared to photovoltaic-only systems but also extends the buoy's continuous operational duration to over six months—overcoming the 60-day limit of traditional solar-powered buoys once polar nights begin. Additionally, the TD3 algorithm's dual-critic networks and target policy smoothing mechanisms enhance scheduling intelligence and robustness, effectively mitigating the uncertainties of renewable energy in extreme environments. This research provides a robust technical solution for overcoming energy bottlenecks in polar monitoring equipment, reduces operational costs and environmental risks associated with lithium battery overreliance, and offers new insights for energy management in intelligent polar observation systems operating in harsh, dynamic environments.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170710: An IoT-Enhanced Life Cycle Assessment Framework for Continuous Environmental Impact Monitoring in Solar Energy Systems

Victor José Olivero^{1*}, Carlos Arturo Robles¹, Mario José Callejas¹, John Alexander Taborda¹ and Laura Alejandra Chia Pinto²

¹ Facultad de Ingeniería, Universidad del Magdalena, Calle 29H3 No 22 - 01, 470004, Santa Marta D.T.C.H., Colombia

² Vicepresidencia Técnica, Agencia Nacional de Hidrocarburos (ANH), Avenida Calle 26 N° 59 - 65 Piso 2, Bogotá, Colombia

The rapid expansion of solar energy systems is a cornerstone of the global energy transition; however, their environmental assessment still relies predominantly on static Life Cycle Assessment (LCA) approaches based on aggregated, time-invariant datasets, which limit the ability to capture operational variability, context-specific dynamics, and data quality challenges—particularly in emerging economies where public institutions, private developers, and local communities interact. To address these limitations, this study proposes an Internet of Things (IoT)-enhanced dynamic Life Cycle Assessment (dLCA) framework aimed at enabling continuous environmental impact monitoring of solar energy systems in support of a sustainable and just energy transition. The proposed approach integrates real-time data streams from IoT devices into a dLCA methodological structure, allowing life cycle inventory parameters to be updated dynamically throughout key project phases. The framework is implemented through an edge/cloud IoT architecture, in which edge devices capture and pre-process environmental and operational data, while cloud-based services aggregate, harmonize, and feed these data into the dLCA workflow. Particular emphasis is placed on data provenance, temporal consistency, interoperability, and transparent documentation of assumptions. The framework has been operationalized within a functional digital platform developed under the IMPACT Energy.CO project and applied to a Latin American—specifically Colombian—solar energy case study characterized by regulatory oversight, public-sector involvement, and community engagement. The results demonstrate that integrating IoT-enabled data collection with dLCA significantly enhances the capacity to track environmental performance over time and across system boundaries, improving traceability, data quality control, and transparency in environmental assessments. Although the results are qualitative and functional rather than quantitative, they show how the proposed framework overcomes key limitations of conventional static LCA, particularly regarding temporal resolution and stakeholder trust. Overall, this work advances LCA practice from retrospective analysis toward dynamic, platform-based environmental monitoring, providing a transferable methodological foundation for evidence-based decision-making in solar energy projects and establishing the basis for future quantitative assessments and full-scale journal publication on the transition from static to dynamic LCA. This research was funded by the Agencia Nacional de Hidrocarburos, through its Vicepresidencia Técnica, under Contract No. 515 of 2025 executed with the Universidad del Magdalena.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170883: Campus Decarbonization in Central Asia through a Whole System Sustainability Transition: A Case Study

Hulkar Abdusalomova¹, Azizbek Kamolov^{1,*}, Zafar Turakulov¹, Jaloliddin Eshbobaev², Adham Norkobilov³, Akramxo'jayev Yo'ldoshxo'ja¹, Sarvar Rejabov¹ and Botir Usmonov¹

¹ Department of Automation and Digital Control, Tashkent Institute of Chemical Technology, Tashkent, Uzbekistan

² Department of IT, Automation, and Control, Tashkent Chemical-Technological Institute, Tashkent, Uzbekistan

³ Department of Engineering Technologies, Faculty of Food Engineering in Shahrizabz, Karshi State Technical University, Karshi, Uzbekistan

Introduction

Higher education institutions (HEIs) are increasingly expected to reduce their carbon footprint in response to climate change, rising energy costs, and the United Nations Sustainable Development Goals. Universities function as small urban ecosystems with substantial energy demand for electricity, heating, laboratories, and digital infrastructure. While many studies have examined campus decarbonization in developed and high-income countries, quantitative evidence from transition economies and Central Asia remains limited, particularly for campuses dependent on fossil-fuel-based district heating and centralized electricity systems. Addressing this literature gap, this study develops and evaluates a campus-scale decarbonization pathway for the Tashkent Institute of Chemical Technology (TICT), located in Uzbekistan.

Methodology

A greenhouse gas (GHG) inventory was developed using an activity-based approach aligned with the GHG Protocol. The baseline inventory represents campus operations prior to the implementation of sustainability measures and integrates energy audits, utility records, and national emission factors to quantify Scope 1 (direct fuel use), Scope 2 (purchased electricity), and selected Scope 3 emissions. The analysis includes electricity consumption in academic and administrative buildings of the TICT, natural gas use for heating, and indirect emissions associated with paper consumption and digital services.

Results

On a technical level, the institute deployed over 4,900 square meters of solar photovoltaic panels to mitigate reliance on carbon-intensive grid electricity. Simultaneously, inefficient district heating connections were replaced with autonomous, high-efficiency boiler systems, which reduced natural gas consumption by approximately 30%. These infrastructural upgrades were paired with institutional digitalization and behavioral awareness campaigns to minimize resource waste, alongside nature-based solutions such as large-scale landscaping to enhance localized carbon sequestration. Following the integration of these combined technological, institutional, and ecological measures, total campus-wide CO₂-equivalent emissions decreased by nearly 61% compared to the baseline.

Conclusion

This study demonstrates that integrating renewable energy, efficient heating systems, digitalization, and nature-based solutions can significantly reduce campus greenhouse gas emissions. In this line, this work provides one of the first comprehensive GHG-Protocol-based campus decarbonization assessments in Central Asia and offers a replicable roadmap for universities in transition economies pursuing sustainable campus transformation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166385: CFD-Based Microclimate Analysis and Energy Assessment of a Photovoltaic Greenhouse under Bogotá Savanna Conditions

Edwin Villagran^{1,*}, Andres Sarmiento², Fabian Velasquez³, Jhon Javier Espitia³ and Jader Rodriguez³

¹ Corporación Colombiana de Investigación Agropecuaria—Agrosavia, Centro de Investigación Tibaitatá, Mosquera, Cundinamarca, Colombia

² Colombian Corporation for Agricultural Research—Agrosavia, Tibaitatá Research Center, Km 14, Mosquera—Bogotá. Mosquera 250040, Colombia

³ Corporación Colombiana de Investigación Agropecuaria: Bogotá, Cundinamarca, Colombia

Photovoltaic greenhouses have emerged as a promising solution to enhance the energy sustainability of protected agriculture by simultaneously enabling crop production and on-site renewable energy generation. This approach is particularly relevant in high-altitude tropical regions, such as the Bogotá Savanna, where solar availability is relatively stable throughout the year and energy costs represent a significant operational constraint. However, the integration of photovoltaic systems introduces shading effects that can alter the internal microclimate, making it necessary to assess their impacts on thermal conditions, airflow patterns, and overall environmental suitability for crop growth. This study presents an integrated assessment of microclimatic behavior and energy performance of a photovoltaic greenhouse using computational fluid dynamics (CFD) simulations coupled with a solar energy generation analysis. A three-dimensional CFD model was developed to evaluate the spatial distribution of air temperature, airflow velocity, and ventilation patterns under three different photovoltaic shading levels applied to the greenhouse roof. Boundary conditions were defined using representative climatic data for the Bogotá Savanna, allowing the simulation of realistic operating scenarios. In parallel, the electrical energy generation potential of the photovoltaic system was estimated based on local solar radiation conditions, enabling an evaluation of the balance between microclimate modification and energy production. The results highlight that photovoltaic shading significantly influences the internal thermal stratification, air circulation, and microclimate uniformity. Moderate shading levels contribute to reducing excessive thermal loads while maintaining adequate ventilation, whereas higher shading intensities may lead to localized temperature gradients and reduced air movement. From an energy perspective, the photovoltaic system demonstrates a meaningful capacity to supply a portion of the greenhouse's energy demand, supporting self-consumption strategies. Overall, the findings demonstrate that the combined use of CFD modeling and energy analysis provides a robust framework for optimizing photovoltaic greenhouse designs, facilitating informed decision-making that balances crop microclimate requirements with renewable energy generation in high-altitude tropical environments.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171293: CO₂ valorization in portable pilot plants for e-fuel production

Encarnación Cruz Sánchez *, Alejandro Cánovas Sánchez, Pedro J. Martínez Román, Roberto Campana and Nuria García-Mancha

Centro Nacional del Hidrógeno, Fernando El Santo S/N, 13500, Puertollano, Ciudad Real, Spain

Introduction

With the aim of promoting the circular economy and generating solutions to mitigate current environmental problems, the National Hydrogen Centre is working on a project that focuses on the recovery of CO₂ to obtain fuels and high-added-value products.

The main innovation of this project lies in the integration of different technologies. The Fischer-Tropsch processes for fuel production, methanol production, anaerobic digestion, oxy-gasification, and electrolysis are included. The gas obtained from oxy-gasification (CO and H₂) and AD (CO₂) facilities, together with a supply of renewable H₂ from an electrolyzer, could be used to feed the Fischer-Tropsch and MeOH plants. On the other hand, the biogas (CH₄ and CO₂) from AD could feed the upgrading pilot plant for biomethane production. This idea therefore supports a technological system that constitutes a new concept of advanced biomass biorefinery.

Methods

The system consists of different pilot plants that host the following processes:

- Oxy-gasification: This allows synthesis gas to be obtained from lignocellulosic biomass waste. The use of oxygen as a gasifying agent allows a gas with a higher calorific value to be produced. This gas can supply the Fischer-Tropsch and methanol production processes, promoting the production of renewable fuels and methanol (e-fuels).
- Fischer-Tropsch: This is a widely studied process. It is based on the catalytic synthesis of hydrocarbons of industrial interest (gasoline, diesel, kerosene, etc.). Waxes are also obtained, which can be transformed into products with added value.
- Methanol production: This pilot plant produces methanol from the hydrogenation of CO₂. Its use as an alternative fuel and H₂ carrier is being promoted.
- Anaerobic digestion + biogas upgrading: The Anaerobic Digestion Plant, together with a biogas treatment stage, will enable biogas and biomethane to be obtained from abundant waste in the region, such as agricultural and livestock by-products. This pilot plant could become a source of energy for other facilities, as they will be able to use this sustainable fuel, thereby promoting the concept of the circular economy and reducing the use of fossil fuels. Additionally, CO₂ from biogas could be used in the other plants to produce various renewable fuels.

Furthermore, this project includes the installation of an electrolyzer to meet the H₂ requirements of the Fischer-Tropsch, methanol, and biogas upgrading plants, as well as the oxygen required for the oxy-gasification process.

Results

The fundamental objective is to optimize processes for subsequent scaling up to demonstrate that this integrated "biorefinery" concept is a sustainable and technically and economically viable alternative for the production of renewable fuels and energy generation from the available waste or by-products in the surrounding area. CO₂ emissions from this technological complex are also significantly reduced by using the synthesis gas obtained in oxy-gasification as a feedstock in Fischer-Tropsch processes and methanol production, as well as using the biogas produced as an energy source in the facilities.

According to the research lines established and in agreement with the different capacities of the pilot plants, the goal is to generate 1.5 kg/h of gasoline and up to 1.5 kg/h of methanol. This will be the result of the valorisation of 50 kg/h of forest biomass in the entrained flow reactor of the oxy-gasification pilot plant. On the other hand, the Anaerobic Digestion Plant will process 100 kg/day of different types of organic waste (agri-food industry waste, municipal solid waste

fractions, sewage sludge, etc.), and the upgrading unit will produce 0.13 Nm³/h of biomethane (96%).

It should also be noted that by-products such as digestates, wastewater, waxes, char, and ash will be characterized and processed for their reuse in a way that directly impacts on the population, such as the development of fertilizers that can be applied to the surrounding land.

Conclusions

This technological platform enables the analysis of synergies and process compatibility on an industrial scale, representing a new concept in advanced biomass biorefining. It facilitates the recovery of waste and by-products, providing economic and social benefits to the local area. Furthermore, the portable design of these pilot plants enables companies and research centres requiring these capabilities to find solutions.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-163206: Comparative Study of Liquid Biofuel Production Pathways for a Sustainable Mobility Solution

Aristide Giuliano *, Antonio Ricca, Nicola Pierro, Pietro Garzone and Isabella De Bari

ENEA—Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Rome, 00196, Italy

Introduction

Biofuels are, and will remain, essential components of sustainable mobility. Their future deployment, however, depends on the availability of sustainable feedstocks, the maturity of conversion technologies, and the stringent EU regulatory framework governing emissions. The objective of this study is to quantitatively assess the performance of multiple biorefinery pathways for liquid biofuel production. Evaluations are intended to inform the feasibility assessment of an innovative sustainable mobility system, the Off-Board Hybrid [1], consisting of a liquid-biofuel-fired electric generator operating in island mode and coupled to electric vehicle charging stations.

Methods

We processed modeling yields, energy consumption, utility needs, and equipment sizing for each biofuel production pathway. To ensure comparability, costs are typically expressed in €/GJ of fuel, as different biofuel types have highly variable energy densities (e.g., 44 MJ/kg for renewable diesel vs. 20 MJ/kg for biomethanol) [2]. These approaches reveal, for example, that biofuels from dedicated crops face high cultivation emissions unless marginal/contaminated lands are valorized.

Results

Energy yield measures energy recovery from feedstock to biofuel, highlighting the clear superiority of catalytic processes from vegetable oils [3] over thermochemical or biochemical routes from lignocellulosics. This is largely due to the higher energy content (LHV of the feedstock) and purity (triglycerides) of oils. Catalytic oil-based processes remain the best performers, but its gap with others narrows. Some thermochemical routes with targeted inputs (biocrude, pyro-oil, EtOH) gain competitiveness, showing sensitivity to reliance on supplementary energy vectors—even for non-oil biofuels (MeOH via enrichment).

Conclusions

The results provide a quantitative comparison of the techno-economic and environmental performance of the examined pathways and identify feedstock, scale and integration conditions that enhance pathway competitiveness. Evaluations are intended to inform the feasibility assessment of an innovative sustainable mobility system, the Off-Board Hybrid.

Giuliano, A.; Brancaccio, D.; Ricca, A.; Polverino, P.; De Bari, I. Biofuels for an Off-Board Hybrid Solution Avoiding the Overloading of the Electricity Grid Producing Power for a More Sustainable Mobility. *Chemical Engineering Transactions* **2025**, *119*.

Lombardelli, G.; Scaccabarozzi, R.; Conversano, A.; Gatti, M. Bio-Methanol with Negative CO₂ Emissions from Residual Forestry Biomass Gasification: Modelling and Techno-Economic Assessment of Different Process Configurations. *Biomass and Bioenergy* **2024**, *188*, 107315, doi:10.1016/j.biombioe.2024.107315.

Fiore, A.M.; Romanazzi, G.; Leonelli, C.; Mastorilli, P.; Dell'Anna, M.M. Partial Hydrogenation of Soybean and Waste Cooking Oil Biodiesel over Recyclable-Polymer-Supported Pd and Ni Nanoparticles. *Catalysts* **2022**, *12*, 506, doi:10.3390/catal12050506.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171317: Comprehensive Life Cycle Assessment (LCA) of the Spanish Electricity Mix: Evaluating Environmental Trade-offs in the Energy Transition

Lorena Sánchez-Relaño *, María-Pilar Martínez-Hernando, David Bolonio, Marcelo F. Ortega and María-Jesús García-Martínez

Escuela Técnica Superior de Ingenieros de Minas y Energía, Universidad Politécnica de Madrid, Madrid, 28003, Spain

In alignment with the European Union's "Fit for 55" package and the Spanish National Energy and Climate Plan (NECP), the Spanish power sector is undergoing a decarbonisation process. While existing research has extensively characterised the transition through specific metrics, a holistic understanding of the environmental trade-offs remains limited. Shifting toward renewable-heavy systems often mitigates climate impacts but may inadvertently increase other environmental burdens. This study aims to provide a comprehensive environmental profile of the seven key technologies in the Spanish electricity mix by applying the European Commission's Environmental Footprint (EF 3.1) methodology.

To this end, a "cradle-to-grave" Life Cycle Assessment (LCA) was conducted for (onshore) wind power, hydropower (reservoir), solar thermal (CSP), solar photovoltaic (PV), hard coal plants, combined cycle gas turbine (CCGT), and nuclear power. To carry out the simulations, the study used the SimaPro software with the Ecoinvent v3.10 database, adapting some of the processes with data from the current Spanish context. This research evaluates all 16 impact categories defined by the EF 3.1 framework, including acidification, freshwater ecotoxicity, eutrophication (marine, freshwater and terrestrial), human toxicity (cancer and non-cancer), ionising radiation, land use, ozone depletion, or mineral and metal resource use. The functional unit is defined as 1 kWh of electricity produced at the plant busbar.

Results reveal significant hidden trade-offs. While wind and nuclear power consistently show the lowest scores in Climate Change overall category (0.0124 and 0.00636 kg CO₂ eq/kWh, respectively), they exhibit distinct pressures in other areas. Nuclear power represents the main contributor to Ionising Radiation (0.72 kBq U-235 eq/kWh) and Fossil Resource Use (13.2 MJ/kWh) due to uranium mining. Conversely, coal power remains the most damaging technology across most categories, notably in Acidification (0.0137 mol H⁺ eq/kWh), Particulate Matter (1.57E-8 disease inc./kWh), and Marine Eutrophication (0.0018 kg N eq/kWh).

The analysis highlights that Photovoltaic (PV) technology, while carbon-efficient, presents a high intensity in Resource Use of Minerals and Metals (2.26E-7 kg Sb eq/kWh) and Land Use (6 Pt), primarily driven by the manufacturing stage of multi-Si panels and mounting structures. Solar thermal energy shows a non-negligible impact in Freshwater Ecotoxicity (0.677 CTUe) due to the use of synthetic oils and nitric acid in nitrate salts used for storage. Hydropower exhibits the highest impact in the Water Use category (2.27 m³ depriv./kWh), reaffirming its critical role in water-stressed regions like Spain. Additionally, Combined Cycle (CCGT) technology, reveals a significant drawback in Ozone Depletion (5.14E-8 kg CFC11 eq/kWh), the highest among all technologies evaluated, primarily due to upstream supply chain emissions.

The study demonstrates that a decarbonisation strategy based solely on GWP reduction provides an incomplete picture of environmental sustainability. The transition to a renewable-based mix in Spain involves shifting burdens from emissions to resource consumption and localised toxicity. By identifying these "burden-shifting" processes, this research provides insights for policymakers to refine the NECP 2030-2050 objectives. It is concluded that integrating the Environmental Footprint framework into national energy planning is vital to ensure that climate neutrality does not come at the cost of mineral exhaustion or increased human toxicity.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170651: Construction of Energy Efficient Sustainable Hempcrete Structure Utilizing Agro Residues

Mansoor Hamza^{1,*}, Shahbaz Nasir Khan¹, Ali Ahmad¹, Muhammad Hashir Javed¹ and Faiz Ur Rehman²

¹ Department of Structures and Environmental Engineering, University of Agriculture Faisalabad

² Institute of Food and Nutritional Sciences, PMAS- Arid Agriculture University Rawalpindi, Pakistan

The construction sector all over the world is one of the great consumers of land and all the natural resources which ultimately contribute to pollution globally. The conventional and traditional construction materials like fire clay bricks (7000 BC) and Ordinary Portland cement concrete are energy-intensive and environmentally detrimental. Now a days, bio-based or agro based construction materials have been introduced as comparative alternatives due to their renewable properties, lower embodied energy, and improved thermal efficiency. Hempcrete is basically a bio-composite material consisting of hemp shiv, mineral binders, and water, and is sustainable and thermally efficient building construction material as its use in farm structures, poultry sheds, farm workshops and other agriculture-based buildings where there are low temperature requirements in summers. The main objective and theme of the proposed research is the development and evaluation of a thermal efficient sustainable hempcrete structure utilizing hemp which is wild herb or weed naturally occurring in Pakistan specially in mid Punjab areas where there is moderate temperature and locally available agro residues like rice crop residue, wheat residue, sugarcane residue, rice husk and waste fodder. The research will focus on optimizing material composition, evaluating thermal, physical, and mechanical properties, and assessing the environmental benefits of hempcrete for its practical application in Pakistan's climatic conditions. Experimental and practical investigations of the research will be carried out to determine thermal conductivity, density, compressive strength, water absorption, and hygrothermal performance. The results are expected to demonstrate that hempcrete and agro residues would offer exceptional thermal insulation and enhanced sustainability as compared to conventional masonry materials like clay bricks etc. This research aims to contribute to sustainable construction practices and promote the utilization of agricultural waste in eco-friendly building systems to utilize the waste residues and hemp resultantly decreasing the carbon footprints in the environment and will reduce the contribution agriculture sector in the indirect smog formation cause due to stubble burnings of different crops residues.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-163569: Development of an Energy Scenario for Improving Energy Infrastructure in a Developing Nation (Nigeria as a Case Study)

Julius Oluwatosin Ajani *, Grace Oluwabukola Kolapo and Monday Hendrick Nwonu

Department of Electrical and Electronics Engineering, Federal University of Technology Minna, Niger state, Nigeria

Despite Nigeria's vast and diverse untapped potential in solar, wind, biomass, and small-scale hydropower, a significant and persistent gap remains between national policy ambition and the practical implementation of renewable energy projects. This study investigates the underlying structural reasons why existing sustainable energy strategies have failed to significantly reduce fossil-fuel dependency or resolve chronic electricity shortages, particularly within underserved semi-urban and rural communities where energy poverty remains a major barrier to development. Through a comprehensive thematic analysis of current regulatory frameworks, international development reports, and peer-reviewed academic literature, the research identifies critical bottlenecks in the energy transition process, with a specific focus on the deployment of solar mini-grids and decentralized energy systems as viable alternatives to the struggling national grid. The findings reveal that progress is hindered not by a lack of natural resources or high-level policy intent, but by fragmented institutional coordination, weak regulatory enforcement, and a lack of robust de-risking mechanisms necessary to attract essential private sector investment. The study highlights that the current reliance on thermal power plants fueled by gas and oil continues to cause significant environmental degradation and economic instability. To bridge this implementation gap, the paper proposes a multi-dimensional strategic framework centered on fostering inter-agency synergy, implementing specialized capacity-building programs for both policy-makers and technical personnel, and the stabilization of financial foundations for renewable infrastructure through targeted incentives. The study concludes that strengthening these institutional, financial, and technical pillars is the vital prerequisite for translating high-level policy commitments into measurable, sustainable development outcomes in addition to good and revised government policies to engage more stakeholders in the energy sector. Furthermore, the lessons derived from the Nigerian context offer a scalable roadmap for low-carbon growth and socioeconomic transformation that is highly relevant for other West African nations pursuing similar sustainable energy goals in the face of global climate challenges and the urgent need for a regional energy transition.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166332: Digital Twin for Smart Grid Integration of Solar Power Plants

Priyanka Abhay Vyas *, Sagar Shinde and Vedant Pampattiwar

Nutan Maharashtra Institute of Engineering and Technology, Talegaon Dabhade, Pune, Maharashtra, India

The integration of solar power into smart grids leads to potential as well as difficult problems such as grid instability, energy supply imbalances, and inefficient energy distribution due to the complexity and variability of renewable energy sources, as the world shifts towards renewable energy. In order to overcome these obstacles, our study creates a virtual replica, a Digital Twin that simulates the grid and solar power plant components in a virtual environment. For that, we have used MATLAB/Simulink and Simscape, which are specifically used to create high-fidelity models of inverters, solar arrays, and interconnection gear. The digital replica is kept closely linked with conditions on site through the use of data streams. Built-in procedures modify energy dispatch in order to federated learn to optimize yield and stabilize the grid. The Digital Twin system helped us to understand the solar power plant's dynamic performance within smart grids by using simulation and analysis tools. Using .mat files, we successfully extracted and analyzed system variables such as solar power, temperature, battery status, and irradiance data for analysis. The time series display of solar generation along with grid power consumption and load requirements revealed different operational behaviors of the system and mismatches under varying conditions. Along with that, actual system analysis was done at the component level to examine the patterns of battery charging along with inverter performance and power grid fluctuations and financial operation details. This simulation showed how different irradiance levels impact power generation while displaying the temporal evolution of battery voltages and illustrating the connection between grid power delivery and economic returns. The application of digital twin has led to a 30% increase in energy production and a 15% improvement in the downtime of resources in the solar power plant. This paper concludes with a staged deployment approach and detailed implementation instructions to provide practitioners with a clear path to more reliable, efficient, and sustainable solar-integrated power systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171201: Drone-Based Defect Detection in Photovoltaic Modules Using YOLOX

Haoxuan Ding * and Yin Ye

School of Information Engineering, Jiangxi University of Water Resources and Electric Power, Nanchang 330099, China

Introduction: The accuracy and real-time performance of drone-based defect detection on solar panels are critical to the operation and maintenance (O&M) efficiency, fault early-warning capability, power generation reliability, and emergency decision-making responsiveness of photovoltaic (PV) power plants. As solar farms expand in scale and complexity, automated inspection solutions have surged. Traditional manual or semi-automated methods are increasingly inadequate due to high labor costs, inconsistent diagnostics, and limited coverage. Efficient and robust defect identification thus becomes a cornerstone of intelligent PV system management, enabling proactive maintenance and maximizing energy yield over the plant's lifetime.

Methods: This study adopts YOLOX—an advanced deep learning-based object detection algorithm—to automatically identify defects in PV modules from large-scale UAV aerial imagery. The model is specifically trained to detect five core defect types: Broken Glass, Diode Failure, Hot Spots, Obscured panels, and Potential-Induced Degradation (PID) Effect. By integrating baseline PV module databases, complex scene adaptation models, and morphology-differentiated recognition algorithms, YOLOX effectively captures both intrinsic fault mechanisms and context-specific distribution patterns. The model leverages its powerful feature extraction and high-precision localization capabilities to suppress common disturbances such as image noise, inter-module shadows, uneven illumination, and strong glare, ensuring reliable detection across diverse environments.

Results: Experimental evaluations confirm that YOLOX maintains high detection accuracy under challenging real-world conditions—including overcast skies, rainy weather, low-light nighttime scenarios, and large-scale PV arrays. The algorithm provides precise spatial coordinates of defects. Comparative tests demonstrate that YOLOX outperforms models like YOLOv5 and Faster R-CNN in both detection precision and inference speed, particularly in scenes with partial occlusion or reflective glare. Its ability to adapt to varying installation types further enhances its practical applicability.

Conclusions: The designed approach significantly enhances the automation, precision, and intelligence of PV plant O&M by enabling rapid fault localization, dynamic repair prioritization, and accurate energy loss quantification. By providing structured outputs that link defect location and severity, YOLOX supports data-driven decision-making in routine operations and emergency inspections. This study confirms the feasibility, robustness, and practical applicability of YOLOX for real-world solar farm inspection, offering a scalable and efficient solution for next-generation intelligent photovoltaic management systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171165: E-fuel production from lignocellulosic biomass oxy-gasification

Alejandro Cánovas Sánchez^{1,*}, Luis Alberto Lara López¹, Encarnación Cruz Sánchez-Alarcos¹, Pedro Juan Martínez Román¹, Manuel Salgado Alejo², Javier Huerga Sánchez², Beatriz Melgar Bachiller², Diego Fernández del Álamo², Andrés Melgar Bachiller³, Alfonso Horrillo Güemes², Nuria García-Mancha Delgado-Ureña¹ and Roberto Campana Prada¹

¹ Centro Nacional del Hidrógeno, Fernando El Santo S/N, 13500, Puertollano, Ciudad Real, Spain

² Fundación Cidaut, Pl. Vicente Aleixandre Campos, 2, 47151 Boecillo, Valladolid, Spain

³ Escuela de Ingenierías Industriales, University of Valladolid, P.º del Cauce, 59, 47011 Valladolid, Spain

Introduction

With the aim of recovering waste for the production of alternative fuels, Centro Nacional del Hidrógeno (CNH2), Fundación CIDAUT and the University of Valladolid are participating in a project focused on the development of lignocellulosic biomass oxy-gasification technology.

The process consists of a first pyrolysis stage, heating the biomass by burning part of the recirculated synthesis gas, and a second stage carried out in an EFG (Entrained Flow Gasification) reactor, in which the high operating temperatures achieved by using oxygen as a gasifying agent facilitate the reaction of solids and the decomposition of tars and heavy hydrocarbons, as well as the production of a synthesis gas with a higher calorific value relative to air-based gasification technologies.

This synthesis gas is converted into synthetic fuels, such as petrol or SAF, using a Fischer-Tropsch process. Additional inputs to both reactors are oxygen and hydrogen, respectively. Both gases are obtained from an alkaline electrolyser, achieving total integration between the processes.

This work focuses on pyrolysis and oxy-gasification; therefore, no modelling results for electrolysis or the Fischer-Tropsch process are presented.

Methods

In order to optimise the process and design and size the equipment, a pyrolysis model was developed in 0D and 1D, and a model of the complete process in 1D and 3D, which includes both pyrolysis and gasification of pine wood chips. This approach allows an initial prediction of the behaviour of the system with the use of other types of biomass.

The pyrolysis model was constructed based on the kinetic model proposed by E. Ranzi [1], which details all the reactions involved in the process. It was developed in both Visual Basic for Applications and Python. In both cases, the results were validated using information available in the literature and through thermogravimetric tests.

The 1D model of the complete process, programmed in C++, enabled rapid parametric studies of the EFG to be carried out to determine its optimal dimensions (diameter and length) in accordance with efficiency requirements, mechanical design and maximum permissible dimensions. It also provides the necessary boundary conditions (mass flow, composition and temperature of the gases at the EFG inlet) to be entered into the 3D model.

The 3D model, created in ANSYS Fluent, which is more computationally expensive, provides detailed information on the behaviour of the fluid inside the reactor. A reactor mesh was generated, with the dimensions considered optimal for the EFG through parametric study, and the boundary conditions obtained at the EFG inlet of the 1D model are introduced so that the two models are similar.

The main methodological contribution of this work lies in the development of a coupled multiscale modelling framework that integrates detailed kinetic pyrolysis modelling with rapid 1D reactor optimisation and CFD-consistent 3D validation for entrained-flow gasifier design within an integrated process for the production of synthetic fuels from biomass.

Results

Simulations were carried out using the pyrolysis model, which enabled the endothermic nature of the process to be analysed through the evolution of temperature in an adiabatic system.

In addition, an estimated 50% tar and 12% char production was calculated, as well as the calorific power required for the pyrolyser.

The results obtained from the simulations of the complete 1D and 3D models carried out with the optimal design geometry and a feed rate of 50 kg/h of pine wood chips have been compared, obtaining a flow rate of 81.11 kg/h of synthesis gas with a composition (dry basis) of 59.14% CO, 27.92% H₂, 10.52% CO₂ and 2.41% CH₄, corresponding to a lower heating value (LHV) of approximately 11.3 MJ/Nm³.

Conclusion

The proposed framework supports the design and pilot-scale integration of an oxy-gasification unit coupled with downstream Fischer–Tropsch synthesis and on-site electrolysis.

Regarding the estimation of the heat output required in the pyrolyser, the results obtained are very close to those published by other researchers in the same field [2]. The results obtained from the 1D and 3D models allow the EFG and pyrolyser to be dimensioned, the recirculated gas and oxygen flow rates to be added at the different stages to be defined, and the size of the carbon particles entering the reactor to be determined, thereby achieving an acceptable degree of solid-to-gas conversion.

References

1. Ranzi, E. et al.: “Chemical kinetics of biomass pyrolysis,” *Energy and Fuels*, vol. 22, no. 6, pp. 4292–4300, Nov. 2008,
2. Daugaard, D. E. and Brown, R. C.: “Enthalpy for pyrolysis for several types of biomass,” *Energy and Fuels*, vol. 17, no. 4, pp. 934–939, Jul. 2003,



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166245: Efficient Pb-Sn Perovskite Solar Cells with additives of Amino Acide Salts

Renhao Zheng^{1,*}, Marina Ustinova¹, Aldo Di Carlo^{1,2}, Giuseppe Ammirati², Venanzio Raglione², Francesco Toschi² and Lavrenty Gutsev³

¹ C.H.O.S.E. (Center for Hybrid and Organic Solar Energy), Electronic Engineering Department, University of Rome Tor Vergata, Rome, Italy

² Istituto di Struttura della Materia (CNR-ISM) National Research Council, Rome, Italy

³ Department of Chemical Engineering, Louisiana Tech University, Louisiana, Institute of Micromanufacturing 505 Tech Dr, Ruston, LA 71270, USA

Mixed Pb-Sn perovskite solar cells have recently demonstrated photoconversion efficiencies (PCEs) comparable to those of fully Pb-based halide perovskite devices. The main advantages of the Sn-containing composition are reduced toxicity and enhanced light absorbance over a wider wavelength range. Furthermore, the narrow bandgap of approximately 1.25 eV gives Pb-Sn perovskites the potential to surpass the photoelectric conversion efficiency of lead halide perovskite solar cells. However, the practical application of these devices is currently limited by the easy oxidation of Sn^{2+} . Avoiding this oxidation is one of the requirements to achieve efficient and stable Sn-based perovskite solar cells (PSCs). The recent few reports have shown that some amino acids used as additives in the Pb-Sn mixtures can effectively passivate defects thanks to their zwitterions properties and also reduce Sn^{4+} cations that present in precursor solutions as impurities [1]. Therefore, this study is dedicated to optimizing a strategy for employing amino acid salts in mixed Pb-Sn perovskite solar cells to improve their performance and stability.

Chloride salts of L-lysine, L-aspartic acid, L-histidine, and other amino acids were introduced into the precursor solutions, followed by interface passivation on the perovskite surface. A comparative study of the structural, photoluminescent and morphological properties of perovskite films and the photovoltaic properties of solar cells allowed us to determine which amino acid salt is the most effective in defect passivation and suppression of Sn^{4+} formation.

In particular, the incorporation of L-lysine-HCl as an additive in Sn-Pb perovskite solar cells resulted in a power conversion efficiency of 18.4% for single-junction devices. These results suggest that amino acid salts represent a promising strategy for enhancing both the efficiency and stability of single-junction Sn-Pb perovskite solar cells. We acknowledge the GOPV project RdS2019-21 CSEAA_00011 - TIPO A - Ministry of Environment and Energy Security (MASE) – CUP E83C23000840001

[1] Zhou, S., Fu, S., Wang, C. et al. Aspartate all-in-one doping strategy enables efficient all-perovskite tandems. *Nature* 624, 69–73 (2023).



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171365: Electrochemical Behavior and Surface Activation of Ni₂₀₀ Electrodes under Dynamic Alkaline Electrolysis: Effects on Hydrogen and Oxygen Evolution with Renewable Power Supply

Rebeca María Simion *, Nerea López García, Jesús Serrano Jiménez, Roberto Campana Prada and Jesús Rodríguez Ruiz

Scientific Development Unit, National Hydrogen Center, Prolongación Fernando el Santo S/N, Puertollano, Ciudad Real, 13500, Spain

Introduction

Hydrogen is a key energy vector for transitioning to sustainable energy systems, with applications in energy storage, power-to-gas systems, fuel cells, and transportation. Water electrolysis powered by renewable energy enables hydrogen production without direct CO₂ emissions, supporting the European Union's climate neutrality goals [1]. Among technologies, alkaline water electrolysis (AWE) stands out for its maturity, robustness, scalability, and use of non-noble metal materials [2,3]. Regarding electrodes, nickel is a reference material for AWE because of its chemical stability and ability to form catalytically active phases such as nickel hydroxides and oxyhydroxides (β - and α -NiOOH) at higher potentials, enhancing reaction kinetics and lowering overpotentials for both HER and OER [2–4].

Furthermore, photovoltaic (PV) energy is becoming a promising renewable energy source. However, the intermittent availability and the fluctuations in the offer–demand market create the need for incorporating energy carriers. Based on this, integrating AWE with renewable sources introduces dynamic operation challenges: load variations and on/off cycles may affect electrode behavior and long-term durability [5].

In this work, we explored the formation of different active catalytic species of Ni under continuous and intermittent regimes simulating realistic photovoltaic (PV) generation profiles, focusing on their potential application in green hydrogen production [2,3].

Methods

This study investigates the electrochemical behavior of smooth Nickel 200 (Ni₂₀₀, Electrocell, Denmark) electrodes as cathodes and anodes under alkaline electrolysis with renewable energy profiles. Experiments were conducted in 30 wt% KOH at 70 °C and atmospheric pressure, applying two polarization regimes: long-term polarization (LP) and intermittent polarization (IP).

Electrochemical characterization and LP tests used three-electrode cells with a 0.95 cm² active area, Pt counter electrodes, and a reversible hydrogen electrode (RHE), connected to an Autolab PGSTAT302N potentiostat.

For hydrogen evolution reaction (HER), a current density of -150 mA cm^{-2} was applied for up to 100 h to assess surface activation and long-term stability. The formation of active species was monitored by cyclic voltammetry at 25, 50, and 100 h of testing. For oxygen evolution reaction (OER), $+150 \text{ mA cm}^{-2}$ was applied, evaluating the formation of β -NiOOH and anodic activation via cyclic voltammetry, polarization curves, and chronopotentiometry.

IP tests were performed in 10 cm² AWE cells on a CNH2-designed test bench, following the criteria defined by the JRC (Joint Research Centre) and using open-access data from the Belgian electricity grid. A simulated PV profile was applied over 100 h to replicate daily cycles consisting of 11 h of daylight (0.01–1.5 A) and 13 h of night (0 A). After testing, electrodes were characterized through cyclic voltammetry, morphological analysis, and X-ray photoelectron spectroscopy (XPS) to identify surface species (nickel hydroxides, oxyhydroxides, and oxides) associated with performance improvements.

Results and Discussion

Results show progressive electrochemical activation of Ni200 electrodes under both regimes. In cathodic conditions, LP reduced the HER overpotential by up to 20 mV, associated with α -Ni(OH)₂ formation, as seen in cyclic voltammetry [2,4]. IP produced similar improvements after several cycles without degradation, showing that surface activation persists under dynamic conditions [5].

Anodic tests showed an increase in the redox peak corresponding to β -Ni(OH)₂ $\rightarrow$ β -NiOOH after 100 h of LP, with OER potential decreasing to $\sim$ 1.4 V vs. RHE [3,4]. IP led to a potential decrease of $\sim$ 300 mV after one day, reducing activation overpotential [5]. Polarization curves revealed a passivation region between 1.0 and 1.5 V vs. RHE, linked to Ni³⁺ species (β -NiOOH) formation, which likely stabilizes the surface and improves OER durability [3,4]. Additionally, iron traces originating from KOH impurities were detected by ICP analysis, contributing to an enhanced electrode performance, as confirmed by long-term testing.

Conclusions

This study highlights the effects of constant and intermittent polarization on Ni electrodes in alkaline water electrolysis. At the anode, polarization promotes β -NiOOH formation, reducing the OER overpotential and improving electrocatalytic performance [3]. At the cathode, surface activation of Ni200 via α -Ni(OH)₂ lowers the HER overpotential, although phase stability may influence long-term durability [2,4]. These results demonstrate that simple polarization strategies can effectively activate Ni electrodes under dynamic conditions, advancing the understanding of Ni electrode behaviour for renewable energy applications [2,3,5].

References

1. Yue, M.; Lambert, H.; Pahon, E.; Roche, R.; Jemei, S.; Hissel, D. Hydrogen energy systems: A critical review of technologies, applications, trends and challenges. *Renew. Sustain. Energy Rev.* 2021, 146, 111180.
2. Xue, S.; Liang, Y.; Hou, S.; Zhang, Y.; Jiang, H. Alpha-Nickel Hydroxide Coating of Metallic Nickel for Enhanced Alkaline Hydrogen Evolution. *ChemSusChem* 2022, 15, e202201072.
3. Danilovic, N.; Subbaraman, R.; Strmcnik, D.; Chang, K.C.; Paulikas, A.P.; Stamenkovic, V.R.; Markovic, N.M. Enhancing the alkaline hydrogen evolution reaction activity through the bifunctionality of Ni(OH)₂/metal catalysts. *Angew. Chem. Int. Ed.* 2012, 51, 12495–12498.
4. De Groot, M.T. *Curr. Opin. Chem. Eng.* 2023, 42, 100981.
5. Rocha, F.; Delmelle, R.; Georgiadis, C.; Proost, J. *J. Environ. Chem. Eng.* 2022, 10, 107648–107659.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166248: Energy and Resource Efficiency in Indoor Pools: The Role of Installation Design

Anna Mika^{1,2,*}, Joanna Wyczarska-Kokot¹ and Anna Lempart-Rapacewicz³

¹ Department of Water and Wastewater Engineering, Faculty of Energy and Environmental Engineering, Silesian University of Technology, Konarskiego 18, 44-100 Gliwice, Poland

² PPUH Transcom Sp. z o.o., Józefowska 5, 40-144 Katowice, Poland

³ Faculty of Materials, Civil and Environmental Engineering, University of Bielsko-Biała, Willowa 2, 43-309 Bielsko-Biała, Poland

Introduction

Indoor swimming pool facilities are classified among the most energy-intensive public buildings due to their continuous operation and the high demand for thermal energy, electricity, and water. The necessity to maintain stable thermal and hydraulic conditions for sanitary safety and user comfort results in substantial energy consumption, primarily associated with pool water heating and mechanical ventilation systems. The temperature of the pool water directly governs evaporation intensity, which affects latent heat losses, indoor air humidity, and ventilation loads, thus creating strong interdependencies between the water treatment processes and energy demand. The consumption in swimming pool facilities is mainly driven by filter cleaning, water renewal requirements, and sanitary regulations, which further increase the demand for thermal energy due to the need for continuous reheating of make-up water. As a result, the heating, ventilation, and pool water treatment systems form an integrated energy-water system, in which suboptimal installation design leads to increased energy consumption and operational inefficiencies. Rising energy prices, growing pressure on freshwater resources, and the implementation of climate and environmental policies require improvement of energy efficiency in existing swimming pool infrastructure. Many facilities constructed 15–25 years ago lack integrated solutions for energy management, heat recovery, and water reuse. This study addresses this gap by evaluating the role of installation design in improving energy and resource efficiency, with a focus on integrated modernization strategies based on hybrid energy systems and water recovery technologies.

Methods

The study used a case study methodology applied to existing indoor swimming pool facilities located in different climatic regions of Poland: Elk, Limanowa, and Skoczów. The selected facilities represent different construction periods, system layouts and operational profiles, allowing a comparative assessment of energy and water performance under varied boundary conditions. The first stage involved the determination of the baseline energy and water consumption. This assessment was based on long-term utility billing data, measurements from building management systems (BMS), direct meter readings, and supplementary on-site measurements. The collected data was used to quantify annual and specific consumption of thermal energy, electricity, and water, as well as to identify the dominant energy loads associated with pool water heating, air handling units, ventilation, and auxiliary installations. Subsequently, a detailed technical evaluation of heating systems, ventilation, air conditioning (HVAC) units, and pool water treatment installations was performed. Based on functional and energy analysis, multiple retrofit scenarios were developed and modelled, including gas-fired boilers, electrically driven heat pumps, micro-cogeneration (CHP) units, photovoltaic (PV) systems and hybrid system configurations. For each scenario, steady-state energy balances, operational expenditures, and CO₂ emissions were calculated, accounting for regional climatic conditions, energy price structures, and system efficiencies. Energy analyses were further integrated with assessments of water recovery potential, water reuse schemes, and heat recovery from wastewater streams, enabling a comprehensive evaluation of coupled energy-water optimization strategies.

Results

The results indicate that optimized installation design and system configuration, particularly the integration of multiple heat and power sources, significantly enhance the overall energy performance of indoor swimming pool facilities. The analysed facilities exhibited annual thermal

energy demands in the range of 1.25–1.64 GWh year⁻¹ and annual electricity consumption between 0.82 and 0.89 GWh year⁻¹ under baseline operating conditions. These values confirm the high energy intensity characteristic of indoor swimming pool infrastructure. The implementation of hybrid energy systems that combine microcogeneration (CHP) units, electrically driven heat pumps, and photovoltaic (PV) installations resulted in substantial reductions in energy demand. Thermal energy consumption decreased by 20–50%, while electricity demand was reduced by 15–25%, depending on facility size, operational profile, and system configuration. Renewable and hybrid energy systems were capable of covering approximately 40–70% of the total energy demand, thus significantly improving energy autonomy. These improvements translated into operational cost reductions of up to 50% and an annual decrease in CO₂ emissions of approximately 30–40 t CO₂ per facility. The highest energy performance was observed in facilities equipped with integrated control strategies that coordinate pool, heating, ventilation, and irrigation systems, which enabled load balance, reduced peak demand, and improved overall system efficiency.

Conclusions

The study confirms that installation design has a decisive influence on the energy performance of indoor swimming pool facilities. Modernization strategies should therefore address the facility as an integrated energy–water system throughout its life cycle. Combining renewable energy technologies with water and heat recovery solutions enables substantial reductions in energy and water consumption while maintaining user comfort and sanitary safety. Such an integrated approach supports the transition toward low-emission, resource-efficient swimming pool infrastructure consistent with circular economy principles.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166072: Energy conversion efficiency and carbon intensity of EU energy systems

Melinda Oroszlanyova * and Özgen Yalçın

College of Engineering and Technology, American University of the Middle East, Kuwait

Introduction: Industry 5.0 challenges European industries to elevate their systems with the help of technological and digital transformations and, at the same time, motivates them towards achieving the sustainable development goals (SDGs). Energy system transformations and sustainable transitions are the key concepts in decarbonizing energy sources, believed to greatly contribute to the achievement of climate neutrality. The mitigation of greenhouse gas emissions is supported by energy production from renewable resources instead of fossil fuels. The present study assesses how efficiently the member states of the European Union (EU) convert primary energy into useful energy and how this efficiency affects carbon emissions, using energy data collection since 1990 by the Directorate-General for Energy of the European Commission.

Methods: We analyze the relationships and trends between energy conversion efficiency and carbon emissions based on metrics including system energy conversion efficiency, carbon intensity of energy use, and energy loss ratio. The system energy conversion efficiency determines how much useful energy comes from the national energy system relative to the total energy input. The carbon intensity of energy use defines how carbon-efficient the energy conversion system is by the ratio of total CO₂ emissions to total energy output. The energy loss ratio quantifies wasted energy in terms of thermodynamic inefficiencies.

Results: Based on the latest available energy data from 2023 for the EU, we report a 71.58% energy conversion efficiency, 90.70% carbon intensity, and an energy loss ratio of 28.42%. Furthermore, we analyze trends among the member states based on the three studied metrics between 1990 and 2023, classifying the countries.

Conclusions: We assess the importance of improving energy conversion efficiency and reducing emissions in the EU using harmonized EU energy statistics, enabling a system-level assessment of national energy performance. Our study relates the changes in practices in energy generation on a country-level over the years to the system energy conversion efficiency, carbon intensity of energy use, and energy loss ratio.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170941: Energy justice in urban climate action planning

Laura Cidras * and Benjamin McLellan

Graduate School of Energy Science, Kyoto University, Japan

1. Cities in Climate and Energy Action

Cities play a significant role in the shift from fossil fuels to renewable energy sources to address climate change, because of mainly two reasons. First, cities are both major energy consumers and contributors to greenhouse gas emissions globally. More than half ($\approx 55\%$) of the world's population live in urban areas (4.6 billion people), and this proportion is projected to increase to 68% by 2050 (+2.5 billion people)[1]. At the same time, cities depend heavily on energy to deliver a wide range of essential energy services. As a result, almost two thirds ($\approx 67\%$) of global primary energy use is attributed to urban areas, and this percentage is expected to rise to 73% by 2030. In turn, urban energy demand accounts for 75% of global carbon dioxide emissions, making cities critical to reduce global GHG emissions[2]. Second, cities are particularly vulnerable to extreme climate change-driven weather events due to their high concentration of people and infrastructure. Natural hazards such as floods and heatwaves can rapidly lead to ripple effect problems in energy systems through direct damage to energy infrastructure, and disruption in energy supply. Other interconnected impacts include increased energy demand and prices, and negative impacts on renewables due to changing weather patterns.

However, not all citizens face severe weather events in the same manner. Low-income groups and marginalized populations often live in inadequate housing, and concentrate in urban areas with aging infrastructure and poor services such as transportation, making them particularly vulnerable to climate change and energy system disruptions.

2. Unequal Distribution of both Benefits and Burdens of the Energy Transition

Just as climate change disasters do not affect all populations in the same proportion, the benefits and burdens of the energy transition are not equally distributed among all citizens. For example, low-income households spend a much higher proportion of their income on electricity bills due to living in energy-inefficient homes, and barriers from adopting cleaner and more affordable technologies. Lack of means and opportunities (ex.: access to adequate housing, education and job centers, transport, etc.) stems from underlying and interconnected systems (ex.: economic, institutional systems, etc.), that perpetuate such injustices and social discrimination, as highlighted by social justice theory.

However, to ensure the effectiveness and long-term viability of the energy transition in cities and all government levels, the representation and involvement of all populations is crucial. This is in line with UN SDG 7 Universal access to energy and SDG 11 Inclusive and sustainable cities. By studying how urban energy policy addresses, or creates and exacerbates different forms of social inequality and injustice among vulnerable groups globally, this research aims to answer the following question: how to make the energy transition more just and equitable in cities?

3. Energy justice, Just Transitions, and Urban Energy Transition Theories

Both energy justice and just transitions theory emerged to address the systemic inequitable outcomes and decision-making processes related to energy systems. Energy justice can be defined as a global energy system that fairly distributes both the gains and burdens of energy services, and considers the interests of all populations in an equitable and impartial manner [3]. In energy justice research, two prominent frameworks can be identified. First, energy justice is defined as having three central tenets: distribution, procedural and recognition justice [4]. Second, ten energy justice principles that can be applied to real-world energy problems are identified: availability, affordability, due process, transparency and accountability, sustainability, intragenerational equity, intergenerational equity, responsibility, resistance, and intersectionality [5]. However, energy justice studies are widely focused on the national government level, and hardly examine the urban level. Urban energy transitions theory, on the other hand, although situated at the city-level and widely focused on energy systems, is rooted in highly techno-

economic theories such as Technological Innovation Systems (TIS), and the Multi-Level Perspective (MLP), hence overlooking social, political and cultural problems.

4. Knowledge Gap, Study Objectives, Methods, and Conclusion

This study addresses the knowledge gap between the energy justice framework and urban energy transitions theory. By combining energy justice theory with recognized urban policy guidelines by the American Planning Association and UN-Habitat, this study investigates how concepts of equity and fairness within energy systems can inform urban energy policy. To conclude, an urban energy justice framework is proposed, highlighting pathways towards defining contemporary applications of energy justice in an urban setting.

5. References

1. UN, "World Urbanization Prospects: The 2018 Revision," 2019.
2. IPCC, "Climate Change 2023: Synthesis Report." 2023.
3. Sovacool et al, "Energy justice: Conceptual insights and practical applications," *Applied Energy*, vol. 142, pp. 435–444, 2015.
4. McCauley et al, "Advancing energy justice: the triumvirate of tenets," *International Energy Law*, vol. 32, no. 3, pp. 107–110, 2013.
5. Sovacool et al, "New frontiers and conceptual frameworks for energy justice," *Energy Policy*, vol. 105, pp. 677–691, 2017.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171175: Energy Transition and Sustainable Transport Development Synergies in the Context of the SDG Paradigm: some Policy Perspectives and Trade-offs

Adrian Foghis^{1,*} and Octavian Mihai Petre²

¹ School of Advanced Studies of the Romanian Academy, Romanian Academy and Institute of National Economy, Romanian Academy House, 13 September Street no. 13, 010071, Bucharest, Romania

² Doctoral School of Economics II, Faculty of Agrifood and Environmental Economics, Bucharest University of Economic Studies, Romania

The paper analyzes some of the potential synergies among energy, transport, and climate action in the European Union, using Sustainable Development Goals SDG-7 (affordable and clean energy), SDG-9 (industry, innovation, and infrastructure), and SDG-13 (climate action) as analytical framework for assessing the coherence and progress of the green transition. Eurostat data from 2015 to 2024 are used to analyze trends in primary energy production, gross inland consumption, energy intensity of GDP, vehicle fleet composition, road freight transport, net greenhouse gas emissions, and private investment in climate change mitigation.

The results indicate a gradual and inconsistent energy transition among Member States, characterized by declining primary energy production and stable gross inland consumption, along with reduced energy intensity, suggesting partial decoupling of economic growth from energy use. Trends changes such as energy security challenges, especially for economies with high import dependence, highlight tensions among efficiency, competitiveness, and energy autonomy. In the transport sector, a dual transition is evident, with internal combustion engine vehicles continuing to dominate the fleet, reflecting structural inertia that slows decarbonization. Since 2019, electric vehicle adoption has grown rapidly, demonstrating the impact of public policies, financial incentives, and technological advances. The effectiveness of electric mobility in reducing emissions depends on the energy mix and the infrastructure's capacity to support large-scale electrification.

Road freight transport is critical for achieving SDG 13, as increasing transport volumes drive higher fossil fuel consumption and emissions. and the ongoing trend reveals the current limitations of modal shift and freight electrification, emphasizing the need for integrated policies that modernize infrastructure, improve energy efficiency, and diversify energy sources. Analysis of net greenhouse gas emissions from 2018 to 2024 shows a temporary reduction in 2020, followed by a moderate rebound, with most countries not returning to pre-pandemic levels. Private investment in climate change mitigation remains focused on the energy and transport sectors, confirming their interdependence in the decarbonization process.

The energy and climate transition within the European Union represents a complex process with substantial implications for achieving Sustainable Development Goals (SDGs) 7, 9, and 13, and attaining these objectives requires a systemic approach that integrates energy, industrial, and transport policies to ensure long-term compatibility among economic growth, energy security, and climate neutrality.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166166: Energy-Efficient Unmanned Ground Vehicle (UGV) for Precision Root Zone Fertilizer Implantation toward Sustainable Agriculture

Koduri Madhu Malathi * and Koduru Koteswara Rao

Farm Machinery and Power Engineering, ICAR-Indian Agricultural Research Institute, New Delhi, 110012, India

Fertilizer management plays a vital role in sustaining crop productivity and soil health. Conventional broadcasting techniques often lead to nutrient losses through leaching, volatilization, and runoff, resulting in reduced fertilizer use efficiency, often resulting in considerable nutrient losses, repeated field operations, and increased energy demand, thereby contributing to environmental pollution and inefficient resource utilization. To address these challenges, precision application methods such as root zone fertilization have gained importance, ensuring nutrients are delivered closer to the plant's uptake region for enhanced efficiency. This research focuses on the introduction of an Unmanned Ground Vehicle (UGV) for precise fertilizer implantation in the root zone of wide-row crops. The energy-efficient Unmanned Ground Vehicle (UGV) system comprises key components including a chassis with an electric drive mechanism, a GPS-based navigation and positioning unit, a soil-probing and penetration tool, and a controlled fertilizer metering and delivery system. The coordinated operation of these components enables accurate placement of fertilizer at predefined depths and spatial intervals, ensuring targeted nutrient delivery with minimal human intervention. Such precision reduces off-target fertilizer losses and enhances nutrient uptake efficiency by placing nutrients closer to the active root zone of plants. From an energy perspective, the proposed UGV system offers multiple advantages over conventional tractor-based fertilizer application methods. Targeted fertilizer implantation near the root zone enhances nutrient uptake efficiency and lowers fertilizer losses to the surrounding environment caused by leaching and volatilization. Consequently, the system reduces the frequency of fertilizer applications and associated energy-intensive field operations. The use of electric drive further supports reduced fossil fuel dependence and lower operational emissions compared to conventional machinery. The proposed UGV-based root zone fertilizer implantation system highlights strong potential to improve energy efficiency, reduce environmental impacts, and support sustainable nutrient management practices. The study highlights the role of electrically powered autonomous machinery as a viable solution for low-energy, climate-resilient agricultural systems, aligning with global efforts toward sustainable energy utilization in modern agriculture.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166264: Enhancing Electrical Energy Generation in a Galvano-Fenton Process through Cathode-to-Anode Surface Optimization

Intissar Gasmi^{1,*}, Kaouther Kerboua^{2,3} and Naoufel Haddour⁴

¹ Environmental Research Center, 23000, Annaba, Algeria.

² Department of Process and Energy Engineering, National Higher School of Technology and Engineering, 23005 Annaba, Algeria.

³ Laboratory of Mining, Metallurgy and Materials L3M, National Higher School of Technology and Engineering, Annaba, Algeria.

⁴ AMPERE Laboratory, H9 Building, École Centrale de Lyon (Lyon Central School), UMR CNRS 5005, 36 Avenue Guy de Collongue, 69134 Ecully Cedex, France

Electrochemical advanced oxidation processes (EAOPs) are increasingly recognized as energy-efficient and sustainable solutions for the treatment of industrial and municipal wastewater, particularly for the removal of recalcitrant organic pollutants that are often resistant to conventional treatment methods. Among these, Galvano-Fenton systems, which exploit the spontaneous corrosion of iron coupled with cathodic catalysis, offer the unique advantage of combining pollutant degradation with in situ electrical energy generation, thereby eliminating the need for external power sources and contributing to more sustainable operation. In this study, a Galvano-Fenton system based on a galvanic Fe/Cu electrode configuration was systematically investigated to evaluate both its environmental and energetic performance under controlled laboratory conditions. The system enables continuous production of ferrous ions and highly reactive hydroxyl radicals, facilitating efficient degradation of organic contaminants under mild operating conditions while minimizing chemical consumption.

Special attention was paid to electrode design and configuration. The effects of increasing cathode surface area relative to the anode, electrode material selection, and cathode-to-anode surface area ratios (ranging from 1:1 to 6:1) were examined in detail. Key operating parameters, including solution pH (2–3), hydrogen peroxide concentration (3 mM), and reaction time (up to 60 minutes), were optimized in terms of pollutant removal efficiency, reaction kinetics, and electrical power output. Results demonstrated that enlarging the cathode surface significantly enhances electrical energy generation, achieving power densities of up to $220 \text{ mW}\cdot\text{m}^{-2}$, currents of 1.5–2 mA, and potentials reaching 0.85 V. Simultaneously, malachite green degradation efficiencies were maintained at very high levels (98–100%), highlighting the system's excellent catalytic performance, operational stability, and potential for scale-up.

Overall, this work demonstrates the dual environmental and energetic functionality of the Galvano-Fenton process. The findings underscore the critical role of electrode configuration in maximizing energy recovery while maintaining high pollutant degradation efficiency. The study provides valuable insights for the rational design of sustainable electrochemical wastewater treatment technologies, bridging the gap between laboratory-scale research and potential real-world applications in energy-positive and resource-efficient wastewater management.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164194: Evaluation of Synergies between Water Desalination, Wastewater, and Nuclear and Renewable Sources for Cost-effective and Resilient Power and Water Schemes

Veera Gnaneswar Gude

Purdue University Northwest Water Institute, Purdue University Northwest, Hammond, Indiana 46323 USA

Introduction

Desalination of saline waters to augment freshwater supplies has become an important component of the water supply portfolio of many communities around the world. Because desalination technologies typically require electricity and/or thermal energy for the conversion of saline water into freshwater, nuclear power plants can serve as ideal sources of heat and electricity for these plants. However, the cost of nuclear energy has increased in recent years due to the shifts in supply chains and global economy, and the inclusion of renewable energy sources such as solar and wind energy conversion technologies is often considered to provide cost-effective solutions. The research objective of this study is to assess various water/power schemes.

Methods

Several water/power scenarios including nuclear, solar and conventional fuel sources were studied. The technoeconomic feasibility of a plant was modeled using the DEEP software created by the International Atomic Energy Agency (IAEA) (DEEP, 2018). The DEEP program allows for the modeling of desalination output and water costs powered by various energy sources. The program analyzes the process based on process variables and configurations, and it is effective in evaluating the feasibility scenarios. Several trials were completed to compare the variance in factors affecting the proposed facility along with the present configuration options. The trials were compared to determine the most economically feasible configuration for the needs and characteristics of the proposed location.

Results

A technoeconomic feasibility study performed on a coastal community in the USA has shown that the desalination option is expensive. When compared with the conventional water supply options, freshwater from nuclear desalination plants integrated with RO, MED, and MSF processes costs \$0.8, \$1.08 and \$1.56 per m³, respectively. These values are up to 3.5-, 4.7- and 6.8-fold higher than the conventional water supply option. In addition, seasonal water temperatures have a significant effect on the freshwater and power costs. For example, for the MED process, the 9.5 °C increase in temperature decreased the cost of water by twelve cents per cubic meter. For each configuration, the cost to produce nuclear power increased from 66.8 \$/MWh at the coldest temperature to 68.7 \$/MWh at the warmest temperature.

Conclusions

This analysis indicates that further evaluation with nuclear and renewable energy combination should be conducted to reduce the water and power costs while enhancing energy resilience and environmental sustainability. This presentation will include (i) nuclear and renewable energy integration; (ii) integration of nuclear and wastewater systems for reuse; and (iii) integration of nuclear and bioenergy for agricultural systems. The scenarios will present the synergies, technoeconomics and environmental benefits of these innovative power/water schemes. Recommendations for developing nuclear energy-based sustainable power-water systems will be discussed.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-167887: Exergy and Thermo-Economic Evaluation of an Integrated Waste-to-Hydrogen and Carbon Capture-Utilization System Using Waste-Derived CaO

Ahmed Mohammed Inuwa^{1,2,*} and Habibu Abubakar Waniyo³

¹ Green Engineering Research Group; Department of Chemical Engineering, Faculty of Engineering and Built Environment, Durban University of Technology 4001, Durban, South Africa

² Department of Chemical Engineering, Abubakar Tafawa Balewa University, Bauchi P.M.B 0248. 740272, Bauchi, Nigeria

³ Department of Chemical and Petroleum Engineering, Bayero University, Kano, P.M.B 3011. 700006, Kano Nigeria

The increasing global demand for clean energy carriers, coupled with the urgent need to mitigate greenhouse gas emissions and manage municipal solid waste (MSW) sustainably, has intensified interest in integrated waste-to-energy and carbon capture technologies. Hydrogen-rich syngas is widely recognized as a versatile intermediate for power generation, synthetic fuels, and chemical production, while carbon capture and utilization (CCU) offers a pathway to transform CO₂ from a liability into value-added products. Gasification of MSW provides an attractive solution by simultaneously addressing waste disposal challenges and enabling renewable hydrogen production. However, conventional gasification processes are often constrained by CO₂ emissions, energy inefficiencies, and limited economic competitiveness. This study presents an integrated modelling and simulation of waste gasification, calcium looping, and carbon capture utilization (CCU) for sustainable hydrogen-rich syngas and value-added calcium carbonate production. A gasification system processing 1000 kg/h of municipal solid waste was simulated in Aspen Plus, producing syngas with 54–58 vol% H₂, 23–26 vol% CO, 10–12 vol% CO₂, and 6–7 vol% CH₄, corresponding to a hydrogen output of approximately 520 kg/h and a cold gas efficiency of 78%. In parallel, 500 kg/h of waste cow bone was calcined to generate 320 kg/h CaO with >95% conversion, achieving 88% CO₂ capture efficiency and yielding 560 kg/h of CaCO₃ via carbonation. Exergy analysis revealed an overall exergy efficiency of 62%, with the gasifier accounting for the largest irreversibility share (35%). Thermo-economic assessment showed a total capital investment of USD 6.8 million, an annual net profit of USD 1.2 million, a net present value (NPV) of USD 4.5 million, and a payback period of 4.1 years. Sensitivity analysis identified gasification temperature and CaO regeneration efficiency as dominant factors affecting hydrogen yield and system profitability. The strong coupling between gasification operating conditions and calcium looping performance highlights the importance of integrated process design rather than isolated unit optimization. Overall, the proposed framework demonstrates a scalable and environmentally robust pathway for carbon-efficient hydrogen production, simultaneous waste valorization, and circular carbon utilization through CaCO₃ synthesis. By converting municipal solid waste and animal-derived residues into clean energy and marketable materials, the system aligns with circular economy principles and offers practical support for the transition toward low-carbon, resource-efficient, and sustainable energy systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164549: Experimental Validation of Steam-Enhanced Calcium Looping for CO₂ Capture

Arturo Barragán Alonso *, José Ramón Fernández and Juan Carlos Abanades

CO₂ capture group - Technologies for Energy Transition - Institute of Carbon Science and Technology (INCAR) - Spanish Council for Scientific Research (CSIC), University of Oviedo, Oviedo, c/ Francisco Pintado Fe, 26. ZIP code: 33011, Spain

Introduction

The decarbonisation of hard-to-abate industrial sectors such as cement, lime, and steel production requires CO₂ capture technologies capable of operating efficiently under high-temperature, dust-laden, and compositionally variable flue gas conditions, while simultaneously delivering CO₂ streams of sufficiently high purity for transport, storage, or utilisation. Calcium looping (CaL) is a promising CO₂ capture technology due to the fast kinetics, low cost, and wide availability of CaO-based sorbents. However, conventional CaL concepts face major challenges associated with the high energy demand of CaCO₃ calcination and the need for downstream CO₂ purification. This work presents the experimental validation of a novel packed-bed calcium looping process incorporating steam-enhanced calcination, designed to exploit the heat released during carbonation to regenerate the sorbent via a rapid CO₂ partial-pressure swing, enabling the direct production of ultra-high-purity CO₂ without costly purification steps.

Methods

The proposed process was experimentally investigated in a laboratory-scale packed-bed reactor (1.2 m bed height, 50 mm internal diameter) loaded with up to 4.4 kg of natural limestone as CaO precursor. The reactor was operated in cyclic carbonation–calcination mode. During carbonation, CO₂-containing gas mixtures (15–40 vol% CO₂ in air) were fed at temperatures between 500 and 750 °C, allowing exothermic CaO carbonation to proceed and store heat within the solid bed. Calcination was subsequently initiated by injecting preheated steam, inducing a rapid decrease in CO₂ partial pressure and triggering CaCO₃ decomposition. Gas compositions were continuously monitored, and axial temperature profiles were measured using a multipoint thermocouple. Additional experiments integrated chemical looping combustion (CLC) stages using CuO-based oxygen carriers to provide in situ heat generation under conditions where carbonation alone could not achieve sufficiently high temperatures.

Results

The experimental results demonstrate that the heat released during carbonation can raise the bed temperature well above 800 °C when CO₂ concentrations exceed approximately 25 vol%, enabling rapid and effective sorbent regeneration during subsequent steam-assisted calcination. CO₂ capture efficiencies above 95% were consistently achieved during carbonation for feed gases containing up to 40 vol% CO₂, with gas residence times of only a few seconds. During calcination, the injection of steam produced outlet gas streams composed of virtually 100% CO₂ on a dry basis, confirming that high-purity CO₂ can be obtained without downstream purification beyond water condensation. Temperature profiles showed sharp and uniform drops during calcination, indicating effective decomposition of CaCO₃ throughout the bed. Multi-cycle experiments confirmed stable operation over successive carbonation–calcination cycles, with capture efficiencies remaining between 85% and 95%, despite the non-adiabatic limitations of the laboratory-scale setup. Integration of CLC stages successfully increased bed temperatures beyond 850 °C, improving calcination rates and enabling robust operation even with low CO₂ inlet concentrations or highly cycled sorbents.

Conclusions

This study provides experimental proof of concept for a novel packed-bed calcium looping process with steam-enhanced calcination capable of delivering ultra-pure CO₂ while significantly reducing the energy penalty associated with sorbent regeneration. By exploiting the heat stored during carbonation and combining it with rapid CO₂ partial-pressure swings and optional in situ heat generation via chemical looping combustion, the process enables near-autothermal operation and eliminates the need for costly CO₂ purification units. The results highlight the strong

potential of this technology for decarbonising hard-to-abate industrial sectors and provide a solid experimental basis for further scale-up, optimisation of multi-cycle stability, and future techno-economic assessment.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171290: Exploring platinum recycling methods towards sustainable and more cost-effective PEM technologies.

Juan Carlos Carmona Pulido *, Irene Peñas Fuertes, Jesús Serrano-Jiménez, Julia Isidro Elvira and Jesús Rodríguez Ruiz

Scientific Development Unit, National Hydrogen Center, Prolongación Fernando el Santo S/N, Puertollano, Ciudad Real, 13500, Spain

Abstract

The large-scale deployment of green hydrogen technologies based on proton exchange membrane (PEM) electrolyzers and fuel cells is widely recognized as a key pillar for global decarbonization strategies. However, analyses conducted by organizations such as the International Renewable Energy Agency (IRENA) and the United States Department of Energy (DOE) consistently highlight that the economic viability and scalability of these technologies remain strongly constrained by their reliance on platinum group metals (PGMs) [1]. In particular, platinum loadings must be significantly reduced in both PEM electrolyzers and fuel cells to meet future cost targets. This challenge has stimulated growing interest in strategies that simultaneously minimize catalyst usage and enable the efficient recovery and recycling of critical raw materials from end-of-life components.

In this context, the present study addresses the recovery and reuse of platinum-based catalysts from exhausted PEM system components, with a specific focus on titanium porous transport layers (PTLs). We report the development of a novel, predominantly mechanical recovery procedure for Pt/C catalysts that enables the reuse of the entire catalytic ink, rather than isolated platinum. By avoiding chemically intensive processing steps and the use of expensive reagents, this approach offers a potentially more cost-effective and environmentally favorable alternative to conventional recycling pathways reported in the literature. The proposed method is systematically compared with established recovery techniques, including electrochemical dissolution of Pt from used electrodes and its subsequent catalyst synthesis, which typically involve higher process complexity and material costs [2].

Methods

Recovered Pt/C catalysts were reformulated into inks and redeposited onto several substrates via spray coating (airbrush Vega V2000). The electrochemical performance of the recycled catalysts was evaluated through a combination of several tests. The characterization included cyclic voltammetry to determine key parameters such as the specific electrochemical surface area (SECSA), providing insight into catalyst accessibility and utilization after recovery. Polarization curves and electrochemical impedance spectroscopy were used in PEM fuel cells to assess overall cell performance, kinetic behavior, and transport losses. In addition, scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDS) was employed to analyze catalyst morphology, dispersion, and elemental composition following recovery and redeposition.

Results and Conclusions

This study presents a novel approach for the recovery of Pt/C catalysts supported on titanium porous transport layers (PTLs), demonstrating its applicability in PEM fuel cell systems and enabling a direct comparison with established recovery protocols reported in the literature. The recovered catalytic ink, obtained directly from PEM electrolysis PTLs with recovery efficiencies of up to 95%, was successfully reused in PEM fuel cells. Although functional operation was achieved, the electrochemical performance did not fully meet initial expectations when compared with catalysts recovered using alternative methods, indicating that additional optimization of the recovery and reformulation processes is required. Furthermore, challenges were identified in the quantitative determination of the specific electrochemical surface area (SECSA) for catalyst layers deposited on carbon paper containing Pt/C and Nafion, highlighting limitations associated with

substrate effects and measurement methodologies. Despite these challenges, the results confirm the technical feasibility of reusing mechanically recovered Pt/C catalysts and underscore the potential of simplified, cost-effective recycling routes as viable alternatives to more complex and resource-intensive recovery strategies.

References

1. U.S. Department of Energy. Hydrogen and Fuel Cell Technologies Office Multi-Year Program Plan (MYPP) 2024; Hydrogen and Fuel Cell Technologies Office, Office of Energy Efficiency & Renewable Energy: Washington, D.C. (2024).
2. Montiel, M.A.; Granados-Fernández, R.; Díaz-Abad, S.; Sáez, C.; Fernández-Marchante, C.M.; Rodrigo, M.A. and Lobato, J. Towards a circular economy for Pt catalysts. Case study: Pt recovery from electrodes for hydrogen production. *Applied Catalysis B: Environmental*, Vol. 327, 122414, (2023).



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166398: Green and Efficient Epoxidation of 1,7-Octadiene Using Polybenzimidazole-Supported Mo(VI) Catalyst in a Continuous-Flow Reactor Optimised by Response Surface Methodology

Md Masud Rana Bhuiyan^{1,*}, Peter Cormack² and Basudeb Saha¹

¹ School of Engineering, Lancaster University, Lancaster, LA1 4YW, UK

² WestCHEM, Department of Pure and Applied Chemistry, University of Strathclyde, Thomas Graham Building, 295 Cathedral Street, Glasgow, G1 1XL, Scotland, UK

Epoxides serve as important intermediates for producing essential industrial and chemical substances, including plastics, resins, coatings, and pharmaceuticals. The sustainability and efficiency of an epoxidation process were significantly enhanced in this work by using molybdenum(VI) catalyst immobilised on polybenzimidazole PBI.Mo. *tert*-Butyl hydroperoxide (TBHP) was selected as an oxidising agent to reduce waste generation and the formation of corrosive byproducts. In this work, continuous epoxidation of 1,7-octadiene was carried out in a flow reactor, which enhances heat and mass transfer efficiency and provides greater control over reaction conditions.

Optimisation of the epoxidation process was conducted by examining how reaction temperature, molar ratio of alkene to TBHP and feed flow rate affect epoxide production. To analyse how varying key parameters influence reaction outcome, the Response Surface Methodology employing a Box-Behnken Design (BBD) was implemented.

A Mo(VI) catalyst immobilised on polybenzimidazole was prepared and characterised. To assess the combined influence of different parameters on epoxide production, experiments were designed through RSM employing a Box-Behnken design.

The optimal reaction condition for the epoxidation of 1,7-octadiene was identified through the optimisation analysis tool in Design Expert. According to the numerical optimisation technique, the maximum yield of 1,2-epoxy-7-octene is 59.52% at an alkene to TBHP molar ratio of 9.650:1, a reaction temperature of 352 K, and a feed flow rate of 0.1 mL/min. The prediction was validated under the optimising condition and epoxide yield was found to be 59.15%, which was comparable to the expected optimal response of 59.52%.

This study shows how the PBI.Mo complex can be utilised as an efficient and environmentally friendly catalyst. The results of this investigation also show that a thorough assessment of reaction parameters can play an important role in improving the performance of alkene epoxidation under continuous flow condition.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166268: Green valorisation of waste vegetable oil into thermo-responsive nanocomposites for enhanced oil recovery

Shahenda Mahran^{1,*}, **Attia Attia**¹ and **Basudeb Saha**²

¹ Faculty of Energy and Environmental Engineering, The British University in Egypt, Misr-Ismailia Road, El-Sherouk City 11837, Cairo, Egypt

² School of Engineering, Lancaster University, Lancaster, LA1 4YW, UK

Abstract

Introduction:

Although polymer flooding is an efficient chemical enhanced oil recovery (CEOR) method, the poor thermal and salinity stability of commonly used partially hydrolysed polyacrylamide (HPAM) hinders its implementation in reservoirs with extremely high-temperature and high-salinity (HTHS) conditions. Hence, the synthesis of environmentally sustainable polymers able to maintain stability under harsh reservoir conditions is of significant research interest for enhanced oil recovery (EOR) applications.

Methods:

In this research, oleic acid-enriched waste vegetable oil (WVO) was valorised to synthesise a green, thermo-responsive nanocomposite composed of very-long-chain fatty acid esters for EOR applications under harsh HTHS reservoir conditions. A sustainable transesterification approach was first applied to produce a fatty acid-based thermo-responsive oleic acrylate macromonomer from WVO. The obtained green macromonomer was subsequently copolymerised with acrylamide, 2-acrylamido-2-methylpropane sulfonic acid, and dimethylphenylvinylsilane via emulsion polymerisation. The structure, morphology and compositional properties of the synthesised nanocomposite were extensively characterised by FTIR, ¹H NMR, TEM, SEM and EDX. Furthermore, the thermal behaviour of the synthesised nanocomposite was assessed using TGA and DTA techniques.

Results:

The results demonstrated clear temperature-responsive thickening behaviour at a minimal polymer content of 0.04 wt.%, with viscosity increasing as the temperature rose from 25 to 110 °C and salinity increased from 1,000 to 250,000 ppm, including deionised water systems. This thermo-responsive thickening behaviour demonstrates enhanced mobility control and improved sweep efficiency during polymer flooding. Flooding experiments indicated that the acrylated oleate-g-terpolymer/silica nanocomposite is a promising polymer flooding candidate and achieved recovery factors of 15.4 % and 21.2 % at concentrations of 0.04 wt.% and 0.05 wt.%, respectively, assessed under harsh conditions of 100 °C and a salinity of 250,000 ppm. Moreover, the synthesised nanocomposite demonstrated significant resistance factor (R_f) values of 5.9 and 8.1 using nanocomposite concentrations of 0.04 wt.% and 0.05 wt.%, respectively. The nanocomposite altered sandstone wettability from oil-wet to water-wet, which improved the oil recovery.

Conclusions:

These results suggest that waste vegetable oil-derived thermo-responsive nanocomposites offer a sustainable, high-performance polymer flooding solution capable of delivering significant oil recovery under ultra-high-temperature and high-salinity reservoir conditions at remarkably low polymer concentrations. The findings highlight the strong potential of these green, thermo-responsive nanocomposites as promising candidates for large-scale EOR applications in HTHS oil reservoirs worldwide.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164749: Mechanistic Insights into the Structural, Electrochemical, and Charge-Storage Behavior of CNT@NiO Electrodes for High Capacitance and Durable Supercapacitors

Oluwasegun Emmanuel Ojodun *, Patrick Ehi Imoisili and Tien-Chien Jen

Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa

Introduction

Although Li-batteries remain widely used, there is a shift toward alternative energy storage solutions, such as supercapacitors (SCs), which offer high power output, long lifespan, rapid charge-discharge performance, low cost, and eco-friendliness. Supercapacitors often use transition metal oxides, such as nickel oxide (NiO), due to their high theoretical specific capacitance of $2,584 \text{ F g}^{-1}$, abundance, eco-friendliness, and chemical stability. However, due to NiO's poor conductivity and structural limitations, it is commonly combined with carbon nanotubes (CNTs), whose high conductivity and large surface area enhance the overall electrochemical performance.

Methods

Herein, spray pyrolysis, a straightforward and cost-effective method, was employed to deposit pure NiO and a composite of NiO and CNT (CNT@NiO) at 350°C for use as supercapacitor electrodes. The structures and morphologies of the materials were probed using X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FT-IR), and nitrogen adsorption/desorption. The electrochemical performance of the pristine and composite electrodes was tested by cyclic voltammetry, galvanostatic charge/discharge, and electrochemical impedance spectroscopy in 2 M KOH over a $0\text{--}0.7 \text{ V}$ potential window.

Results

SEM analysis revealed that pristine NiO nanoparticles had an irregular shape, whereas the composite exhibited a cylindrical morphology. According to Brunauer-Emmett-Teller (BET) analysis, the specific surface area of the composite was measured at $46.51 \text{ m}^2 \text{ g}^{-1}$, which is greater than the $29.55 \text{ m}^2 \text{ g}^{-1}$ observed for pristine NiO, and the average pore diameter was 27.37 nm , surpassing NiO's 6.10 nm . Electrochemical testing revealed that incorporating CNTs significantly improved the composite's electrochemical performance. The CNT@NiO electrode supplied an exceptional specific capacitance of 472.4 F g^{-1} at 2 A g^{-1} , far greater than pristine NiO's 18.92 F g^{-1} . Additionally, the composite exhibits a 68.8% rate capability (13.6% for NiO) and 93.3% cyclic stability (81.5% for NiO) at 2 A g^{-1} after 1,000 cycles, indicating its suitability for high-performance supercapacitors.

Conclusion

These favorable results point to two deductions: (i) CNT@NiO is a promising candidate for energy storage, and (ii) spray pyrolysis is an affordable and effective electrode material fabrication method. Two novelties regarding the use of spray pyrolysis as a fabrication technique are presented in this work: (i) an in-depth discussion on reasons for prolonged cycle life in connection with structural modifications, and (ii) investigation and comparison of the Faradaic and capacitive charge storage contributions of the synthesized materials. Future work will focus on detailed interfacial analysis (e.g., using TEM and XPS) and long-term cycling assessments ($>5,000$ cycles) in full-cell configurations to further validate the practical application potential. Overall, this study presents a viable path toward locally fabricated, efficient energy storage systems that can drive the adoption of clean energy in Africa and help bridge the global energy gap.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-145663: Optimizing Rooftop Solar Energy at Sakarya University: UAV-Based Assessment and Multi-Criteria Decision Analysis

Mehmet Fatih Döker¹, Masoud Minaei^{1,2,3,*}, Cem Kirlangicoglu⁴ and Esra Özдорuk¹

¹ Faculty of Humanities and Social Sciences, Department of Geography, 54050 Serdivan, Sakarya, Turkey

² Department of Geography, Faculty of Letters and Humanities, Ferdowsi University of Mashhad, Mashhad, Iran

³ Geographic Information Science/Syste

⁴ Faculty of Art Design and Architecture, Department of Architecture, 54050, Serdivan, Sakarya, Turkey

Climate change presents an urgent global challenge, necessitating innovative and data-driven solutions for carbon mitigation. Universities, as hubs of research and innovation, are uniquely positioned to lead the implementation of sustainable energy transitions. This study develops a comprehensive methodological framework to evaluate and optimize rooftop solar energy potential across Sakarya University, using high-resolution Unmanned Aerial Vehicle (UAV) data integrated with Multi-Criteria Decision-Making (MCDM) techniques. A total of 70 buildings were identified as suitable for photovoltaic (PV) installation, yielding a usable rooftop area of approximately 44,500 m² after filtering out structural constraints and shading elements. Rooftop Global Horizontal Irradiance (GHI) ranged from 875 to 1,300 kWh/m² annually. The estimated cumulative solar potential across all rooftops reached ~53,000 MWh/year, with individual building potential varying between 21 and 2,300 MWh/year. Educational and administrative buildings emerged as the primary contributors, together accounting for more than 70% of the total solar yield, with educational facilities alone offering ~27,000 MWh/year. To prioritize rooftop installations, two criteria weighting techniques—Ordinal Priority Approach (OPA) and Ranking Comparison (RANCOM)—were applied, followed by the implementation of five recent and efficient MCDM methods: RAM, PROBID, MARCOS, SPOTIS, and EDAS. The final ranking of alternatives was synthesized using the Footrule Aggregation method. All computations were carried out in the Google Colab environment utilizing the Python libraries PyMCDM, pyDecision, and pyRankMCDA. With the deployment of around 16,500 solar panels (500 W, 24% efficiency), the university could install an 8.2 MW PV system, capable of generating approximately 22.18 GWh annually—more than double the current campus electricity demand of 9.7 GWh. This surplus of 12.48 GWh creates opportunities for future energy expansion and integration with electric mobility systems. Financial analysis revealed a Net Present Cost (NPC) of ~36,000 TRY/kW (~900–950 USD/kW), confirming the economic viability of rooftop PV infrastructure, especially given the remarkably low Levelized Cost of Energy (LCOE). The integration of UAV-derived geospatial data, open-source modeling tools, and MCDM-based decision frameworks offers a scalable, transferable model for data-informed policy-making in higher education institutions. This study aligns with key Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 11 (Sustainable Cities and Communities), and positions universities as strategic actors in advancing climate action and energy resilience. These findings contribute practical insights into the operationalization of campus-scale decarbonization strategies, offering a replicable roadmap for sustainability leadership in the academic sector.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-169743: Performance Comparison of Natural and Low-GWP Refrigerants in a Water-to-Water Heat Pump

M. Reda Haddouche

Department of Mechanical Engineering, Universitat Rovira i Virgili, Avda. Paisos Catalans, 26, 43007, Tarragona, Spain

Introduction

Heat pumps are a key technology for decarbonizing space heating and domestic hot water production. The selection of an appropriate refrigerant strongly influences system efficiency, operating range, safety, and environmental impact. Carbon dioxide (CO₂) has attracted considerable attention as a natural refrigerant due to its negligible Global Warming Potential (GWP), however, its transcritical operation introduces challenges at high heat sink temperatures. In parallel, low-GWP alternatives such as propane (R290) and hydrofluoroolefins (HFOs), including R1234ze, have emerged as promising candidates for subcritical heat pump applications. A consistent and physically sound comparison between these refrigerants remains essential, particularly under water-to-water operating conditions relevant to building heating systems. The objective of this study is to develop a thermodynamic modelling framework for a water-to-water heat pump to compare the performance of CO₂, R290, and R1234ze under identical boundary conditions.

Methodology

A steady-state lumped-parameter model of a water-to-water heat pump was developed in MATLAB. The evaporator and condenser (or gas cooler in the case of CO₂) were modelled using prescribed water inlet and outlet temperatures, allowing heat transfer to be calculated directly from the water side. Compressor performance was modelled using a constant isentropic efficiency. For subcritical refrigerants, realistic operating conditions were imposed, including a small degree of superheating at the compressor inlet and subcooling at the condenser outlet. For CO₂, transcritical operation was considered, with the gas cooler outlet temperature determined by the heat sink conditions. Expansion was assumed to be isenthalpic for all cases. The model was first validated against experimental data obtained from a CO₂ water-to-water heat pump test rig. After validation, the same modelling assumptions, heat exchanger boundary conditions, and efficiency parameters were applied to all refrigerants to ensure a consistent basis for comparison.

Results

The model successfully reproduced the main thermodynamic trends observed in the experimental CO₂ heat pump, confirming the reliability of the modelling approach. Under the investigated operating conditions, the simulated coefficient of performance (COP) for CO₂ was approximately 4.9, which is consistent with values reported for similar experimental systems. When the same boundary conditions were applied to alternative refrigerants, significant differences in cycle performance were observed. The simulations predicted COP values of approximately 10 for both R290 and R1234ze, indicating substantially lower compressor work compared with the CO₂ cycle under the same heat sink conditions. In addition to efficiency differences, the refrigerants exhibited distinct thermodynamic behaviour. Subcritical refrigerants operated with compressor inlet states close to the saturation line and moderate pressure levels, whereas CO₂ required significantly higher operating pressures due to its transcritical cycle. The results also showed that CO₂ performance is strongly influenced by the gas cooler outlet temperature, whereas the performance of subcritical refrigerants is more stable under the same operating range. These findings highlight the importance of operating conditions and refrigerant thermophysical properties in determining heat pump performance.

Conclusions

A unified thermodynamic modelling framework for water-to-water heat pumps has been developed and validated using experimental CO₂ data. The main novelty of the study lies in the consistent comparison of transcritical and subcritical refrigerants using identical boundary

conditions, modelling assumptions, and compressor performance parameters, enabling a fair evaluation of refrigerant performance. The comparative analysis indicates that, under the investigated operating conditions, R290 and R1234ze achieve significantly higher COP values than CO₂, primarily due to lower compression work and favourable thermodynamic properties in subcritical operation. However, the results also demonstrate that CO₂ performance is highly sensitive to gas cooler outlet temperature and may become more competitive at higher heat sink temperatures. The proposed modelling framework provides a robust tool for evaluating alternative refrigerants and supports the assessment of environmentally friendly working fluids for future heat pump applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171049: Powering the Low-Carbon Transition: A Socio-Economic Analysis of Renewable Energy in the European Union

Manuela Rozalia Gabor ¹, Mirela Panait ², Răzvan Ionescu ^{3,*} and Maria Giovanna Confetto ⁴

¹ “George Emil Palade” University of Medicine, Pharmacy, Sciences and Technology of Targu Mures, Faculty of Economics and Law, Department ED1 – Economic Sciences & Department of Economic Research, Targu Mures, Romania

² Faculty of Economic Sciences, Petroleum-Gas University of Ploiesti, Romania

³ Romanian Academy, School of Advanced Studies of the Romanian Academy, Doctoral School of Economic Sciences, National Institute for Economic Research "Costin C. Kirițescu", Institute of National Economy, Bucharest, Romania

⁴ University of Salerno, Department of Political and Communication Sciences, Fisciano, Italy

The low-carbon transition in the EU is structured around a legally binding path to climate neutrality by 2050, with deep emission cuts and a full transformation of the energy and industrial system by 2030–2040. The member states of the European Union are deeply engaged in the energy transition, evidencing a consolidated commitment to advancing sustainability objectives and reducing carbon emissions. Public authorities across the Union have undertaken substantial efforts by designing and operationalizing comprehensive regulatory frameworks that stimulate and, where appropriate, mandate responsible behavior on the part of both firms and final consumers. These frameworks are oriented towards accelerating the diffusion of renewable energy sources, improving energy efficiency across sectors, and fostering innovation in low-carbon and clean technologies. At the same time, the regulatory architecture reinforces initiatives that promote corporate social responsibility and raise consumer awareness, seeking to ensure that economic growth trajectories are compatible with environmental protection and long-term climate objectives.

In this context, the present study aims to investigate the interdependencies between a series of socio-economic and environmental factors that influence the level of CO₂ emissions in the Member States of the European Union, paying special attention to the often pronounced differences between the EU15 and the EU27 countries. By using a combination of statistical methods and machine learning techniques, the analysis explores the link between carbon dioxide emissions and relevant indicators, such as foreign direct investment, energy consumption, the degree of urbanization and the level of literacy. The objective is to generate empirical evidence and analytical insights to support the formulation of concrete strategies at the public policy level. The results obtained aim to provide decision-makers with information on the most effective levers for reducing emissions in both the EU15 and the EU27 countries, thus contributing to the achievement of the wider objectives of the European Union in terms of environmental sustainability and climate neutrality.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165641: Practical Implications of Tessellated Geometric Façades for Optimal Daylighting Performance

Mana Dastoum

Escuela Técnica Superior de Arquitectura de Madrid (ETSAM), Universidad Politécnica de Madrid (UPM), Madrid, 29040, Spain

Tessellated geometric façades are increasingly employed as performative building envelopes capable of modulating daylight, controlling glare, and mediating solar exposure. Composed of repetitive or rule-based geometric units, tessellated systems enable controlled permeability, pattern differentiation, and modular fabrication, allowing façades to operate simultaneously as environmental regulators and architectural expressions. Advances in parametric design and digital fabrication have further expanded their application, making tessellated façades attractive as climate-responsive shading systems. Despite growing academic interest and extensive simulation-based evaluation of their daylighting potential, their practical application remains limited by the lack of design-oriented guidance that translates parametric results into operational façade strategies. While existing studies successfully quantify daylight performance, the step from numerical evaluation to actionable architectural decision-making remains underdeveloped. This paper addresses this gap by focusing on the practical implications of tessellated geometric façades for daylighting performance, with particular emphasis on how parametric findings can inform façade design decisions. The study adopts a performance-informed design synthesis methodology, aimed at translating validated parametric daylighting results into design-operational knowledge. Rather than conducting new simulations, the research is based on a secondary analytical reinterpretation of an existing, peer-reviewed parametric dataset, allowing the study to shift from performance generation to design translation. This methodological approach positions simulation outputs as evidence for architectural reasoning, rather than as isolated numerical results. The methodological process reframes computational parameters, such as perforation ratio, geometric pattern, and spatial configuration, as architectural design variables that directly correspond to façade openness, geometric organization, and functional daylight demand. A comparative analytical framework is employed to examine how variations in façade geometry and porosity interact with different spatial functions, revealing recurring performance tendencies rather than singular optimized solutions. To support holistic interpretation, a composite daylight performance indicator is used as a synthesis tool to integrate multiple daylight metrics, while illuminance thresholds are applied as external design constraints to ensure functional adequacy. Through this interpretive process, tessellated façades are understood not as static decorative screens but as tunable daylight-modulating systems, whose effectiveness depends on the alignment between geometric logic, façade openness, and spatial use. The synthesis highlights how façade porosity and pattern organization jointly influence the balance between daylight sufficiency and visual comfort across varying interior conditions. The outcomes are consolidated into a simplified decision-support logic that enables rapid comparison of façade alternatives without reliance on complex multi-objective optimization workflows. By providing design-operational rules and a transparent evaluation logic, this study offers actionable guidance for architects and façade designers and supports the integration of tessellated façade systems into daylighting standards, design guidelines, and performance-driven architectural practice.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165923: Predicting EUA Price Volatility: A Multivariate Approach Integrating Lasso Feature Selection and Vector Autoregression

Teodora Mitu^{1*} and **Mirela Panait**²

¹ Romanian Academy, School of Advanced Studies of the Romanian Academy, Doctoral School of Economic Sciences, National Institute for Economic Research "Costin C. Kirițescu", Institute of National Economy, Bucharest, Romania

² Department of Cybernetics, Informatics, Finance and Accounting, Faculty of Economic Sciences, Petroleum-Gas University of Ploiesti, 100680 Ploiesti, Romania

The European Union Emissions Trading System (EU ETS) serves as the primary market-based mechanism for driving the continent toward carbon neutrality. However, the market for EU Allowance (EUA) prices is characterized by significant historical volatility driven by regulatory shifts, geopolitical shocks, and complex energy dynamics. This inherent instability poses substantial challenges for industrial operators managing compliance costs and for regulators ensuring market credibility. This research addresses these challenges by developing a robust quantitative framework for the short-term forecasting of EUA prices to support effective risk management.

The study utilizes a comprehensive 10-year dataset of daily closing prices spanning from September 2015 to September 2025. To capture the "Energy Complex" influencing carbon demand, the analysis incorporates key energy drivers, including Natural Gas (TTF benchmark), Coal (Rotterdam API2), and Brent Crude Oil. To ensure econometric rigor, an Augmented Dickey-Fuller (ADF) test was applied to all variables, confirming that the raw price series were non-stationary. To address this, the study applied first-order differencing to achieve stationarity, focusing on daily returns rather than price levels. While cointegration and Vector Error Correction Models (VECM) were considered, a differenced Multivariate Vector Autoregression (VAR) and a Lasso Regression model were prioritized to better capture short-term dynamic interdependencies and mitigate the risks of model overfitting in high-dimensional datasets.

The evaluation protocol employs a one-day-ahead forecasting horizon based on a strict chronological out-of-sample backtesting procedure. The data is divided into an 80% training set (September 2015 – 2023) and a 20% test set (2024 – September 2025). To reflect real-world trading conditions, the models were evaluated using an expanding window approach, ensuring that all available historical information was utilized for each prediction. The models are compared against a "Naive" Baseline, which assumes the price for T+1 is equal to the price at T, a rigorous benchmark in efficient financial markets.

The findings demonstrate that both the VAR and Lasso models significantly outperform the naive baseline in terms of Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE), confirming that the carbon market contains valuable predictive signals rather than following a random walk. Notably, the Lasso model's feature selection capabilities identify natural gas as the most influential driver of carbon price formation, validating the critical role of fuel-switching dynamics in the European power sector. By providing a replicable methodology for isolating volatility drivers, this research offers essential tools for capital allocation and policy monitoring.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166382: Quantitative Analysis of the Implementation of Photovoltaic Systems and Biomass in Panela Production

John Javier Espitia Gonzalez *, Jader Rodriguez, Edwin Villagran, Fabian Andres Velasquez and Andres Ivan Sarmiento

Research Department, Colombian Agricultural Research Corporation (Agrosavia), Mosquera, 250047, Colombia

Introduction

The production of non-centrifuged sugar (NCS) is a key agro-industrial activity in rural Latin America, contributing to local economies and employment. However, traditional processing systems rely on inefficient energy practices and fossil fuels, leading to high operating costs and environmental impacts. The integration of renewable energy technologies offers a promising pathway to improve sustainability and energy efficiency in the sector.

Methods

A technical and quantitative assessment was conducted for an NCS production plant with a processing capacity of 100 kg/h of NCS. The proposed hybrid configuration integrates photovoltaic (PV) electricity generation with the thermochemical utilization of sugarcane bagasse to meet the facility's thermal energy requirements. The electrical demand of the plant was estimated at 17 kW, corresponding to a daily consumption of approximately 264 kWh. This demand profile reflects the operational characteristics of panela processing units, where the milling process operates for 16 hours at a power of 15 kW, while lighting and auxiliary equipment require 2 kW for 12 hours. Based on these conditions, a photovoltaic system with an installed capacity of 48–52 kWp was designed to supply most of the electrical demand. Thermal energy requirements for juice evaporation and concentration processes were estimated at 380 kWh and are supplied through the controlled combustion of bagasse generated during milling, thereby valorizing an internal process byproduct.

Results

Mass and energy balance calculations indicate that processing 1,000 kg/h of sugarcane generates approximately 380 kg/h of bagasse. With a lower heating value of approximately 7.7 MJ/kg, this biomass resource provides sufficient energy to achieve thermal self-sufficiency levels exceeding 90% for juice evaporation and concentration processes. Regarding electricity supply, the proposed 48–52 kWp photovoltaic system, designed using an average solar irradiance of 4.4 kWh/m²/day typical of the Barbosa region, ensures that the plant's electrical demand is met during operational hours. Overall, the hybrid energy architecture enables an external energy substitution rate between 70% and 80%, resulting in an estimated reduction of 9–12 tons of CO₂ emissions annually. These results demonstrate the potential for significantly lowering the carbon footprint of panela production while increasing energy independence and operational resilience.

Conclusions

The comparative economic analysis highlights clear advantages for the renewable hybrid system. Purchasing electricity from the grid would represent an estimated annual cost of approximately USD 10,500. In contrast, the installation of a 52 kWp photovoltaic system capable of supplying around 80% of the plant's electricity demand would generate annual energy savings close to USD 8,500, resulting in a payback period of approximately six years. Although the analysis uses the municipality of Barbosa as a geographical reference, the methodological framework and system design are transferable and scalable to other rural agro-industrial contexts across Latin America. Overall, the results confirm that hybrid renewable energy systems combining solar photovoltaic generation with biomass utilization constitute a technically feasible, economically viable, and environmentally sustainable pathway toward the decarbonization of small-scale sugarcane processing industries.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166083: Recent advances in Direct Air Capture (DAC) using Ca-solid forms

Roberto García *, Yolanda A. Criado and María Elena Diego de Paz

CO₂ Capture Group (CapCO₂), Institute of Carbon Science and Technology (INCAR-CSIC). C/ Francisco Pintado Fe 26, 33011, Oviedo, Asturias, España (Spain)

INTRODUCTION

Limiting global warming to 1.5 °C above pre-industrial levels is one of the greatest challenges humanity faces in the 21st century. Achieving this goal requires capturing CO₂ emissions not only from large point sources but also from dispersed and hard-to-abate sectors. Traditional CO₂ capture systems have been optimized for large-scale emitters, such as power and cement plants and steel industries. Therefore, a completely new approach is needed.

Direct Air Capture (DAC) emerges as a complementary technology, enabling the removal of CO₂ directly from the atmosphere by using a solvent or sorbent that binds with CO₂ in an air contactor. Then, a CO₂-concentrated gas stream is produced during the regeneration step. DAC can deliver negative emissions when combined with permanent CO₂ storage, or contribute towards carbon neutrality if the captured CO₂ is reused, for instance, in synthetic fuel production. As such, it is considered a promising option for offsetting past emissions and those generated by sectors that are difficult to decarbonize. DAC systems offer additional advantages, as they can be deployed without disrupting current systems and almost anywhere independently of emission sources, which allows them to operate in affordable locations with abundant renewable energy.

Despite its benefits, DAC faces challenges that hinder large-scale deployment stemming from the low concentration of CO₂ in ambient air—around 500 ppm. This results in high process energy requirements and capital costs for large air contactors that are needed to process vast volumes of air to reach relevant scales (i.e., capturing MtCO₂ per year), thus leading to higher costs per tCO₂ captured compared to conventional methods targeting major emitters. It is therefore essential to ensure that air contactors and functional materials are of low specific cost in order to design competitive DAC systems at large scales.

In this context, the use of solid lime-based materials such as Ca(OH)₂ is regarded as a promising solution to overcome the costly barriers associated to the capture device. Over the last few years, the CO₂ Capture Group at INCAR-CSIC (CapCO₂) has focused on the development of Ca(OH)₂-based DAC systems, leveraging its extensive experience in CO₂ capture using Ca-based sorbents at high temperatures in several Calcium Looping configurations for a range of industrial applications. Carbonation of CaO or Ca(OH)₂ sorbents with CO₂ is at the core of these systems, followed by sorbent regeneration via oxy-calcination to produce a nearly pure CO₂ stream.

This work provides a summary and update of the research conducted by CapCO₂ in the field of DAC by testing Ca-based sorbents under different configurations and operating conditions, with the aim of scaling up the proposed technology.

METHODS

Several gas-solid contact configurations were evaluated to identify optimal Ca-based materials and air contactor modes that maximize CO₂ capture rates and overall efficiency. Particle-scale experiments were conducted to determine reaction kinetics, maximum conversion and the influence of key parameters, such as air humidity and effective solid porosity, on material carbonation under ambient conditions.

Subsequent scale-up of the Ca-based air contactor was achieved at TRL3. To this end, Ca-based powders, dry mortars and other Ca-based forms were arranged to validate the gas-solid contact modes proposed.

These experimental setups enabled the evaluation of a broad range of operating conditions, including effective porosities between 0.20 and 0.55, gas velocities from 0.5 to 5.5 m/s, air humidity ranging from 0 to 90% RH and gas-solid contact lengths spanning from a few centimeters in fixed-bed configurations to up to 10 m in single-channel arrangements.

RESULTS

Tests conducted at both particle scale and TRL3 have served as a proof of concept for Ca-based air contactors designed to maximize CO₂ capture from ambient air under extended operating periods and variable conditions. More than 3,000 operating hours under CO₂ capture have been accumulated at TRL3 so far, with individual experiments lasting up to 300 hours in capture mode and demonstrating sustained average CO₂ capture efficiencies of approximately 55%, at least 20% greater than those observed in batch mode under similar conditions.

Particle-scale reaction modeling indicates that the carbonation kinetics are primarily governed by CO₂ diffusion through the carbonated product layer. The measured kinetics were subsequently incorporated into a simplified one-dimensional reactor model, which was validated against TRL3 experimental results for both batch and counter-current contact modes, thereby providing a robust basis for technology scale-up.

CONCLUSIONS

The results presented here indicate that Ca-based sorbents constitute a viable alternative for DAC under standard conditions. The CapCO₂ Group is actively advancing research in this area and will present its latest developments.

ACKNOWLEDGEMENTS

This work is part of the project PID2024-162594OB-I00 funded by MICIU/AEI/10.13039/501100011033 and by ERDF/UE.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166792: Recent Developments in the Utilization of Glass Waste for Green Concrete: Toward Sustainable and Energy-Efficient Construction

Arindam Debnath *, Mukul Chandra Bora and Partha Protim Borthakur

Dibrugarh University Institute of Engineering & Technology, Dibrugarh, 786004, Assam, India

Introduction:

The pressing need for sustainable and energy-efficient construction practices has propelled the exploration of alternative materials in concrete production. One promising avenue is the incorporation of glass waste into green concrete. This approach addresses environmental challenges such as landfill accumulation and natural resource depletion, while also aiming to reduce the carbon footprint associated with cement manufacturing.

Methods: This study systematically analyzes recent advancements in using glass waste—such as glass powder, crushed glass aggregates, expanded glass, and glass fibers—as partial replacements for cement, fine, and coarse aggregates. The study evaluates various forms of glass waste based on particle size, chemical composition, and replacement ratios. Mechanical performance, durability, microstructural behavior, and environmental benefits are assessed through comparative analysis of laboratory experiments and life cycle assessments.

Results and Discussion: Findings reveal that finely ground glass powder (90 μm) enhances the pozzolanic reaction, leading to improved compressive strength (up to 14%) and reduced water absorption when used at replacement levels of 10–30% for cement. Crushed glass aggregates offer improved packing density and flexural strength at moderate substitution rates (10–25% for sand, $\leq 10\%$ for coarse aggregate), though excessive use compromises strength due to poor bonding and increased porosity. The integration of glass fibers further boosts tensile and flexural properties by over 20%. Engineered geopolymer composites and mixtures with additives like CNTs and fly ash show promise for high-performance applications. However, challenges such as alkali-silica reaction (ASR), workability reduction, and strength loss at high replacement levels persist. Environmentally, glass waste concrete can lower CO_2 emissions by up to 30% and energy use by 17–20%, supporting circular economy principles and landfill diversion.

Conclusion:

The utilization of glass waste in concrete offers compelling mechanical, durability, and sustainability benefits when applied within optimal replacement thresholds. While current applications are more prevalent in non-structural components (e.g., paver blocks, foam concrete), innovations in processing and mixture optimization are expanding its potential for structural use. Future research should focus on long-term field validation, ASR mitigation strategies, and scaling up implementation to advance the role of glass waste in next-generation green infrastructure.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166286: Rethinking Methane Dynamics in Wetland Ecosystems under Floating Solar PV: Documented Effects, Mechanisms, Mitigation-Harvesting Strategies, and Design Gaps

Angelo Dave Infante

College of Engineering Education, University of Mindanao - Main Campus, Davao City, 8000, Philippines

Wetlands are recognized as significant natural sources of global methane emissions, contributing substantially to climate forcing through complex biogeochemical and microbial processes. At the same time, Floating Solar Photovoltaic (FSPV) systems are rapidly expanding worldwide due to land scarcity, increasing energy demand, and their perceived favorable trade-offs compared to land-based solar installations. As a result, countries with limited available land increasingly consider wetlands, reservoirs, and other water bodies as strategic sites for FSPV deployment. However, the limited consideration of wetland ecological processes in current FSPV planning and design raises concerns that such installations may unintentionally increase methane emissions and generate adverse environmental impacts rather than delivering net climate benefits.

To examine these issues, the researchers conducted a systematic qualitative literature review of fifty (50) peer-reviewed journal articles published between 2010 and 2025. The researchers applied the Comparative Analysis Framework (CAF) to synthesize and categorize existing studies into four major thematic areas: the effects of FSPV on wetland ecosystems, methane dynamics under FSPV installations, methane mitigation strategies associated with floating solar systems, and integrated research frameworks that explicitly link methane emissions with FSPV deployment. The review reveals that most existing studies focus on lakes and reservoirs, while ecologically sensitive wetlands such as marshes and peatlands remain underrepresented in the literature.

Furthermore, the analysis indicates a lack of empirical data on hydrological alterations, nutrient cycling, methane-specific microbial activity, and biogeochemical processes associated with FSPV installations, as well as limited development of predictive models and validation studies. Current research rarely examines methane emissions through technological assessments and policy-oriented reviews, and most FSPV frameworks fail to incorporate methane reduction strategies. Overall, the synthesis identifies critical thematic gaps and highlights emerging priorities for interdisciplinary research approaches that integrate ecological monitoring, methane control strategies, system-level modeling, and policy development. This review highlights the importance of comprehensive, ecosystem-scale research and holistic modeling frameworks to optimize the benefits of FSPV while mitigating the risks associated with methane emissions in wetland environments.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171181: Simulation and Optimisation of Methanol Production and Fischer–Tropsch Process from Biogas Methane Reforming

Pedro Juan Martínez Román *, Nuria García-Mancha Delgado-Ureña and Roberto Campana Prada

Centro Nacional del Hidrógeno, Fernando El Santo S/N, 13500, Puertollano, Ciudad Real (Spain)

1. Introduction

This work falls within the scope of ‘Energy and Environment. Sustainable Transition’ because it focuses on converting renewable biogas into methanol and synthetic fuels through integrated processes, contributing directly to industrial decarbonisation and the transition to more sustainable energy systems. The main objective is to develop a methanol production model in a pilot plant, integrated with a steam methane reforming (SMR) unit, fed with biogas from anaerobic digestion processes of organic waste, thus enabling the production of H₂ from renewable sources.

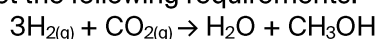
In addition, the integration of a synthesis gas purification stage is proposed, which will not only allow the stream to be adapted for methanol synthesis, but also enable its possible recovery in a Fischer–Tropsch plant for the production of liquid hydrocarbons. In this way, the proposed system is conceived as a flexible platform for converting biogas into fuels and chemical products, whose technical and economic viability can be evaluated using the model developed.

2. Methods

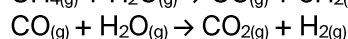
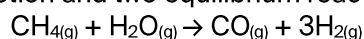
The analysis was carried out using Aspen HYSYS software (Aspen Technology, Inc.), widely used in the industry for chemical process simulation. The methodology included the following stages:

Process definition: all plants were designed with preliminary calculations of conversions, efficiencies and methanol yields, standardised for a pilot capacity of approximately 2 kg/h of CH₃OH and 1.5 kg/h of petrol.

The methanol plant was modelled using a plug flow reactor under conditions determined to meet the following requirements:

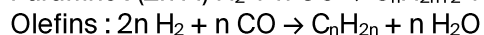
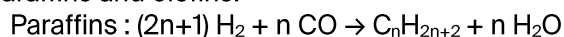


The SMR was modelled as a tubular conversion reactor for the steam methane reforming reaction and two equilibrium reactors for the water gas shift reaction:



This scheme allows the H₂/CO ratio of the synthesis gas to be adjusted according to the requirements of the subsequent synthesis stages.

The Fischer–Tropsch plant was modelled based on representative reaction conditions for the synthesis of hydrocarbons from synthesis gas, considering the overall reactions for the formation of paraffins and olefins:



The model allows the conversion of synthesis gas into a mixture of liquid hydrocarbons such as synthetic fuels to be represented, highlighting the role of the Fischer–Tropsch process as a complementary route to methanol synthesis for the valorisation of reformed biogas.

Integration of units and economic estimation: the necessary equipment was integrated to ensure continuity of operation and cushion fluctuations in biogas flow. A preliminary assessment of the most relevant costs of the system was also initiated, considering both capital expenditure (CAPEX) and operating expenditure (OPEX).

3. Results

The HYSYS simulation showed that integrating a methanol plant with a biogas-fed SMR unit is technically feasible, provided that suitable equipment and thermal and compression strategies are used to ensure operational stability. The energy balance shows that SMR is highly demanding in terms of thermal energy, although it has CH₄ to H₂ conversion efficiencies of over 70%. Its

integration with the methanol plant makes it possible to easily achieve production rates of around 2 kg/h of CH₃OH.

Furthermore, the results indicate that the same synthesis gas purification system can be used both for methanol synthesis and to feed the Fischer–Tropsch plant, which increases the versatility of the process scheme. In this sense, the Fischer–Tropsch process appears to be a complementary alternative for transforming synthesis gas into liquid hydrocarbons, expanding the range of products that can be obtained from biogas as a raw material.

From an economic point of view and for both systems, the most relevant equipment in terms of CAPEX is the reformer, the conversion and plug flow reactors, and the purification system. In terms of OPEX, the costs associated with biogas supply and thermal energy input are noteworthy. However, this production method has an advantage in terms of the specific cost of hydrogen (€/kg H₂), due to the lower relative cost of the renewable raw material.

4. Conclusions

The study confirms the technical feasibility of integrating a pilot methanol plant of up to 2 kg/h with a methane reforming plant fuelled by biogas. Simulations show that this configuration can be cost-competitive and also offers high operational flexibility by allowing the synthesis gas to be converted into both methanol and synthetic fuels using Fischer–Tropsch technology.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165147: Solar Energy Assessment in Rural Areas of the Colombian Caribbean Using Sunshine-Based Empirical Models for Water Treatment Applications

Fernando Aricapa^{1,2*}, **Jorge L Gallego**³, **Alejandro Silva-Cortés**⁴, **Claudia Díaz-Mendoza**¹ and **Jorgelina Pasqualino**¹

¹ GISAH Research Group, Environmental Engineering Program, Universidad Tecnológica de Bolívar Campus Tecnológico km 1 vía Turbaco Cartagena, Cartagena de Indias, Colombia

² GIA Research Group, Department of Engineering, Fundación Universitaria Tecnológico Comfenalco, Cartagena de Indias 130015, Colombia

³ Biodiversity, Biotechnology and Bioengineering Research Group GRINBIO, Department of Engineering, University of Medellín, 050026, Medellín, Colombia

⁴ Department of Management Sciences, Instituto Tecnológico Metropolitano, 050013 Medellín, Colombia

Introduction

Access to reliable drinking water remains limited in many rural and non-interconnected areas of lower-income countries, where conventional water treatment infrastructure is absent or insufficient. In these contexts, solar water disinfection has been recognized as a low-cost and decentralized alternative that relies on the availability of adequate solar irradiance. However, the assessment of solar energy potential is frequently constrained by the lack of ground-based radiometric measurements, particularly in rural regions. Empirical models for solar radiation estimation provide a practical solution under such data-scarce conditions. The Colombian Caribbean region presents favorable climatic characteristics for solar applications, yet comprehensive evaluations of solar energy availability in its rural zones remain limited. This study estimates the solar energy potential in rural and non-interconnected areas of the Colombian Caribbean region using sunshine-based empirical models and evaluates its suitability for solar water disinfection applications.

Methods

Global solar radiation was estimated using five empirical models based on sunshine duration: Angstrom-PreScott, Glover and McCulloch, Dogniaux and Lemoine, Page, and Bahel. Monthly average meteorological data were obtained from the nearest available stations operated by the Institute of Hydrology, Meteorology and Environmental Studies of Colombia, IDEAM, due to the absence of local measurements in several evaluated areas. The analysis focused on rural zones across 92 municipalities located in the departments of Atlántico, Bolívar, Cesar, Magdalena, Córdoba, Sucre, and La Guajira. Estimated irradiance values were evaluated on monthly and annual bases and compared with satellite-derived solar radiation data obtained from the Prediction Of Worldwide Energy Resources (POWER) platform. Model performance was assessed using statistical indicators including Mean Bias Error, Mean Absolute Error, Root Mean Square Error, coefficient of determination, and Pearson correlation coefficient. Spatial distribution maps of annual average solar radiation were generated for each empirical model to evaluate regional consistency.

Results

The estimated annual solar energy potential in rural areas of the Colombian Caribbean region ranged between approximately 4.8 and 6.2 kW m⁻². All evaluated models exhibited consistent seasonal behavior with moderate monthly variability, reflecting the relatively stable solar resource characteristic of low-latitude regions. The coefficient of determination values were approximately 0.22 across models, indicating limited temporal variability, while additional statistical indicators showed no significant systematic bias and satisfactory predictive performance. Root Mean Square Error values remained within acceptable ranges, and Pearson correlation coefficients indicated moderate positive linear relationships between estimated and satellite-derived irradiance values. Among the evaluated formulations, the Page model presented the lowest error

metrics, although all models showed comparable performance. Spatial analysis revealed a relatively homogeneous distribution of solar radiation across the evaluated rural zones, with minor geographic variations associated with location and sunshine duration inputs.

Conclusions

The results indicate that rural and non-interconnected areas of the Colombian Caribbean region exhibit solar energy availability compatible with the operational requirements reported for solar water disinfection systems. Sunshine-based empirical models provide a practical and reliable approach for assessing solar radiation in data-limited regions, supporting preliminary feasibility analyses for decentralized solar water treatment technologies. The integration of empirical estimations with satellite-derived reference data enhances confidence in regional-scale assessments and offers a transferable framework for evaluating solar-based solutions in rural environments lacking direct radiometric measurements.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171287: Spatio-Temporal Evaluation of Crop Residue Burning, Smog Formation and Energy Loss in Transboundary Punjab Regions of Pakistan and India

Uzair Hashim ¹, Hafiz Muhammad Safdar Khan ^{1,*}, Muhammad Yamin ², Azhar Ali ³, Imran Shauket ¹ and Mohsin Noor ¹

¹ Department of Structures and Environmental Engineering, Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad 38000, Pakistan

² Department of Farm Machinery and Power, Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad 38000, Pakistan

³ Department of Food Engineering, Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad 38000, Pakistan

Introduction

Seasonal smog has become a major environmental and public health concern in the transboundary Punjab region of Pakistan and India. Extensive open field burning of crop residues upon harvesting of major crops like rice and wheat are the significant causes of air pollution, greenhouse gas emissions and the loss of recoverable bioenergy. This research is intended to test the impact of the socio-spatial features of crop residue burning, its connection with smog formation and the loss of bioenergy in the transboundary regions of the Indo-Pak Punjab border.

Methods

The study focuses on four divisions in India (Amritsar, Jalandhar, Ludhiana, and Patiala) and four divisions in Pakistan (Lahore, Gujranwala, Faisalabad, and Sahiwal). The method used in the estimation of crop residue generation was crop-to-residue ratio using crop production. The NASA FIRMS provides satellite-based fire data, which was examined with Geographic Information System (GIS) tools in order to determine the presence of residue burning hotspots and temporal changes in the past decade. Air quality indicators such as Air Quality Index (AQI) and particulate matter (PM) were also studied to determine the correlation with the occurrence of the residue burning events.

Results

It is revealed that about 15–22 million tonnes of crop residues are burnt in the study area every year. According to satellite reports, this coincides with the high levels of AQI and PM during periods of peak smog. The amount of energy lost in open field burning is estimated to be between 210 and 330 petajoules (PJ) every year, which is a huge loss of potential bioenergy resources.

Conclusions

The results indicate the close relationship between the burning of crop residues, poor air quality and wasted bioenergy resources within the transboundary region of the Punjab. The research also suggests that biomass briquetting may be an alternative solution to the utilization of crop residues that would help decrease emissions and promote energy recovery in the region and the transition to sustainable energy.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-169878: Spatiotemporal Analysis of Land-Use and Land-Cover Transitions Using Google Earth Engine: A Case of Tendele Coal Mine, Somkhele, In KwaZulu Natal Province, South Africa

Thobelani Jiyane *, Zandile Mncube and Solomon Zondo

Department of Geography, University of the Free State (Qwaqwa Campus), Phuthaditjhaba, South Africa

Introduction

Coal mining continues to play a central role in South Africa's energy system, contributing significantly to national electricity generation. However, coal-based energy extraction is also associated with substantial environmental pressures, particularly land degradation, ecosystem disruption, and water resource stress. Understanding the spatiotemporal impacts of mining-induced land-use and land-cover (LULC) change is therefore essential for informing sustainable energy planning and environmental governance. Advances in satellite remote sensing, cloud computing, and artificial intelligence provide new opportunities for continuous, large-scale monitoring of energy-related environmental impacts. This study investigates LULC dynamics associated with coal mining activities around the Tendele Coal Mine in Somkhele, KwaZulu-Natal, South Africa, within the broader context of the energy–environment nexus.

Methods

Multi-temporal Landsat satellite imagery spanning the period 2008–2023 was processed using the Google Earth Engine (GEE) cloud-based geospatial analysis platform. Five primary LULC classes—forests, grasslands, built-up areas, water bodies, and mines and quarries—were mapped using a supervised machine-learning approach based on the Random Forest (RF) algorithm. Classification accuracy was evaluated using overall accuracy and Kappa statistics to ensure robust model performance. Post-classification change detection techniques were applied to quantify spatial and temporal transitions among LULC classes. To support future-oriented energy and environmental planning, a Cellular Automata–Markov (CA–Markov) model was implemented to project LULC changes to 2028 based on historical transition probabilities.

Results

The RF-based classification achieved reliable performance, with overall accuracies ranging from 73.62% in 2008 to 93.33% in 2020 and Kappa coefficients indicating substantial to near-perfect agreement, peaking at 0.9123. Change detection analysis revealed that coal mining activities significantly influenced regional land dynamics. The mining footprint expanded markedly between 2008 and 2014, stabilized during the 2017–2020 period, and exhibited a slight decline by 2023, suggesting the influence of regulatory controls and environmental management measures. Forest cover demonstrated an overall net increase by 2023, while grasslands showed an initial expansion followed by subsequent decline. Built-up areas expanded rapidly during periods of intensified mining activity before contracting after 2017. CA–Markov projections indicate continued growth in forest and built-up areas by 2028, alongside a modest expansion of mining and quarrying areas to approximately 7.19 km².

Conclusions

The findings highlight the complex and evolving environmental impacts of coal-based energy extraction on land systems. By integrating remote sensing, cloud computing, machine learning, and spatial modelling, this study demonstrates the effectiveness of AI-enabled geospatial frameworks for monitoring energy-related environmental change. The results provide decision-support insights for policymakers, environmental managers, and energy-sector stakeholders seeking to balance energy security with sustainable land management. Such approaches are essential for supporting environmentally responsible energy transitions in mining-dependent regions.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171130: Strategic Approaches for Building Decarbonisation: Descriptive Evidence from Built Environment Professionals

Olusegun Aanuoluwapo Oguntona¹, Thabang Modula^{2,*} and Clinton Ohis Aigbavboa²

¹ Department of Built Environment, Faculty of Engineering, Built Environment and Information Technology, Walter Sisulu University, South Africa

² cidb Centre of Excellence, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, South Africa

Decarbonising the built environment has emerged as a critical pathway for mitigating climate change impacts, particularly in developing economies with rapidly growing construction activities. Despite the availability of diverse decarbonisation strategies, their effective implementation within the architecture, engineering and construction (AEC) sector remains uneven and insufficiently understood. This study aims to determine the strategic approaches for promoting the implementation of building decarbonisation initiatives in South Africa, drawing on descriptive evidence from built environment professionals. A descriptive research design was adopted, utilising structured questionnaire data collected from professionals across the AEC disciplines. Descriptive statistical techniques, including frequency distributions and mean score rankings, were employed to examine construction professionals' perceptions of key strategic measures that can enhance the uptake of building decarbonisation practices. The findings indicate that ease of access to green financing options, implementing energy efficiency upgrades, promoting the use of green rating tools, using building energy management systems, and raising public awareness are perceived as the most effective strategies for accelerating building decarbonisation. These strategies place strong emphasis on financial support mechanisms, institutional frameworks, and behavioural change as critical enablers of decarbonisation in the built environment. In conclusion, the study demonstrates that successful building decarbonisation extends beyond technological availability and is strongly influenced by supportive financial structures, regulatory alignment, and stakeholder awareness. This study contributes to the growing body of knowledge on building decarbonisation by providing empirically grounded, practitioner-focused insights into implementation strategies rather than relying solely on technological solutions. The findings offer practical guidance for policymakers, industry leaders, and regulatory institutions seeking to operationalise decarbonisation objectives within the built environment. It is therefore recommended that policymakers strengthen green financing frameworks, embed decarbonisation requirements within building regulations, and promote industry-wide capacity-building initiatives. From a practical standpoint, industry stakeholders are encouraged to mainstream energy management practices and actively utilise green rating systems to guide low-carbon decision-making. Future research should explore integrating these strategic approaches with quantitative performance-based assessments, longitudinal studies, and sector-specific case studies to further validate and refine building decarbonisation pathways in South Africa and comparable developing economies.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171196: Symmetric SOECs based on $\text{PrBaMn}_2\text{O}_{5+\delta}$ electrodes for co-electrolysis processes

Noelia Díaz Navarro ^{1,*}, Angela Moratalla ¹, María del Rosario Serrano de la Cruz ¹, Adrián Pardo ¹, Irene Ayuso ¹, Alfredo Iranzo ², Francisco José García García ², Cristina Montes ¹ and Roberto Campana ¹

¹ Scientific Development Unit, National Hydrogen Center, Puertollano, 13500, Spain

² Department of Materials and Transport Engineering and Science, University of Seville, Spain

Introduction

The transition toward sustainable energy systems and decarbonization has driven the development of energy conversion technologies integrated with renewable sources. In this context, solid oxide electrolysis cells (SOECs) are promising technologies for the electrochemical conversion of CO_2 and H_2O through co-electrolysis, producing synthesis gas and fuels from renewable electricity. Conventional electrodes, particularly Ni-YSZ anodes, suffer from degradation due to coking, sulfur poisoning, and loss of stability under variable operating conditions. Advanced mixed ionic-electronic conductors (MIECs), such as PBMO ($\text{PrBaMn}_2\text{O}_{5+\delta}$), LSCM ($\text{La}_{0.75}\text{Sr}_{0.25}\text{Cr}_{0.5}\text{Mn}_{0.5}\text{O}_{3-\delta}$), LSF ($\text{La}_{1-x}\text{Sr}_x\text{FeO}_{3-\delta}$), LSCF ($\text{La}_{1-x}\text{Sr}_x\text{Fe}_{1-\gamma}\text{Co}_\gamma\text{O}_{3-\delta}$), and LST ($\text{La}_{0.2}\text{Sr}_{0.8}\text{TiO}_{3+\delta}$) [1], exhibit robust structural stability and versatile functionality. Among them, double-layer perovskites such as PBMO stand out due to their high electrical conductivity, fast oxygen exchange kinetics, excellent redox tolerance, and stability against carbon and sulfur. In this way, symmetric solid oxide cells have emerged as an alternative, employing a single ceramic material as both electrodes, which simplifies fabrication processes, reduces costs, and improves material compatibility, while also enabling their application as reversible electrodes in SOFC/SOEC systems [2].

Materials and methods

In this work, different PBMO samples were synthesized via mechanosynthesis of binary oxides using high-energy planetary ball milling. Symmetrical cells with a PBMO-GDC / GDC / YSZ / GDC / PBMO-GDC configuration were fabricated using YSZ electrolytes prepared by the tape-casting technique. A protective GDC layer and the electrode layers were deposited by semi-automatic ultrasonic spray coating. The electrode powders, mixed with 50 wt.% GDC, were symmetrically deposited onto the YSZ electrolyte and subsequently sintered. The performance of PBMO electrodes was evaluated through electrochemical and microstructural characterization, considering their activity in electrolysis and $\text{H}_2\text{O}/\text{CO}_2$ co-electrolysis. Electrochemical measurements were carried out using an open-flanges test set-up, which allowed a rigorous assessment of the activity of the electrodes in reversible operation, both in fuel cell and electrolyzer modes. Durability and redox stability during operation cycles were also analyzed, correlating post-mortem microstructural changes with electrochemical performance. Microstructural characterization included electrode morphology by scanning and transmission electron microscopy (SEM/TEM), and elemental mapping by energy-dispersive X-ray spectroscopy (EDX).

Results

The results showed that in steam electrolysis mode (75% H_2O / 25% H_2), the cells exhibited a clear temperature-dependent behavior, with a decrease in operating voltage as the temperature increased from 800 to 900 °C at a given current density. Current densities above 250 mA cm^{-2} were achieved at voltages below ~1.35 V at 900 °C. Electrochemical impedance spectroscopy (EIS) revealed a significant reduction in polarization resistance with increasing temperature, indicating enhanced electrode kinetics. Under co-electrolysis conditions (45% H_2O / 45% CO_2 / 10% H_2), similar trends were observed, with improved performance at higher temperatures and current-voltage characteristics comparable to those obtained under steam electrolysis. The EIS spectra showed a decrease in total resistance with temperature, confirming the positive effect of

thermal activation on charge-transfer processes and surface reactions during co-electrolysis. Short-term constant-current tests conducted at 850 °C under 50% H₂O and a current of 800 mA showed a stable voltage response over time, indicating good operational stability of the PBMO–GDC electrodes under high current density conditions. Post-mortem characterization by scanning electron microscopy (SEM) revealed a dense and homogeneous microstructure, good interfacial adhesion between layers, and the absence of delamination or fracture after electrochemical operation.

Conclusions

Mechanochemical synthesis enabled the production of phase-pure PBMO materials with a uniform morphology and properties suitable for electrode processing and integration into electrochemical cells. PrBaMn₂O_{5+δ}, employed simultaneously as both anode and cathode in symmetric SOECs, exhibited promising electrochemical performance under H₂O/CO₂ electrolysis and co-electrolysis conditions, with a clear enhancement in performance at higher operating temperatures. Symmetric cells with PBMO electrodes showed a homogeneous microstructure, adequate porosity, and excellent interfacial adhesion between layers, evidencing high structural integrity. In addition, constant-current tests confirmed the electrochemical operational stability of the PBMO-based symmetric configuration, with no signs of degradation observed during prolonged operation.

Acknowledgements

This work was carried out within the Renewable Energy and Hydrogen Program, included in the Complementary R&D&I Plans of the Spanish Ministry of Science, Innovation and Universities (MICIN), and was funded by the European Union's NextGenerationEU, under Component 17 of the Recovery, Transformation and Resilience Plan (C17.I01.P01).

It is also framed within the research project PID2024-162053OB-C31, funded by the Spanish Ministry of Science, Innovation and the State Research Agency (AEI), as well as the project SBPLY/24/180225/000095, funded by the Regional Government of Castilla-La Mancha (JCCM).

References

1. Wang, M., Wang, J., Du, J., “A symmetrical solid oxide electrolysis cell supported by nanostructured electrodes for highly efficient CO₂ electrolysis”, *Journal of Power Sources* 2024, 610, 234742.
2. Garcia-Garcia, F.J., Sayagués, M.J., Gotor, et al., “A Novel, Simple and Highly Efficient Route to Obtain PrBaMn₂O_{5+δ} Double Perovskite: Mechanochemical Synthesis”, *Nanomaterials* 2021, 11, 380.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-163159: Technical and Environmental Assessment of Green Hydrogen Production Using Advanced Electrolysers Powered by Solar Energy: Middle Asia Case Study

Wagd Ajeeb^{1,2}

¹ Department of Mechanical Engineering, School of Engineering, New Uzbekistan University, Movarounnahr Street 1, Mirzo Ulugbek District, Tashkent, 100000, Uzbekistan

² IN+ Center for Innovation, Technology and Policy Research, IST-ID - Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento, University of Lisbon, 1049-001 Lisbon, Portugal

Decarbonizing industry and accelerating the deployment of clean energy technologies are increasingly important priorities across Central Asia as countries pursue long-term strategies to reduce emissions and enhance energy security. Uzbekistan, with its high solar potential and rising energy demand, provides a relevant case for evaluating the role of low-carbon hydrogen in supporting this transition. In this study, green hydrogen is produced using an alkaline water electrolyser enhanced with metal-organic framework (MOF) materials (MOF-WAE) and powered entirely by solar photovoltaic (PV) electricity. The MOFs are integrated into the electrolyser electrode structure to improve electrochemical performance and hydrogen production efficiency. The system is modeled at an industrially relevant scale, consisting of a 40 MW alkaline electrolysis plant operating at 85% annual capacity factor, resulting in an annual hydrogen production of approximately 5,100 tonnes. The environmental performance of the proposed system is evaluated using a life-cycle assessment (LCA) implemented in SimaPro, covering the full hydrogen pathway from solar electricity generation to hydrogen utilization. Results show that the MOF-WAE configuration achieves a life-cycle global warming potential of approximately 1.97 kg CO₂ per kg of hydrogen produced. When compared with a conventional steam methane reforming (SMR) reference pathway, this corresponds to an annual reduction of about 13,340 tonnes of CO₂, representing an overall reduction of nearly 80% in global warming potential. The remaining impacts are largely driven by electricity-related processes, underlining the importance of clean and reliable renewable power supply for large-scale hydrogen deployment. The advantages of renewable hydrogen are also evident in transport applications. Fuel-cell vehicles powered by solar-based hydrogen can emit up to 89% less CO₂ per 100 km than diesel vehicles, and approximately 83% less CO₂ than vehicles using SMR-derived hydrogen. Overall, the findings indicate that solar-powered, MOF-enhanced alkaline electrolysis is technically feasible and capable of delivering substantial environmental benefits, making it a promising pathway for Uzbekistan and other Central Asian countries pursuing resilient, low-carbon energy systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171386: Techno-Economic and Life-Cycle Assessment of Sustainable Bioenergy Production through Gasification of Torrefied Municipal Solid Waste: A South African Case Study

Ahmed Mohammed Inuwa *, Usman Aliyu Mohammed, Emmanuel Kweinor Tetteh and Sudesh Rathilal

Green Engineering Research Group; Department of Chemical Engineering, Faculty of Engineering and Built Environment, Durban University of Technology 4001, Durban, South Africa

South Africa faces significant challenges in managing rapidly growing municipal solid waste (MSW) streams, which contribute to environmental pollution and lost energy potential. Converting municipal solid waste (MSW) into bioenergy presents a dual opportunity to generate renewable energy while mitigating environmental pollution in rapidly urbanizing regions like South Africa. This study evaluates the techno-economic and life-cycle performance of bioenergy production through gasification of torrefied MSW, using a 100 kg feedstock scenario representative of local municipal waste streams. Torrefaction improves feedstock quality by increasing energy density and reducing moisture content to 10%, yielding a higher heating value (HHV) of 20 MJ/kg, thereby enhancing gasification efficiency. The techno-economic assessment demonstrates that a 1 ton/hour plant converting torrefied MSW into syngas requires a capital investment of USD 4.5 million, with annual operating costs of USD 45,000. Revenue from syngas sales is projected at USD 67,000 per year, producing a Net Present Value (NPV) of USD 560,000 and an Internal Rate of Return (IRR) of 12%. The levelized cost of energy (LCOE) is USD 0.03/kWh, competitive with conventional fossil fuels. Sensitivity analyses indicate that feedstock composition, plant scale, and local energy pricing significantly influence economic viability, highlighting opportunities for optimized operational strategies. The life-cycle assessment underscores substantial environmental benefits, including GHG emission reductions of 15 kg CO₂-equivalent per 100 kg of torrefied MSW, displacement of fossil fuels, and improved energy recovery, achieving a process energy efficiency of 36% and an energy return on investment (EROI) of 3. Gasification produces 60 kg of syngas with an HHV of 12 MJ/kg and 15 kg of char, demonstrating effective material and energy utilization. Overall, torrefied MSW gasification provides a technically feasible, economically viable, and environmentally sustainable bioenergy pathway for South Africa. These findings offer critical guidance for policymakers, industry stakeholders, and researchers seeking to implement advanced waste-to-energy systems that support renewable energy deployment, methane mitigation, and the transition toward a circular bioeconomy



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-162987: The CMIP6 Efficiency of Capturing Wind Energy Potential Over the Southeastern Mediterranean and Future Projections According to SSP2-4.5 and SSP5-8.5

Ioannis Logothetis^{1,2,*}, Kleareti Tourpali², Dimitris Melas², Dimitrios-Sotirios Kourkoumpas¹, Adamantios Mitsotakis¹ and Panagiotis Grammelis¹

¹ Centre for Research and Technology Hellas, Chemical Process and Energy Resources Institute, Thessaloniki, Greece

² Laboratory of Atmospheric Physics, Department of Physics, Faculty of Sciences, Aristotle University of Thessaloniki, GR 54124 Thessaloniki, Greece

Renewables are crucial for climate and socioeconomic sustainability, reducing the environmental footprint of fossil fuels, and supporting the green transition. Wind energy is one of the most competitive renewable energy sources, playing a pivotal role in achieving the United Nations Sustainable Development Goals (SDGs; namely, SDG 7 and 13—Affordable and Clean Energy and Climate Action). Moreover, the potential of Aeolian energy is acknowledged as a key factor in enhancing energy security, fostering socioeconomic resilience, and contributing to climate change mitigation. This work investigates the mean efficiency of the Coupled Model Intercomparison Project Phase 6th (CMIP6) models (MM) in capturing and reproducing distributional and temporal wind energy potential (WEP) features over a geographical window that covers the climatically vulnerable region of the central Eastern Mediterranean (cEMed). Outputs from eighteen (18) CMIP6 model simulations are utilized to compute the CMIP6 MM WEP, which is subsequently evaluated against the fifth-generation global climate reanalysis dataset from ECMWF (ERA5 reanalysis). In addition, WEP projections under two Shared Socioeconomic Pathways (namely, moderate, SSP2-4.5, and extreme, SSP5-8.5, scenarios) are studied, focusing on the changes between the last period of the 21st century and a basis period that covers the historical period from 1970 to 2000. Results show that CMIP6 MM demonstrates low performance (in terms of Kling–Gupta efficiency index; KGE ~ -0.22) in capturing and reproducing the WEP features over cEMed. Both SSP scenarios show WEP increasing over the central, and slightly decreasing over the south, area of the southeastern Mediterranean, respectively. CMIP6 show high multi-model variability in model simulations WEP outputs over cEMed area. Considering the model simulations that show better performance in reproducing WEP over cEMed (four out of eighteen model simulations; KGE>0.35), a reduction in WEP over the southeastern Mediterranean is shown. However, due to high multi-model variability and uncertainty in the WEP results, further investigation combining different datasets is needed.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165785: The dynamic energetic response of a zero-gap PEM electrolyzer: tracking thermal losses and energy conversion efficiency

Nour El Imene Brahmi^{1,2,*} and Kaouther Kerboua^{2,3}

¹ Department of Process and Energy Engineering, National Higher School of Technology and Engineering, 23005 Annaba, Algeria

² Laboratory of Mining, Metallurgy and Materials L3M, National Higher School of Technology and Engineering, Annaba, Algeria

³ Department of Mining Engineering, National Higher School of Technology and Engineering, 23005 Annaba, Algeria

Efficient small-scale hydrogen production via proton exchange membrane (PEM) electrolysis is increasingly recognized as a key pathway for producing green hydrogen and supporting the transition toward low-carbon energy systems. Achieving this goal requires a detailed understanding of the coupled electrochemical, thermal, and energetic phenomena governing stack performance under dynamic operating conditions. This study experimentally investigates a five-cell zero-gap PEM electrolyzer stack equipped with Nafion™ 117 membranes, titanium mesh electrodes, and stainless steel bipolar plates. The system is designed for laboratory-scale hydrogen production and evaluated under controlled operating conditions to quantify energy losses, thermal behavior, and hydrogen generation efficiency.

The experimental protocol includes membrane hydration, stack thermal stabilization, low-current electrochemical conditioning, and systematic polarization testing over an applied current density up to 0.3 A/cm². Stack temperatures during operation range from approximately 312.1 at to 322.8 K, for water circulating at 55±3 °C at 200 mL/min. Hydrogen production is experimentally measured using a calibrated collection bag and compared against theoretical hydrogen generation calculated using Faraday's law. The resulting Faradaic efficiency increased at relatively moderate current densities, indicating improved electrochemical utilization, to reach 98.03%.

Infrared (IR) thermography reveals non-uniform temperature distributions across the electrolyzer stack, with inter-cell and in-plane temperature gradients exceeding 9 °C, even under relatively low-current operation. As current density increases, localized hotspots become more pronounced, highlighting the role of ohmic heating and uneven current distribution.

Energy efficiency, calculated by combining electrical input power with measured hydrogen production rates, remains above 50% at relatively moderate current densities. However, efficiency declines significantly at higher currents due to the combined effects of increased ohmic losses, charge transfer limitations, and thermal non-uniformities. The results demonstrate a clear coupling between electrochemical resistance growth, thermal gradients, and reduced hydrogen production efficiency.

Overall, this work provides a comprehensive characterization of the dynamic energetic response of a small-scale zero-gap PEM electrolyzer. By directly linking experimental hydrogen production and spatially resolved thermal behavior, the study offers valuable insights into loss mechanisms that limit efficiency and operational stability. These findings underscore the importance of optimized thermal management, material selection, and operating strategies for improving the performance and durability of small-scale PEM electrolyzers in green hydrogen applications. These findings are particularly relevant for improving the energy efficiency and durability of PEM electrolyzers used in renewable-energy-driven hydrogen production, thereby contributing to the development of more environmentally sustainable hydrogen technologies.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166121: The Energetic Compromise in Small-Scale H₂ Energy Storage: A Comparative Experimental Study Based on Electrolyzer's Separators and Architectures.

Kaouthar Kerboua^{1,2,*}, Nour El Imene Brahmi^{1,2}, Abderrahmane Selmani³ and Nour Hane Merabet⁴

¹ Department of Process and Energy Engineering, National Higher School of Technology and Engineering, 23005 Annaba, Algeria

² Laboratory of Mining, Metallurgy and Materials L3M, National Higher School of Technology and Engineering, Annaba, Algeria

³ Department of Chemical Engineering, Sorbonne University, Paris, France

⁴ Karlsruhe University of Applied Sciences, Karlsruhe, Germany

Introduction:

The design of efficient small-scale hydrogen energy storage systems requires balancing hydrogen production rate, electrical efficiency, and system simplicity. This study investigates the energetic trade-off between kinetic performance and energy conversion efficiency imposed by electrolyzer architecture and separator materials.

Methods:

A comparative experimental analysis was conducted using finite-gap (H-cell) and zero-gap electrolyzer configurations for both alkaline and proton exchange membrane (PEM) systems. Zirfon® Pearl 500 diaphragms were employed in alkaline electrolyzers (25 wt% KOH), while Nafion™ 117 membranes were used in PEM systems, operating in acidic medium (2.55 M H₂SO₄) for finite-gap and deionized water for zero-gap configurations. Polarization behavior, hydrogen production rate, Faradaic efficiency, and apparent cell resistance were evaluated under comparable operating conditions to assess the trade-offs associated with separator properties and electrolyte conductivity.

Results:

Zero-gap PEM electrolyzers exhibited significantly reduced internal resistance and superior kinetic performance, achieving currents from 1.5 to 3.8 A at voltages below 2.5 V, and up to 10 A at 2.8 V. In contrast, finite-gap PEM systems required higher voltages, delivering only 0.73 A at 4 V and 2.86 A at 18 V. Alkaline H-cell electrolyzers using Zirfon® diaphragms showed lower current densities (0.24–0.27 A at 4 V and 2.35 A at 18 V), with improved performance observed using nickel electrodes. At 4 V, acidic H-cell systems with Nafion™ 117 membranes exhibited internal resistance (~5.5 Ω) approximately three times lower than alkaline counterparts (~14.81 Ω), resulting in hydrogen production rates up to 2.3 times higher. However, alkaline Ni/Zirfon configurations achieved higher Faradaic efficiency (~98%) and energy efficiency (~36%), attributed to reduced parasitic reactions and improved gas separation.

Conclusions:

The results demonstrate a clear trade-off between kinetic performance and energy efficiency depending on electrolyzer architecture and separator choice. While acidic PEM systems favor higher reaction rates due to lower internal resistance, alkaline systems provide superior energy utilization. This study establishes a comparative framework for selecting electrolyzer configurations tailored to decentralized hydrogen storage, highlighting the critical role of separator properties, ionic path length, and electrolyte conductivity in determining system performance.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-159855: Theoretical Design and Efficiency Analysis of a Small-Scale Hydropower Turbine: Insights for Sustainable Energy Applications

Surupa Shaw and Ethan Roberts *

Department of Multidisciplinary Engineering, Texas A&M University, 3127 TAMU, College Station, USA

This paper presents a comprehensive theoretical design framework and efficiency analysis for a small-scale hydropower turbine intended to support sustainable, decentralized, and low-impact energy generation. As global energy demand continues to rise and the effects of climate change intensify, the need for resilient renewable power systems has become increasingly urgent. Small hydropower (SHP) technologies offer a practical solution for rural, remote, and off-grid regions by providing reliable, low-cost electricity without the ecological disruption commonly associated with large dam infrastructure. In response to this need, the present study develops and evaluates a simplified impulse-turbine model-representative of Pelton- and Turgo-type micro-hydro systems-using fundamental fluid mechanics principles, Bernoulli-based jet velocity predictions, and classical momentum-transfer turbine equations.

The analysis investigates the relationship between hydraulic head, flow rate, jet formation, and mechanical power output while accounting for real-world loss mechanisms introduced by penstock friction, nozzle inefficiencies, turbulence, flow separation, jet dispersion, mechanical drag, and misalignment. By integrating analytical modeling with insights from contemporary computational fluid dynamics (CFD) literature, the study identifies how nozzle geometry, jet coherence, bucket shape, and runner design strongly influence momentum transfer and overall turbine efficiency. Loss mechanisms are categorized into penstock, nozzle, runner, and mechanical components, each quantified with established efficiency factors and combined multiplicatively to provide a realistic system-level performance estimate.

Results demonstrate that while power output increases with hydraulic head and flow rate, diminishing returns emerge at high operating extremes due to intensifying turbulence and mechanical losses. The analysis confirms that peak efficiency occurs only within a narrow bucket-to-jet speed-ratio range, consistent with established impulse-turbine theory. The study additionally highlights practical considerations essential for real-world applications, including material selection, erosion resistance, sediment effects, manufacturability, site-specific turbine adaptation, and the influence of seasonal flow variability on long-term system reliability. Overall, the findings provide a detailed foundation for optimizing micro-hydropower systems intended for sustainable, decentralized energy deployment.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-163712: Transforming Energy Sector: A Policy-Oriented Approach to Carbon Neutrality through Green Innovation and Carbon Pricing

Zia Ur Rahman

Department of Economics, Ghazi University, Dera Ghazi Khan, Pakistan

Green innovation and carbon pricing have gained renewed attention as credible pathways for achieving low-carbon and sustainable economic growth, particularly following the maturation of energy transition policies across major economies. Both developed and developing countries increasingly prioritize green technological advancement and market-based carbon pricing instruments to meet long-term carbon neutrality commitments. Against this backdrop, this study aims to empirically examine the interlinkages between energy transition, green innovation, carbon pricing, and zero-carbon outcomes, with the objective of clarifying how these mechanisms jointly contribute to carbon neutrality.

To achieve this objective, the study employs a Dynamic Simulated Autoregressive Distributed Lag (DS-ARDL) framework, which allows for the assessment of both short-run dynamics and long-run adjustments under simulated policy shocks. Using annual data for China spanning 1990 to 2024, sourced from the World Development Indicators, the model captures nonlinear and forward-looking responses relevant to long-term decarbonization strategies. China offers a compelling case due to its rapid economic expansion, evolving energy structure, and increasing reliance on green policy instruments.

The empirical findings confirm that energy transition, green innovation, and carbon pricing play statistically significant and economically meaningful roles in advancing carbon neutrality. Specifically, the DS-ARDL estimates indicate that a 1% increase in next-generation energy deployment, clean and green technological innovation, and carbon pricing intensity leads to reductions in carbon emissions of 0.637%, 0.534 %, and 0.531 %, respectively. These results underscore the effectiveness of coordinated policy interventions in reducing emissions without undermining long-term economic performance.

From a policy perspective, the findings highlight the necessity for policymakers and legislators to adopt integrated and forward-looking strategies that simultaneously promote renewable energy adoption, incentivize green innovation, and enforce stringent carbon pricing mechanisms. Aligning these instruments is particularly critical for economies following an Environmental Kuznets Curve trajectory, where structural transformation and technological progress are essential for decoupling growth from emissions. Consequently, comprehensive and transformative policy measures are required across environmental regulation, energy system reform, green technology diffusion, and clean energy utilization to ensure the realization of carbon neutrality over the long term.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170700: Turning Tyre Waste into Energy: Sustainable Valorisation via Microwave-Induced Plasma Gasification

Joshua Chooyin, Amos Dexter, Long Duong and Basudeb Saha *

School of Engineering, Lancaster University, Lancaster, LA1 4YW, UK

Introduction

The United Nations has emphasised the urgent need to transition towards a more sustainable and resource-efficient global economy, with improved waste management identified as a key enabler. One major challenge is the disposal and valorisation of end-of-life tyres. The global tyre industry produces approximately 3.66 billion tyres annually, creating significant environmental and energy concerns. Conventional disposal routes, such as landfilling and incineration, are associated with toxic emissions, environmental risks, and poor energy recovery. In this context, gasification offers a promising route for converting waste into valuable energy carriers.

This paper investigates microwave-induced plasma gasification as a sustainable alternative for tyre waste treatment. Experimental studies are conducted using a novel microwave plasma furnace equipped with a mode converter that maintains the plasma core away from reactor walls, improving thermal efficiency and eliminating the need for ceramic linings. Tyre crumb is used as a representative feedstock. Although tyres are generally safe to handle, their combustion can release 10-100 times more polycyclic aromatic hydrocarbons than coal, whereas gasification enables cleaner conversion into synthesis gas.

Microwave plasma gasification achieves efficient destruction of complex organics, producing inert ash with negligible fixed carbon and significantly reduced VOC emissions. Independent control of temperature and oxidant supply enables optimisation of syngas quality and process economics. Ongoing research at Lancaster University focuses on improving applicator efficiency and advancing scalable, energy-efficient waste-to-energy technologies.

Methods

Previous gasification research at Lancaster University employed a 2.45 GHz, 6 kW microwave-induced plasma torch (Sairem SAS, France). Atmospheric-pressure microwave plasmas are most readily sustained within electrically insulating, microwave-transparent ceramic vessels, which reduce electron losses and enable operation at lower power. In this system, the plasma torch comprised a fused silica tube (25.4 mm internal diameter) passing through a WR340 rectangular waveguide operating in the TE₁₀ mode. Microwave leakage was suppressed using concentric metallic chokes, while plasma ignition was achieved via a transient tungsten arc. Although effective, the fused silica tube required intensive cooling to prevent thermal damage, significantly reducing system efficiency.

To address these limitations, a new applicator was developed to increase plasma volume, enable scale-up, and eliminate the need for a cooled ceramic tube. The design operates in the TE₀₁ mode of a cylindrical waveguide, where the azimuthal electric field and low wall field strength minimise electron and heat losses, improving thermal efficiency. For 2.45 GHz operation, a cylindrical diameter of 182 mm was selected and a dedicated mode converter fabricated. While stable operation requires specific gas flow and power thresholds, the design is readily scalable to 915 MHz, where magnetron efficiencies exceed 90%, enabling industrial-scale processing. Independent control of gas flow and power can be achieved through hot-gas recirculation, further optimising gasification performance.

Results

The current test bed comprises three main components: a microwave plasma chamber, a gasification furnace, and a gas recirculation system. The gasification stage of the process is modelled using ASPEN Plus, enabling heat and enthalpy balancing under assumed constant pressure and enthalpy conditions. Although the overall system operates as a single reactor experimentally, a hybrid modelling approach is adopted, dividing the gasification process into

three stages: drying at 105 °C, pyrolysis at 500 °C (modelled using an RYield block), and gasification (modelled using an RGibbs block). Heat for drying and pyrolysis is supplied by the plasma exhaust stream, while the final gasifier temperature depends on reaction heat and available exhaust energy. Two operating cases are examined: without syngas recirculation and with recirculation. In the non-recirculation case, air is heated by microwave input in the plasma chamber and fully directed to the gasifier. In the recirculation case, the plasma is modelled using three temperature zones to reflect realistic plasma–gas interactions, followed by heat exchange and partial syngas extraction. ASPEN Plus simulations indicate that an optimal airflow of 16.5 kmol h⁻¹ eliminates fixed carbon while minimising undesirable by-products. Importantly, incorporating up to 80% gas recirculation significantly reduces exhaust temperatures and microwave power demand by a factor of approximately 2.8 without adversely affecting syngas composition or calorific value, thereby improving overall process efficiency and economics.

Conclusions

A stable atmospheric-pressure microwave-induced plasma was successfully generated within a steel vessel, demonstrating robust and controllable operation. The high-temperature plasma exhaust exhibited the thermal intensity and chemical reactivity required to effectively gasify a range of waste feedstocks, including tyre crumb. Key operational parameters governing efficient plasma formation and stability were identified, providing essential baseline data for the evaluation of tyre-derived materials as viable feedstocks in plasma-assisted gasification processes.

These results highlight the strong potential of microwave-induced plasma technology as a cleaner and more efficient alternative to conventional thermal treatment methods, offering enhanced destruction of organic compounds with the prospect of reduced harmful emissions. Importantly, stable operation at atmospheric pressure significantly improves the practicality of this approach, supporting the development of compact and modular waste-to-energy systems. Such systems could be deployed closer to waste generation sites, thereby reducing transportation requirements, lowering environmental impact, and advancing sustainable waste management strategies.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Session 4. Smart Cities and Urban Management

sciforum-166140: Energy-Aware Route Planning for Differential-Drive Mobile Robots in Polygonal Urban Environments via Feasibility-First Metaheuristic Optimization

Vanessa Botero-Gómez ¹, Cristian Mateo Hernandez ^{1,2,*}, Juan C. Tejada ³, Luis Fernando Grisales-Noreña ⁴ and Daniel Sanin-Villa ²

¹ Department of Mechatronics and Electromechanical Engineering, Faculty of Engineering, Instituto Tecnológico Metropolitano, Medellín 050034, Colombia

² Area of Industry, Materials, and Energy, School of Applied Sciences and Engineering, Universidad EAFIT, Medellín 050022, Colombia

³ Department of Engineering Studies for Innovation, Universidad Iberoamericana Ciudad de México, Prolongación Paseo de la Reforma 880, Colonia Lomas de Santa Fé, Mexico City 01219, Mexico

⁴ Grupo de Investigación en Alta Tensión-GRALTA, Escuela de Ingeniería Eléctrica y Electrónica, Facultad de Ingeniería, Universidad del Valle, Cali 760015, Colombia

Introduction

Urban service robots, such as last-meter delivery platforms, inspection robots, and indoor-outdoor logistics units, increasingly operate in cluttered environments where safe navigation must be balanced against limited onboard energy. In many deployed systems, path planning still prioritizes geometric shortest paths with collision penalties, which can produce stop-turn-go behaviors that increase battery drain and reduce operational endurance. This work proposes an energy-aware planning formulation for differential-drive robots in static polygonal environments, targeting smart-city scenarios where repeated missions and charging constraints make energy a first-class criterion rather than an afterthought.

Methods

The workspace is modeled as a bounded planar set with obstacles represented by closed polygons. The robot footprint is modeled as a disk of radius with an additional safety clearance (c), enforcing a minimum separation ($r+c$) from all obstacle boundaries. Candidate routes are parameterized as polylines connecting the start and goal through continuous intermediate waypoints, assembled into the decision vector $x \in \mathbb{R}^{2m}$.

Energy is modeled through a physically interpretable proxy consistent with differential-drive motion primitives: the robot rotates in place to align with the next segment and then translates along that segment. The objective combines translational effort, proportional to total route length, and rotational effort, proportional to cumulative heading changes and their concentration, capturing the fact that frequent or abrupt turns increase wheel actuation and dissipative losses.

Feasibility is enforced through exact geometric checks for polygonal obstacles. For each segment, collision and clearance are verified via segment-polygon intersection tests and minimum segment-to-polygon distance calculations, eliminating the false negatives that occur with coarse point sampling. Boundary constraints restrict intermediate waypoints to the admissible workspace, and an optional turning constraint bounds inter-segment heading changes to avoid extreme cornering demands. The optimization is solved using continuous metaheuristics, genetic algorithms and particle swarm optimization, with a feasibility-first constraint handling rule: any feasible solution dominates any infeasible solution, among feasible solutions lower energy dominates, among infeasible solutions lower constraint violation dominates. This removes dependence on penalty weight tuning.

Results

In simulated urban-like layouts with multiple polygonal obstacles and narrow corridors, the feasibility-first energy formulation consistently produced collision-free routes that favored smoother steering sequences compared to distance-only planning and penalty-weighted feasibility schemes. The energy-aware objective reduced stop-turn-go patterns by discouraging sharp heading discontinuities, while the exact polygon distance evaluation improved reliability by

preventing missed collisions between sampled points. Across repeated random initializations, both metaheuristics converged to feasible solutions when feasible corridors existed, with genetic search showing strong exploration in cluttered maps and particle swarms showing rapid improvement in early iterations. The method also demonstrated stable behavior under changes in obstacle shape and arrangement, since feasibility is enforced by dominance rules rather than fragile penalty scaling.

Conclusion

An energy-aware, feasibility-first route planning method is presented for differential-drive robots navigating static polygonal environments, aligned with smart-city service robotics where endurance and safety must be co-optimized. The combination of an interpretable energy proxy, exact polygonal clearance checks, and dominance-based constraint handling yields robust feasible trajectories without ad hoc penalty tuning. Future work will integrate platform-specific calibration of energy coefficients from measured power profiles and extend the formulation to time-parameterized control optimization while maintaining polygonal safety guarantees.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165656: ISO-Based Smart City Assessment as an Urban Management Tool: Comparing the Connected Smart Cities Frameworks of 2024 and 2025

Leandro Teófilo Pinto Dos Reis^{1,2,*}, **João Vítor Piagem Pereira**¹, **Michael Israel Sousa Santos**¹, **Charles Jefferson Rodrigues Alves**^{3,4} and **Regina Negri Pagani**^{2,5}

¹ Federal Institute of Education, Science and Technology of Tocantins (IFTO), Paraíso do Tocantins, Brazil

² Graduate Program in Production Engineering, Federal University of Technology – Paraná (UTFPR), Ponta Grossa, Brazil

³ Federal Institute of Education, Science and Technology of Tocantins (IFTO), Araguaína, Brazil

⁴ Graduate Program in Production and Systems Engineering, University of Vale do Rio dos Sinos (UNISINOS), São Leopoldo, Brazil

⁵ Research Unit on Governance, Competitiveness and Public Policies (GOVCOPP), University of Aveiro, Aveiro, Portugal

The assessment of Smart City performance has progressively evolved from competitive benchmarking-based assessment exercises toward evaluation models grounded in internationally recognized standards of sustainability, resilience, and governance. In Brazil, this evolution is clearly reflected in the methodological transition between the 2024 and 2025 editions of the Connected Smart Cities (CSC) Ranking, the country's most comprehensive smart city intelligence ecosystem. This study examines this transition as a fundamental shift in the philosophy of urban assessment, moving from a logic of peer-based competitive comparison to one centered on adherence to international quality benchmarks. The objective is to analyze how this normative turn reshapes urban governance frameworks and management practices, with a particular emphasis on energy planning as a strategic dimension of smart and sustainable cities. The 2024 edition of the CSC Ranking was based on a weighted, comparative assessment grounded in the Market Quality Index (Índice de Qualidade Mercadológica, IQM). In this model, urban performance was assessed relative to the observed maximum and minimum values within the group of analyzed cities, comprising 656 municipalities with populations above 50,000 inhabitants. Indicators were assigned differentiated relevance weights ranging from 0.5 to 1.0, enabling the ranking framework to capture structural interdependencies among thematic axes while emphasizing competitiveness and relative positioning. Within this structure, the energy axis did not receive an independent ranking, as it comprised only four indicators mainly related to renewable energy sources and intelligent public lighting, resulting in limited analytical density and reduced applicability to strategic urban management. The 2025 edition introduces a paradigmatic methodological shift by adopting a normative, non-weighted, and universal assessment framework. The new CSC model expands its territorial scope to all 5,575 Brazilian municipalities and is explicitly grounded in ISO 37120 (urban services and quality of life), ISO 37122 (smart cities), ISO 37123 (resilient cities), and ISO 37125 (ESG indicators for cities). Rather than ranking cities based on relative performance, the 2025 framework assesses absolute performance by measuring each municipality's distance from predefined reference values or targets established by international benchmarks, such as those proposed by the United Nations (UN) and the World Health Organization (WHO). Methodologically, this shift entails adopting a simple arithmetic mean to calculate overall and thematic scores, assigning equal weight to all 75 indicators. This design choice aims to improve the transparency, communicability, and accessibility of results for a broad audience, including public managers, policymakers, and civil society. Scores are standardized on a 0–100 scale, with 100 representing full achievement of the reference value. As a result, the CSC 2025 framework primarily serves as a diagnostic and management-orientated assessment tool, focusing on progress toward global standards rather than on relative competition among municipalities. The implications of this transition for urban governance and management are substantial. First, the universal coverage of municipalities transforms the CSC framework into a nationwide monitoring instrument capable of revealing structural disparities across regions and city sizes. Second, alignment with ISO standards and the Sustainable Development Goals (SDGs)

enhances international comparability and strengthens the credibility of urban data, potentially increasing cities' attractiveness for investment and international cooperation. Third, integrating the MySmartCity platform enables continuous monitoring of indicators, supporting interdepartmental coordination and evidence-based decision-making. Finally, the distinction between ranking and certification becomes explicit: while the CSC provides comparative diagnostics, standards-based certification processes focus on verifying data quality and methodological conformity, allowing municipalities to evolve through certification levels without normative judgment of performance. Energy planning emerges as one of the most relevant dimensions affected by this methodological shift. In the 2025 framework, energy becomes a ranked thematic axis supported by ISO-based indicators that capture multiple facets of urban energy systems. These include decentralized energy generation, measured as the proportion of locally produced electricity relative to total consumption; energy efficiency, assessed by final energy consumption per capita; and electromobility infrastructure, evaluated by the availability of electric vehicle charging stations. This expanded treatment positions energy not merely as a technical subsystem but as a strategic component of integrated urban management, closely linked to climate resilience, mobility systems, environmental performance, and governance practices. Despite the move toward a more normative structure, the CSC 2025 model preserves the foundational principle of sectoral interdependence that characterized earlier editions. Urban development is understood as a holistic process in which improvements in one domain, such as energy or sanitation, generate cascading effects across health outcomes, economic productivity, and social well-being. This interconnected perspective is reinforced by consolidating related themes into broader thematic axes, fostering integrated policy analysis and coordinated urban management. Overall, the transition from CSC 2024 to CSC 2025 represents a significant maturation in the assessment of Brazilian cities, redirecting urban governance frameworks and management practices toward systematic alignment with internationally recognized sustainability and quality benchmarks.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165917: AIoT-Driven Smart Public Lighting as a Cybernetic Infrastructure for Environmental and Climate Justice

John Taborda¹, Miguel Iglesias^{2,*} and Pedro Fernandez de Cordoba²

¹ Facultad de Ingeniería, Universidad del Magdalena, Santa Marta, Colombia

² Instituto Universitario de Matemática Pura y Aplicada, Universitat Politècnica de València, Valencia, España

Urban energy infrastructures are increasingly called upon to play a dual role: ensuring energy efficiency while simultaneously supporting environmental monitoring, climate adaptation, and inclusive governance. However, most smart city implementations continue to treat public lighting systems as isolated technological upgrades, rather than as systemic infrastructures capable of enabling participatory environmental intelligence. This paper addresses this gap by proposing a novel cybernetic framing of smart public lighting as a strategic AIoT-enabled infrastructure for environmental and climate justice within smart cities. The study responds to the need for integrated, scalable, and governance-oriented approaches that connect energy efficiency, environmental risk management, and open data-driven participation in the context of sustainable urban transitions.

The proposed approach introduces an AIoT-based cybernetic framework grounded in the Viable System Model (VSM) to reconceptualize smart public lighting networks as viable socio-technical systems. Methodologically, the framework integrates distributed environmental sensing embedded in public lighting infrastructure with AIoT data pipelines, edge-cloud processing, and open data platforms. The VSM is employed as an organizing meta-framework to structure system viability across five functional domains: System 1 (operational environmental sensing and energy-efficient lighting control), System 2 (coordination and data harmonization across distributed nodes), System 3 (operational control, performance monitoring, and resource optimization), System 4 (environmental intelligence, risk anticipation, and adaptive planning), and System 5 (policy, governance, and alignment with environmental justice objectives). This cybernetic architecture enables continuous feedback loops between energy infrastructure performance, environmental data production, and participatory governance mechanisms, operationalizing open science principles within urban management.

The results are presented at a conceptual and methodological level, demonstrating how the proposed framework advances beyond conventional smart lighting and urban monitoring paradigms. The framework articulates smart public lighting as a dual energy-environmental infrastructure capable of simultaneously improving energy efficiency, expanding high-resolution environmental monitoring, and enabling data-driven participation by local stakeholders. By embedding AIoT sensors within existing lighting assets, the model reduces marginal energy and infrastructure costs while increasing spatial coverage and temporal resolution of environmental data. The integration of open data and interoperable architectures supports transparency, accountability, and community engagement, transforming environmental monitoring from a purely technical function into a governance instrument. From a cybernetic perspective, the explicit mapping of VSM functions clarifies roles, feedback mechanisms, and decision pathways, strengthening system resilience and adaptive capacity in the face of environmental and climatic uncertainty.

The paper concludes that AIoT-driven smart public lighting, when designed as a cybernetic infrastructure, constitutes a powerful lever for smart cities seeking to align energy transition goals with environmental and climate justice. The proposed framework contributes theoretically by extending cybernetic governance models into the domain of urban energy infrastructure, and methodologically by offering a transferable blueprint for participatory, data-driven environmental management. As an initial case of application, the framework is contextualized through the Hub Ambiental del Caribe as an early methodological reference in the Caribbean region of Colombia, illustrating its relevance for cities facing environmental vulnerability and governance challenges.

The approach provides a robust foundation for future empirical validation and positions smart public lighting networks as key enablers of sustainable, just, and resilient urban transitions.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166415: Artificial Intelligence, Digital Twins, and Data-Driven Decision Support for Urban Energy Management in Zambian Cities

Kachana Kasulu

Independent Researcher, Kitwe, 10101, Zambia

Introduction

Urban energy management in Zambia is experiencing both a pressing demand for energy infrastructure expansion and a potential for innovative, data-driven solutions. As it stands, only 43% of the Zambian population is connected to the national power grid, with an urban-rural divide of 67% and 14.5%. Over-reliance on hydropower, which accounts for about 80% of the country's electricity, represents a critical vulnerability to climate change. A severe drought in the 2023/24 period led to an 80% reduction in electricity production from Lake Kariba, leaving Lusaka residents with up to 20 hours of daily power outages. This has led to a need for smarter energy management systems that can optimise limited resources, anticipate energy needs, and incorporate distributed renewable energy sources. The National Digital Transformation Strategy 2023–2027 and Vision 2030 framework have laid the foundation for AI adoption, digital twin technologies, and data-driven decision support systems. The Ministry of Technology and Science has stated that 'digital transformation is as much about technology as it is about people, equality and the just distribution of resources and sustainable development.' This paper will investigate the feasibility, implementation considerations, and contextual adaptation required for the use of AI to support urban energy management systems in Zambia, focusing on aspects such as solar photovoltaic (PV) integration, demand-side management, and smart grid frameworks.

Methods

The study was conducted through a literature review, document review, and case study analysis. The literature review focused on AI in smart energy systems, digital twins for infrastructure management, and smart city projects in Sub-Saharan Africa. The document review focused on Zambia's National Energy Policy, National Digital Transformation Strategy, Integrated Resource Plan, and related regulations and policies for electricity generation and distribution. Case study analysis covered smart energy projects in Africa, including Kenya's renewable energy diversification, Rwanda's smart grid pilots, and Zambia's Smart Village project. Findings were synthesised and presented under four thematic areas: technological readiness and infrastructure; institutional and regulatory frameworks; human capacity and skills; and financing and investment. Attention was given to digital twin modelling for Zambia's electricity distribution grid and to the evaluation of machine learning algorithms for solar irradiance prediction, given Zambia's high solar resource.

Results

There are strong opportunities for AI solutions in the Zambian energy management space, but multiple challenges remain for project implementation. Machine learning models for load forecasting, particularly for shorter horizons, have established technical viability; this capacity to model and predict load behaviour on the grid enables more efficient management of generation units. Digital twin technology has strong applications for network simulation in Zambian cities, particularly Lusaka, enabling scenario modelling such as fault analysis, technical loss quantification, and network reconfiguration without physical intervention. Solar irradiance prediction tools for distributed solar photovoltaic (PV) integration are highly beneficial to Zambia's national target of 1,000 megawatt (MW) solar PV capacity by 2025 and the related task of addressing solar PV generation intermittency. Local challenges that persist in the context of AI include low internet penetration in peri-urban environments, limiting the viability of IoT-connected sensor nodes; skill and experience gaps in local human capital, resulting in a bottleneck for system upkeep and tuning of machine learning models; and a lack of financial capital to deploy these use cases, such as smart meter rollouts. National fibre coverage for smart city projects across Lusaka

and other major cities, such as those aligned with DTRA's smart poles, which include micro base stations and 4G/5G connectivity, provides a technological foundation for scaling up but is not yet broad enough to be deployed outside business districts. The UNDP initiative, Timbuktoo AI Compute Nodes, aims to provide nations in Africa, including Zambia, with their own sovereign AI computer cloud powered by renewable energy and could set precedents for regional and local AI capacity-building that integrate environmental and sustainability goals. Policy development for data privacy and security is needed, as well as regulation for decentralised models such as peer-to-peer energy trading.

Conclusions

Incorporating AI, digital twins, and data-driven decision support into ZESCO's operations is a forward-thinking approach that can potentially revolutionise urban energy management in Zambia. These technologies promise to optimise energy distribution and consumption, even within the constraints of existing infrastructure, while also facilitating large-scale integration of renewable energy. This can be achieved through a combination of strategic actions, including the deployment of smart grid technologies, investment in human capital, modernisation of regulatory frameworks, and mobilisation of innovative financing mechanisms. Immediate priorities could include establishing pilot digital twin projects for specific urban distribution networks, developing machine learning models tailored to Zambian load and generation data, and building technical capacity within ZESCO and municipal authorities. Leveraging international partnerships and knowledge transfer can also expedite progress while ensuring contextual relevance. As Zambia advances towards its Vision 2030 development goals, intelligent energy systems are not just technological enhancements but fundamental drivers of inclusive and sustainable urban growth.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170261: Digital Twins for Integrated Energy and Structural Performance Assessment of Buildings: A Systematic Review and Research Gap Analysis

Muhammad Khubaib

Department of Civil Engineering University of Engineering and Technology, Peshawar, Pakistan

Although urban structures are essential to achieving sustainability, resilience, and public safety objectives, energy performance and structural integrity are still predominantly evaluated using discrete analytical frameworks. This fragmented approach limits holistic lifecycle decision making and reduces the effectiveness of retrofit strategies. Digital twin (DT) technology, supported by Internet of Things (IoT) sensing, Building Information Modeling (BIM), and data-driven analytics, offers a promising paradigm for integrated building performance assessment. However, despite the rapid growth of DT applications, there remains a lack of consolidated evidence on the joint implementation, validation, and operationalization of energy and structural assessment within unified DT frameworks. Unlike prior reviews that primarily focus on single-domain applications, this study presents a systematic review and research gap analysis of DT-based approaches for integrated energy and structural performance evaluation of buildings.

A systematic literature review was conducted following PRISMA guidelines. A total of 1,248 records were identified from Scopus, Web of Science, and IEEE Xplore using structured keyword combinations including “digital twin,” “BIM,” “energy performance,” “structural health monitoring,” and “building assessment” for the period 2015–2025. After removing duplicates ($n = 312$) and applying title–abstract screening ($n = 936$), 214 articles were assessed for full-text eligibility, resulting in 82 studies included in the final synthesis. The selected studies were analyzed using a combined thematic and quantitative synthesis framework covering DT architectures, BIM integration, energy simulation techniques, structural analysis approaches, sensor-data assimilation, and validation strategies.

The results indicate that, while 68% of studies focus on energy performance optimization and 54% on structural health monitoring, only 17% propose partially integrated frameworks, and fewer than 8% demonstrate fully interoperable co-simulation environments. Data exchange between energy and structural domains remains limited, with only 12% of studies enabling bidirectional coupling. Validation practices are largely scenario-based (approximately 70%), with minimal real-time or long-term field validation. Furthermore, only 9% of studies address district- or network-scale DT implementations. Key methodological challenges include BIM standardization, interoperability across simulation platforms, uncertainty quantification, lifecycle scalability, and computational efficiency.

This review advances beyond existing surveys by providing one of the first quantitatively grounded and integration-focused syntheses explicitly addressing the coupling of energy and structural domains within DT frameworks, alongside a structured evaluation of interoperability mechanisms and validation maturity levels. The findings highlight that integrated digital twin development remains an emerging research frontier. Future progress depends on AI-driven surrogate modeling, robust IoT-enabled real-time data synchronization, cloud-based co-simulation infrastructures, and multi-objective optimization frameworks. This study establishes a comprehensive evidence base and research agenda to support the development of scalable, lifecycle-aware, and resilient digital twins for sustainable and structurally robust built environments.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171106: Energy-Aware Urban Management for Smart Mobility: Coordinating Transport Operations, Edge Computing, and Public Value

Han Xiang Guo * and Wai Ye Leong

Faculty of Business, INTI International University, Nilai 71800, Malaysia

Smart mobility is often assessed through congestion relief and travel-time indicators, but urban managers operate within a coupled system in which transport operations, digital infrastructure, and energy goals shape one another. The coupling becomes harder to ignore as electrification expands and as cities are asked to report carbon outcomes alongside service reliability in reporting cycles. Analytics-enabled control may lower energy use indirectly when stop-start driving is reduced, average speeds are stabilised, and bus operations become more predictable, which changes traction energy demand and idling losses. At the same time, sensors, communications, and cloud-edge processing draw power continuously, and their lifecycle costs are borne by transport agencies even when energy reporting focuses on vehicles alone.

This study treats city-scale intelligent transportation platforms as an energy-aware urban service system and examines how energy considerations are translated into management practice. A comparative case-study design is applied to Hangzhou, Singapore, and Kuala Lumpur, where different delivery logics (platform-centric public-private delivery, government-led reliability management, and multi-agency coordination under compound risks) have been used to scale data-driven operations. Evidence is triangulated from policy documents, implementation reports, and peer-reviewed studies, and it is interpreted with attention to indicator definitions, baselines, and reporting scope.

What makes similar tools produce different energy and service outcomes? Three management mechanisms are traced. One concerns the local performance regime: which targets are set (delay, reliability, energy or CO₂), how objectives are weighted, and how distributional effects are checked when reported gains concentrate on selected corridors or user groups. Another concerns lifecycle governance for digital infrastructure. Low-latency operation is often supported through edge deployment near intersections, yet distributed hardware increases power draw and maintenance work, especially when models must be monitored and updated under drift. A third mechanism concerns coordination with energy actors, since EV charging peaks, pricing, and demand response can be affected by routing and signal policies that shift load in time and place.

Reported differences are interpreted through these managerial conditions, while recurring constraints are acknowledged. Metric heterogeneity, vendor dependency, and limited independent benchmarking reduce cross-city comparability and make causal claims difficult to sustain when evaluation windows and definitions vary.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166409: Integrated Urban Energy Systems: Smart Grids, Microgrids, and District-Level Energy Optimisation

Kachana Kasulu

Independent Researcher, Kitwe, 10101, Zambia

Introduction

In the face of rapid global urbanisation, the need for sustainable energy systems and infrastructure is becoming increasingly pressing. Cities now host over 50% of the global population and account for around 75% of primary energy consumption and 80% of anthropogenic greenhouse gas emissions. As urban energy demands continue to grow, conventional centralised grid infrastructure, with its one-way power flows and relatively inefficient energy transmission and distribution, is struggling to keep up with the evolving needs of cities and their inhabitants. Integrated urban energy systems, including smart grids, microgrids, and district-level energy optimisation systems, are emerging as a potential solution to these challenges, with their potential to enhance energy efficiency, flexibility, and resilience while simultaneously reducing environmental impact. Smart grids are electric power grids that utilise information and communication technologies to optimise electricity flow, facilitate two-way power flows, and provide grid stability and reliability, even in the presence of variable renewable energy sources. Microgrids, on the other hand, are localised energy systems that can operate in both grid-connected and islanded modes, integrating distributed energy resources, such as solar PV, energy storage, and controllable loads, to provide improved reliability and autonomy. At a larger scale, district-level energy optimisation involves coordinating energy systems and infrastructure at the neighbourhood level to enable energy management and optimisation across multiple buildings, transport systems, and infrastructure. This paper provides a detailed analysis of the various aspects of integrated urban energy systems, including their technologies, architectures, operations, challenges, and implementation strategies, with a focus on demand-side management, peer-to-peer energy trading, and the coordination of DERs in urban electric grids.

Methods

The paper uses a mixed-methods approach, integrating a systematic literature review with a comparative case-study analysis to provide a comprehensive overview of the state of the art in urban energy systems. The research comprises three key elements. First, a bibliometric review was conducted to identify peer-reviewed articles on smart grids, microgrids, and the optimisation of urban energy systems from 2018 to 2025. Second, a content analysis of the identified literature was conducted to map technological solutions and implementation strategies. This analysis categorises findings into five key thematic areas: (i) grid modernisation and smart grid technologies; (ii) microgrid and distributed energy resource (DER) integration; (iii) demand response and demand-side management (DSM); (iv) peer-to-peer (P2P) energy trading and local energy markets; and (v) district energy planning and positive energy districts (PEDs). Third, selected case studies of deployed urban energy systems were analysed to understand their performance metrics and operational insights, including the Brooklyn Microgrid pilot project, the Amsterdam Smart Grid program, and European Positive Energy District projects. The assessment framework combines quantitative measures such as energy efficiency gains, peak load shaving, and carbon emission reductions with qualitative evaluations of policy frameworks, stakeholder participation, and enabling regulations.

Results

A key finding from the literature is that, while significant technological progress has been made in integrated urban energy systems, several implementation barriers remain. The reliability and integration of renewable energy in smart grids have shown measurable improvement, and smart meters and other AMI technologies have provided real-time visibility into the urban electric grid. Energy resilience has also improved in microgrid systems, and it has been shown that optimal

control of a group of microgrids can enhance the self-consumption of locally produced renewable energy. The benefits of peer-to-peer energy trading have been discussed, and the use of blockchain smart contracts to manage local energy sharing has been proposed to improve prosumers' energy balance within the urban energy system. Demand-side management strategies, including real-time pricing and incentive-based demand response, have been effective in flattening cities' load curves. District-level optimisation, particularly in the form of Positive Energy Districts aiming for net-zero energy districts, is a feasible strategy when high-efficiency buildings are combined with on-site renewable energy generation and advanced energy management systems. Some of the barriers identified include a lack of regulations aligned with the decentralised nature of smart energy systems, interoperability issues across diverse devices, cybersecurity risks, and social equity concerns.

Conclusions

Smart grids, microgrids, and district-level optimisation are three types of integrated urban energy systems that are crucial to the transition towards sustainable, climate-neutral cities. However, for these systems to be implemented at scale, several prerequisites must be met. These include advancements in technology, supportive policies and regulations, financial incentives, and stakeholder collaboration. In the near future, research should focus on the challenges and opportunities of integrated urban energy systems, including the scalability of successful pilot projects, standardisation of interoperability protocols, integration of artificial intelligence and machine learning for predictive energy management, and inclusive governance models to ensure equitable access to the benefits of these systems for all segments of urban populations.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165958: Parallel Metaheuristic-Based Optimization for Electric Vehicle Charging Station Integration and Sizing in Distribution Systems

Luis Fernando Grisales-Noreña^{1*}, Daniel Sanin Villa² and Oscar Danilo Montoya Giraldo³

¹ Grupo de Investigación en Alta Tensión–GRALTA, Escuela de Ingeniería Eléctrica y Electrónica, Universidad del Valle, Cali 760015, Colombia

² rea de Industria, Materiales y Energía, Universidad EAFIT, Medellín 050022, Colombia

³ Grupo de Compatibilidad e Interferencia Electromagnética (GCEM), Facultad de Ingeniería, Universidad Distrital Francisco José de Caldas, Bogotá 110231, Colombia

Currently, the massive integration of electric vehicles (EVs) into the global mobility market has generated a growing and urgent need for the adequate planning, integration, and sizing of Electric Vehicle Charging Stations (EVCSs) within Distribution Systems (DSs). The primary objective of this integration is to maximize the available charging capacity while preserving the secure and reliable operation of the electrical network. However, the large-scale deployment of EVCS introduces a substantial increase in power demand, which can significantly affect grid performance. In particular, higher charging penetration levels intensify operational stresses on the distribution infrastructure, leading to potential violations of voltage regulation limits, thermal constraints of distribution lines, among others.

From a modeling perspective, the integration and sizing of EVCS constitute a highly complex optimization problem. This complexity arises from the nonlinear nature of power flow equations governing distribution systems, as well as from the coexistence of discrete decision variables, associated with the location of EVCS within electrical system, and continuous decision variables, related to their charging capacities. As a result, the problem is naturally formulated as a Mixed-Integer Nonlinear Programming (MINLP) problem, which is known to be computationally challenging, especially for large-scale networks and realistic operating scenarios.

To effectively address this challenge, it is essential to develop an accurate mathematical model that captures both the electrical behavior of the distribution system and the operational characteristics of EVCS. Moreover, the solution of such a model requires the use of high-efficiency optimization techniques capable of handling nonlinearity, mixed decision variables, and large solution spaces. In this context, this work proposes a comprehensive optimization framework for the integration and sizing of EVCS in distribution systems, with the objective of maximizing the total charging capacity while strictly satisfying all operational constraints of the DS under EVCS-intensive conditions.

As solution strategies, parallel implementations of Particle Swarm Optimization (PSO), a Population-based Continuous Genetic Algorithm (PGA), and Monte Carlo methods are employed. These methodologies are evaluated using a benchmark 33-bus distribution system, considering realistic variability in both photovoltaic (PV) generation and load demand. Each algorithm is executed 100 independent times to assess solution quality, robustness, repeatability, and computational efficiency, enabling a fair comparison and the identification of the most suitable approach for solving the proposed optimization problem.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166181: Social responsibility of energy companies under the sign of the twin transition. The European perspective

Mirela Panait^{1,*}, Cătălin Popescu¹, Daniel George Surdu² and Adrian George Foghiș²

¹ Petroleum-Gas University of Ploiesti, Ploiești, Romania

² Romanian Academy, School of Advanced Studies of the Romanian Academy, Doctoral School of Economic Sciences, National Institute for Economic Research “Costin C. Kirițescu”, Institute of National Economy, Bucharest, Romania

The paper examines how energy companies integrate social responsibility into the twin transition, defined as the simultaneous shift toward a low-carbon economy and deep digitalization, and argues that CSR must evolve from peripheral compliance to a core strategic imperative in this context. The study combines conceptual analysis with evidence from recent industry data on renewable energy expansion, digital investments (AI, IoT, smart grids, data analytics) and corporate ESG practices, highlighting how environmental, social and digital ethics intersect in corporate strategies. It explores four key dimensions: environmental stewardship beyond carbon (biodiversity, water, circular economy, waste reduction), community and stakeholder engagement, data privacy and cybersecurity for critical infrastructure, and innovative financing mechanisms (green bonds, sustainability funds, shared value models) that can support responsible transition pathways.

Methodologically, the paper advances a staged implementation framework that connects assessment, planning, implementation and evaluation in a continuous learning cycle, thereby making explicit the causal links between strategic intent, operational change and observed socio-environmental outcomes in the context of the twin green-digital transition. Within this framework, the assessment phase combines diagnostic tools on digital maturity, climate risk exposure and stakeholder expectations, while the planning phase translates these diagnostics into integrated portfolios of low-carbon and data-driven investments that are aligned with evolving ESG standards and regulatory trajectories. The analysis further systematizes typical implementation challenges into financial, institutional and socio-political categories, emphasizing how high transition costs, regulatory complexity and tensions between short-term shareholder value and long-term sustainability commitments interact to slow down or derail transformation processes. Empirically, the findings indicate that firms which embed social responsibility into the core of their governance architectures, risk management systems and digital innovation strategies develop more robust capabilities to secure and reproduce their social license to operate under tightening climate and digital regulation. In these firms, digital technologies are mobilized not only for efficiency gains, but also for enhanced transparency, participatory engagement and real-time monitoring of environmental and social impacts, which in turn supports higher levels of stakeholder trust and perceived corporate credibility. The paper proposes an integrated outlook in which environmental, social and digital ethics are treated as mutually reinforcing components of a unified governance paradigm for energy companies, rather than as separate or competing agendas. By adopting this unified normative basis, energy firms can reposition themselves as key enablers of a just and inclusive twin transition, leveraging their infrastructural, financial and data capabilities to support decarbonization, social protection and fair access to digital and energy services, especially for vulnerable groups.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166182: Universities as key actors in the green transition ecosystem. Romanian perspective

Mirela Panait^{1*}, **Manuela Rozalia Gabor**², **Ștefan Virgil Iacob**¹, **Marian Cătălin Voica**¹ and **Mădălina Sămărghișan-Sîrbu**³

¹ Faculty of Economic Sciences, Petroleum-Gas University of Ploiesti, Ploiesti, 100680, Romania

² ED1 - Economic Science Dep/ Faculty of Economics and Law, "George Emil Palade" Univ. of Medicine, Pharmacy, Science and Technology of Targu Mures, Targu Mures, 540369, Romania

³ Romanian Academy, School of Advanced Studies of the Romanian Academy, Doctoral School of Economic Sciences, National Institute for Economic Research "Costin C. Kirilescu", Institute of National Economy, Bucharest, Romania

The paper analyses the role of universities as key actors in the green transition ecosystem, focusing on the interface between smart cities, urban management and different stakeholders. From a multi-level governance perspective, universities are approached as nodes of knowledge, innovation and policy co-creation, capable of integrating the objectives of decarbonisation, urban resilience and digitalisation into local development strategies. The study examines three main dimensions: (1) the university as a provider of scientific expertise and data for smart urban planning; (2) the university as a facilitator of green innovation and technology transfer, through urban living labs, innovation hubs and public-private partnerships; (3) the university as a normative and educational actor, forming green and digital competences for local administrations, businesses and citizens. In the cities included in the European mission "100 climate neutral cities", local universities provide expertise for energy transition plans, decarbonization scenario assessments and green mobility solutions. In addition, in Romania, universities participate in national platforms and initiatives such as "The Future of Energy", where industry experts and academics contribute to the debate and co-design of policies for the transition to renewable sources alongside the younger generation. Various universities in Romania are involved alongside energy companies in national and European projects aimed at deeply modernizing energy systems through advanced technologies and interdisciplinary solutions regarding smart grids, energy storage, energy-efficient buildings and the digitalization of energy systems. The methodology combines conceptual and policy analysis with case studies on university initiatives integrated into smart city strategies and local climate action plans. The results highlight that universities can function as orchestrators of the green transition ecosystem, accelerating the integration of digital and sustainable solutions in urban management, with direct impact on the quality of governance, community participation and environmental performance at the urban level. In this role, universities operate as intermediary institutions that connect local authorities, businesses, civil society and technology providers, facilitating dialogue, co-creation and experimentation around low-carbon, resource-efficient and data-driven urban solutions. By leveraging their research capacities, living labs and interdisciplinary expertise, they help translate climate and digital strategies into concrete pilot projects, decision-support tools and evidence-based policies that can be scaled across the city.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166419: Urban Mobility Electrification and Sector Coupling for Sustainable City Ecosystems in Zambia

Kachana Kasulu

Independent Researcher, Kitwe, 10101, Zambia

Introduction

Zambia's growing urban areas face several mobility issues. Lusaka, the capital city of Zambia, has an urban population of over 2.5 million, with an urban growth rate of 4.9%. Rapid urbanisation, population growth, and motorisation are major issues to be considered in Lusaka to develop a sustainable transport sector. In Lusaka, 65% walk to their destinations, 23% use minibuses or taxis, 10% use private vehicles, and only 2% use bicycles. The data from this survey highlight the accessibility issues faced by residents, as well as important opportunities for sustainable change if the public transport system is electrified. Zambia does not have a specific strategy for electrifying transport. The 2019 National Transport Policy and the Eighth National Development Plan (2017-2021) have no sections dealing with the adoption of electric vehicles or charging infrastructure. On the other hand, the energy sector in Zambia is being restructured. A target of 1,000 megawatts (MW) of solar power generation capacity by 2025 is part of the country's aim to reduce its vulnerability to climate change due to its over-dependence on hydropower. Transport electrification and renewable energy growth have the potential to result in sector coupling, in which the integration of mobility, buildings, and energy can yield beneficial systems that improve urban areas.

Methods

The study utilized policy landscape analysis, techno-economic evaluation, and comparative case studies. Through policy analysis, we reviewed Zambia's National Transport Policy, National Energy Policy, the Eighth National Development Plan, and urban development strategies for Lusaka and other cities to identify regulatory drivers and barriers for e-mobility. The techno-economic analysis compared costs of electric vehicles (EVs) and internal combustion engine (ICE) vehicles for applications such as public transport buses and passenger cars, using data on electricity rates, fuel costs, and incentives. Comparative case studies examined electric bus initiatives from African nations, including Kenya's BRT system and South Africa's electric minibus pilots, to identify applicable lessons for Zambia. Sector coupling was explored through scenario modelling involving vehicle-to-grid technologies and solar-powered charging stations. Stakeholder interviews with members of the Zambian Electric Mobility and Innovation Alliance, government entities, utilities, and transport operators provided insights into priorities and challenges in the e-mobility landscape.

Results

The present assessment has identified Zambia's specificities and barriers in deploying electric mobility. Policy instruments already implemented by the Zambian government have proven effective: the removal of import duties on EVs increased the number of registered electric vehicles by more than 300% in two years. The inclusion of Zambia in regional EV value chains, such as the tripartite agreement signed by Morocco, DR Congo, and Zambia, represents a means of localising content and stimulating technology transfers. A Total Cost of Ownership analysis shows that EV buses can be economically competitive with diesel buses in Zambia: the lifetime operational cost savings from electrification offset the higher capital cost. Sector coupling with Zambia's power sector, where solar PV deployment is on the rise and electricity networks are still developing, shows major potential for EVs in Zambia, which could help them serve as distributed energy storage units. Among the elements that could hold back further scale-up of electric mobility in Zambia are infrastructure-related factors. The charging infrastructure is still embryonic. The number of public charging points is low, and they are mainly located in Lusaka. The analysis of the barriers to the ZAMBIAeMOBILIZE project also identified barriers related to access to

finance, a lack of technical capacity for charging infrastructure maintenance or installation, and a lack of grid connection capacity at locations where charging stations could be installed. Non-motorised transport requires better infrastructure and integrated action to close the missing link between homes and the electrified public transport systems. The NMT Strategy was adopted in 2019, but no further action has been taken to support its deployment, mainly due to a low investment in this mode and a lack of enforcement of the NMT standards.

Conclusions

Electrification of transport is a priority in urban areas where, when combined with integrated land use, urban transport, energy, and building sector planning, it can help Zambia achieve multiple development objectives, including increased mobility, better air quality, climate change mitigation, and a resilient energy sector. Zambia can move towards e-mobility by i) developing and updating transport and other related policies to mainstream electric mobility and EV charging; ii) leveraging concessional finance to procure electric buses and charging infrastructure; iii) enhancing technical skills to maintain the vehicles and manage the grid; iv) planning and investing in non-motorised transport to ensure last mile connectivity for users; and v) electrifying public transport that is used on high-frequency routes in Lusaka. Zambia could prioritise installing EV charging infrastructure at existing or new solar power stations and pilot vehicle-to-grid services. Zambia's rich critical minerals for battery production and value chain linkages with its neighbours can enable the country to tap into electric mobility markets.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Session 5. Advanced Energy Materials

sciforum-171124: Bimetallic Transition-Metal Supported Biomass-Derived Carbon Catalyst for Efficient Hydrazine Oxidation

Huma Amber^{1*}, **Karina Vjūnova**¹, **Dijana Šimkūnaitė**¹, **Zenius Mockus**², **Aleksandrs Volperts**³, **Ance Plavniece**³, **Galina Dobeļe**³, **Aivars Zhurinsh**³, **Loreta Tamasauskaite-Tamasiunaite**⁴ and **Eugenijus Norkus**¹

¹ Department of Catalysis, Center for Physical Sciences and Technology (FTMC), Vilnius 10257, Lithuania

² Department of Chemical Engineering and Technology, Center for Physical Sciences and Technology (FTMC), Vilnius 10257, Lithuania

³ Latvian State Institute of Wood Chemistry, Dzerbenes Str. 27, LV-1006 Riga, Latvia

⁴ Department of Catalysis, Center for Physical Sciences and Technology (FTMC), Sauletekio Ave. 3, Vilnius, Lithuania

Direct hydrazine fuel cells (DHFCs) have attracted significant interest as a promising method for sustainable hydrogen production, as they can overcome the slow oxygen evolution rate that limits conventional water splitting. The practical deployment of DHFCs is strongly dependent on the availability of cost-effective and efficient anode electrocatalysts for the hydrazine oxidation reaction (HzOR). The current study proposes a straightforward, scalable, and ecologically sustainable approach to the synthesis of non-noble metal electrocatalysts derived from sustainable biomass resources. The synthesis of nitrogen-doped carbon (N-C) was achieved through a hydrothermal carbonisation (HTC) process, utilising birchwood chips. This was followed by activation and nitrogen incorporation, yielding a porous, conductive carbon framework. Subsequently, iron (Fe) and manganese-iron (MnFe) were introduced as active components. The morphology, structure, and elemental composition of the MnFe, MnFe/N-C, and Fe/N-C catalysts were characterised by scanning electron microscopy (SEM), X-ray diffraction (XRD), and energy-dispersive X-ray spectroscopy (EDS). The catalytic activity of the catalysts for HzOR was evaluated in an alkaline medium by performing cyclic voltammetry (CV).

Electrochemical investigations have demonstrated that the MnFe/N-C catalyst demonstrates a significantly enhanced HzOR activity, exhibiting a lower onset potential and a substantially higher current density in comparison with both Fe/N-C and MnFe counterparts. The enhanced electrocatalytic performance of MnFe/N-C is attributable to a combination of factors, including the presence of numerous exposed active sites, the optimised mass transport within the porous nitrogen-doped carbon matrix, and the robust synergistic interactions between Mn, Fe, and N-C. The results of this study identify MnFe/N-C as a highly promising anode material for DHFCs. This work offers a viable, cost-effective, and sustainable approach to the design of efficient electrocatalysts that do not utilise noble metals. It provides significant insights into the development of next-generation hydrazine-based energy conversion and hydrogen production technologies.

Acknowledgment

This research was funded by a grant (No. P-ST-23-310) from the Research Council of Lithuania.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166089: CMC-AC-CB-Based Separator-Free Quasi-Solid Supercapacitors: Bifunctional Polymer Architecture Enabling Fluorine-Free Grid-Scale Energy Storage for Decarbonization

Thiago Ferro de Oliveira^{1,2,3,4,*} and **Simoni Margareti Plentz Meneghetti**^{2,3}

¹ Institute of Mathematics, Federal University of Alagoas, Maceió 57072-970, AL, Brazil

² Postgraduate Program in Chemical Engineering, Federal University of Alagoas, Maceió 57072-970, AL, Brazil

³ Catalysis and Chemical Reactivity Group (GCAR), Chemistry Department, Federal University of Alagoas, Maceió 57072-970, AL, Brazil

⁴ Postgraduate Program in Renewable Energies, Federal University of Alagoas, BR-104, Km 85, s/n, Rio Largo - AL, 57100-000, Brazil

Quasi-solid-state supercapacitors (QSSCs) utilizing bio-derived polymers represent a pivotal technology for sustainable energy storage, bridging high power density with environmental compatibility [1]. This study proposes an integrated, sequential layer-by-layer fabrication strategy for QSSCs that exploits the multifunctional properties of carboxymethylcellulose (CMC). This protocol uniquely employs CMC as a bifunctional material, acting simultaneously as a sustainable, biodegradable binder in the electrodes and as the host polymer matrix in the electrolyte [1]. This dual role ensures superior chemical and mechanical compatibility between components [1, 2].

Unlike conventional methods relying on fluorinated binders and toxic solvents, the electrode paste preparation adopts a green aqueous processing route. The formulation adapts the standard 80:10:10 mass ratio of Activated Carbon (AC), Carbon Black (CB), and binder established [3], strategically substituting the conventional binder with CMC. To ensure the integrity of the conductive network, the mixture undergoes ultrasonication (10–30 min); this homogenization step induces cavitation forces critical for uniformly dispersing the amphiphilic CMC and breaking down particle agglomeration, thereby yielding a robust dry electrode with optimized percolation pathways [4, 5].

Device assembly is performed in a single stage directly on metal current collectors. The applied electrode paste undergoes controlled pre-drying at 60–70 °C. This specific thermal range is critical; it is sufficient to evaporate free water (thermal peak onset ≈ 62.76 °C [6]) while strictly preserving coordinated water, which is vital for cation solvation and ionic mobility within the polymer matrix [6, 7]. Subsequently, the highly viscous CMC/Na₂SO₄ gel electrolyte [8] is deposited, followed by the application of the second electrode layer. The resulting sandwich structure is consolidated under a controlled contact pressure of 0.5 MPa [5, 7]. This mechanical compression optimizes interfacial contact by promoting conformal adhesion and filling surface roughness, effectively reducing equivalent series resistance (ESR) without the need for external separators [5, 7].

Finally, device validation employs a comprehensive characterization suite. Structural properties and polymer-salt complexation are investigated via X-ray Diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR) [6]. Surface morphology and electrode/gel interfacial integrity are examined by Scanning Electron Microscopy (SEM) [6]. Thermal stability, free and coordinated water management, and polymer degradation transitions are investigated using Thermogravimetric Analysis (TGA) coupled with Derivative Thermogravimetry (DTG) and by Differential Scanning Calorimetry (DSC) [6, 7]. Electrochemical performance is rigorously evaluated using Electrochemical Impedance Spectroscopy (EIS) across a frequency range of 100 mHz to 10 kHz [8], alongside Cyclic Voltammetry (CV) and Galvanostatic Charge/Discharge (GCD). These assays are designed to confirm operational stability within extended potential windows and validate the efficiency of ionic transport across the quasi-solid interface [8].

This integrated fabrication protocol represents a methodological framework for developing fully bio-derived supercapacitors using CMC in dual functional roles. By consolidating the literature evidence regarding CMC processability, polymer-salt chemistry, and electrochemical

device assembly, this approach offers a rational design strategy for quasi-solid-state energy storage systems. If validated through experimental implementation, this methodology could enable the development of supercapacitors with reduced reliance on fluorinated polymers and synthetic separators, potentially expanding the applicability of bio-derived materials in energy storage and grid-scale applications. The sequential layer-by-layer assembly strategy presented herein provides a foundation for future optimization of bio-based electrochemical device architectures.

References

1. Akhlaq, M., et al.(2023). Carboxymethyl cellulose-based materials as an alternative source for sustainable electrochemical devices: A review. *RSC Advances*, 13(9), 5723–5743. <https://doi.org/10.1039/D2RA08244F>
2. Landi, G., et al. (2022). Electrochemical performance of biopolymer-based hydrogel electrolyte for supercapacitors with eco-friendly binders. *Polymers*, 14(20), 4445. <https://doi.org/10.3390/polym14204445>
3. Demarconnay, L., et al. (2010). A symmetric carbon/carbon supercapacitor operating at 1.6 V by using a neutral aqueous solution. *Electrochemistry Communications*, 12(10), 1275–1278. <https://doi.org/10.1016/j.elecom.2010.06.036>
4. Gordon, R., et al. (2020). Effect of polymeric binders on dispersion of active particles in aqueous LiFePO₄-based cathode slurries as well as on mechanical and electrical properties of corresponding dry layers. *ACS Omega*, 5(20), 11455–11465. <https://doi.org/10.1021/acsomega.0c00477>
5. Xu, L., et al. (2023). Nanocellulose-carboxymethylcellulose electrolyte for stable high-rate zinc-ion batteries. *Advanced Functional Materials*, 33(16), 2302098. <https://doi.org/10.1002/adfm.202302098>
6. Darmawan, D. A., et al. (2023). Fabrication of solid polymer electrolyte based on carboxymethyl cellulose complexed with lithium acetate salt as Lithium-ion battery separator. *Polymer Composites*, 45(1), 273–285. <https://doi.org/10.1002/pc.27902>
7. Tombolesi, S., et al. (2023). A sustainable gel polymer electrolyte for solid-state electrochemical devices. *Polymers*, 15(14), 3087. <https://doi.org/10.3390/polym15143087>
8. Li, Z., et al. (2019). High-energy quasi-solid-state supercapacitors enabled by carbon nanofoam from biowaste and high-voltage inorganic gel electrolyte. *Carbon*, 149, 273–280. <https://doi.org/10.1016/j.carbon.2019.04.056>



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166157: A Finite Element Framework for Assessing Diffusion Length–Thickness (L_d – d) Limitations in MA–FA Mixed Perovskite Semiconductor Absorber Layers for Solar Cells

Nilay Ağaçkesen^{1,*}, Fatma Pinar Gökdemir Choi¹, İbrahim Murat Öztürk², Buse Koçak¹, Şevval Öztürk¹, Pelin Kavak¹ and Hamed Moeini Alishah¹

¹ Department of Physics, Yıldız Technical University, Istanbul, Turkey

² The Scientific and Technological Research Council of Türkiye

The cation composition of metal halide perovskites plays a critical role in determining internal charge carrier dynamics and volumetric recombination within the absorber layer. While methylammonium (MA) based perovskites serve as a foundational baseline, the incorporation of formamidinium (FA) cations has been shown to enhance optoelectronic properties under various environmental conditions [1, 4]. Despite these advancements, the quantitative relationship between specific MA:FA ratios and the resulting carrier survival within the perovskite domain remains a subject of intense research. In this study, the internal generation-recombination balance and its dependence on absorber thickness (d) are investigated using a one-dimensional (1D) finite element method (FEM) framework, strictly validated against champion experimental data obtained from sol-gel fabricated solar cells [5].

Three representative compositions were analyzed: pure MA (MA100), MA-rich (MA70:FA30), and equimolar MA-FA (MA50:FA50). Experimental characterization reveals distinct performance trends across the compositions. The pure MA baseline achieved a power conversion efficiency (PCE) of 14.4% with an open-circuit voltage (V_{oc}) of 1.040 V. In contrast, the MA-rich (MA70:FA30) composition emerged as the champion, reaching a PCE of 18.6% and a V_{oc} of 1.029 V. The equimolar MA-FA composition resulted in a PCE of 14.1% and a V_{oc} of 0.948 V. These results provide the empirical foundation for a numerical assessment of internal loss mechanisms.

The simulation follows a structured two-stage approach. First, specific volumetric recombination rates are extracted by calibrating the model to match the experimental results at the baseline thickness. Second, a systematic thickness sweep is performed to evaluate the carrier collection efficiency. The spatial distribution of SRH recombination obtained from the FEM simulations enables the extraction of a volume-averaged effective carrier lifetime (τ_{eff}). Based on this, the carrier diffusion length is calculated as $L_d = \sqrt{D \cdot \tau_{eff}}$. These calculated diffusion lengths are directly compared with the absorber thickness (d) to explicitly demonstrate diffusion-length-limited ($L_d < d$) and transport-balanced ($L_d \geq d$) regimes [3,7]. This L_d - d comparison establishes a direct quantitative link between observed performance trends and recombination-dominated transport, providing a robust framework for thickness optimization in mixed-cation perovskite photovoltaics [5, 7].

[1] Tress, W. Perovskite Solar Cells on the Way to Their Radiative Efficiency Limit – Insights into a Success Story of High Open-Circuit Voltage and Low Recombination. *Advanced Energy Materials*, 2017, 7, 1602358.

[2] Kirchartz, T.; Staub, F.; Rau, U. Recombination, Collection, and Voltage Losses in Solar Cells. *Physical Review Applied*, 2016, 6, 034003.

[3] Kirchartz, T. Photon Management in Perovskite Solar Cells. *Journal of Physical Chemistry Letters*, 2019, 10, 5892–5896.

[4] Chen, J.; Xu, J.; Xiao, L.; Zhang, B.; Dai, S.; Yao, J. Mixed-Organic-Cation (FA) $_x$ (MA) $_{1-x}$ PbI $_3$ Planar Perovskite Solar Cells with Enhanced Carrier Lifetime and Stability. *ACS Applied Materials & Interfaces*, 2017, 9, 2449–2458.

[5] Gökdemir Choi, F. P.; Güneş, S. et al. A Novel Interface Layer for Inverted Perovskite Solar Cells Fabricated in Ambient Air under High Humidity Conditions. *Solar Energy*, 2020, 209, 400–407.

[6] Berhe, T. A.; Su, W.-N.; Chen, C.-H.; et al. Organometal Halide Perovskite Solar Cells: Degradation and Stability. *Energy & Environmental Science*, 2016, 9, 323–356.

[7] Stranks, S. D.; Snaith, H. J. Metal-Halide Perovskites for Photovoltaic and Light-Emitting Devices. *Nature Nanotechnology*, 2015, 10, 391–40



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170859: Additive Manufacturing Of Energy Materials With Composite Structure

Svetlana Boshnakova

Center of Competence “Intelligent Mechatronic, Eco- and Energy-Saving Systems and Technologies”, Technical University Sofia, branch Plovdiv, 4000 Plovdiv, Bulgaria

Introduction: Waste-to-hydrogen technology requires the involvement of new material development and performance evaluation for Additive Manufacturing (AM). Metal 3D printing is a very good possible alternative and is delivering results visible in the circular economy environment. By using the AM technique, complex operations are avoided when combining the individual components, which is a typical disadvantage in obtaining composite materials; such samples are prepared with only one operation from the starting melt, which is chemically defined. Pyrolysis rotary kiln sealing rings are to be upgraded with several different in microstructure coatings in order to improve the surface performances. The surface topology is aimed to be fine, dense and smooth. Also, the target characteristics are a low friction coefficient and a high hardness value, suggesting enhanced wear resistance. For elevated temperatures, 900 °C is selected for cobalt-based superalloy Stellite types with particle reinforcement.

Method: Two possibilities for advanced materials obtainment are proposed with the Directed Energy Deposition Plasma Arc (DED-arc) and Laser Directed Energy Deposition (DED-LB). The shell of the rotary kiln sealing ring is to be made of stainless steel as the base, with the coating overlayed. Selected mixtures in powder form with defined composition are applied. For the DED-arc, commercially available Stellite 6 (Deloro Stellite® 6, GmbH, Germany) and 20 vol% WC particles with a grain size of 63 - 150 µm were employed. For the DED-LB, we employed TRIBALLOY® T-800 (Kennametal Stellite™) with 25 vol% TiC and a mesh size of -100/+325 (particle diameter between 45 and 150 µm). After the representative samples were metallurgically bonded with the base stainless steel, the relevant properties were obtained.

Results: Manufactured samples are compared in terms of microstructures and mechanical properties. Analysis of structure: Intermetallic carbides that formed on the cobalt basis make the composite harder and increase the plasticity in a defined direction. The hypoeutectic structures of Stellite 6 + 20%WC consist of dendrite and interdendrite eutectic. It is observed that with an increase in WC volume fraction, the size of the dendrites becomes finer and the amount of eutectic structure is increased. For the TRIBALLOY® T-800 with TiC, we obtained relatively smaller grain sizes. The roughness values for the tested samples with WC were initially Ra=0.8 µm, increasing up to Ra=3.44 µm after the wear test, whereas for the TiC, it was slightly lower. Microhardness testing revealed increased values compared to the base stainless steels. Advanced sensor analysis with Acoustic Emission (AE) and Electrical Contact Resistance (ECR) also showed the properties of the new materials.

Conclusion: Customizable coatings with tailored properties were deposited by DED-arc and DED-LB. From the tests performed, a new technological procedure for obtainment is proposed for novel pyrolysis rotary kiln sealing rings. The microhardness, roughness, microstructure and abrasive wear-resistant response of the metallic composite material were examined in order to characterize the stable multiphase system.

Funding: The author acknowledges support from project BG16RFPR002-1.014-0005.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-167096: Band Gap Tunability and Optical Properties of FAPbX₃ and CsPbX₃ Perovskites: A DFT Approach

Preetha S

Department of Physics, Govt. College Kariavattom, Thiruvananthapuram, Kerala, India

The remarkable electrical and optical properties of lead halide perovskites have made them potential materials for next-generation optoelectronic applications. This work uses first-principles density functional theory using Quantum Espresso to conduct a thorough theoretical investigation of the electro-optical properties of hybrid and inorganic perovskites FAPbX₃ and CsPbX₃ (X = Cl, Br, I). Through geometry optimization, the compounds' structural stability is examined, yielding accurate equilibrium lattice parameters for ensuing electronic and optical computations. All compositions show a direct band gap nature, with the band gap values largely reliant on the halide anion, according to calculations of the electronic band structure and density of states. The adaptability of these materials for optoelectronic design is demonstrated by the continuous band gap tuning from the ultraviolet to the visible range made possible by systematic halide replacement.

Calculations of the frequency-dependent dielectric function, absorption coefficient, refractive index, reflectivity, and optical conductivity are used to assess optical characteristics. The findings show a high dielectric response and significant optical absorption in the visible spectrum, suggesting effective light-matter interaction. Lattice expansion and stronger orbital hybridization are responsible for the slightly reduced band gaps and improved optical absorption of FAPbX₃ perovskites when compared to their inorganic counterparts CsPbX₃, according to a comparative analysis. It is discovered that the electro-optical response is extremely sensitive to the halide composition, providing a feasible route for band gap engineering and optimizing optical performance. Furthermore, the calculated optical parameters indicate favorable transparency-absorption trade-offs, which are crucial for efficient optoelectronic device performance. The present theoretical results are expected to serve as a useful reference for future experimental validation and material optimization. This study thus contributes to a deeper understanding of structure-property relationships in lead halide perovskites from a purely first-principles perspective. All things considered, this first-principles investigation offers basic understanding of the electrical structure and electro-optical behavior of FAPbX₃ and CsPbX₃ perovskites. The results highlight the promise of inorganic and hybrid lead halide perovskites for use in photovoltaics, light-emitting devices, and photodetectors and provide theoretical direction for the logical design of high-performance optoelectronic materials.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165898: Compressive Energy Absorption Behavior of Porous Aluminum Structures

Md Salah Uddin

Department of Mathematics and Physics School of Engineering & Physical Sciences North South University
Dhaka, Bangladesh

Lightweight metallic porous materials with high energy absorption efficiency are of increasing interest for advanced energy materials, impact mitigation, and structural protection applications. Such structural and high-performance energy-absorbing materials are mostly used in automotive, aerospace, and protective applications, which drive innovation in metallic foams. Silicon carbide (SiC)-reinforced aluminum alloy (AlSi10Mg) attracts attention across the globe in a variety of areas, ranging from aerospace, automotive, heat exchangers, electronic components, and biomedical implant scaffolds. The porous AlSi10Mg-SiC composite material provides good mechanical properties and wear resistance, and is applied to lightweight structural components and tribological parts. The materials are mostly designed for energy absorption and impact resistance applications, where the mechanical properties are strongly influenced by the porosity, pore size, and SiC content in the materials. In this investigation, porous AlSi10Mg and AlSi10Mg-SiC are investigated under compressive loading conditions. The samples were manufactured using a replication casting process that provides microstructural uniformity in the material. The porous structure was designed with an average pore size of 0.8 – 1.2 mm. Quasi-static compression testing was performed at strain rates of 0.01 s^{-1} and 0.001 s^{-1} . Quasi-static uniaxial compression tests were conducted to evaluate compressive strength, plateau stress, and energy absorption capacity. The material deformation behavior under compressive loading was analyzed by stress-strain curves from the available data resources. The work absorption behavior and its efficiency were analyzed in a material deformation regime. This research indicates that the energy absorption behavior is primarily influenced by the strain rate rather than the size of the porous structure. Additionally, higher strain rates exhibit higher energy absorption characteristics than lower strain rate deformations. Both porous AlSi10Mg and aluminum composites (AlSi10Mg-SiC) show similar behavior during compressive deformation process. These findings are necessary for understanding the potential of replication-cast AlSi10Mg-based porous structures as high-performance advanced energy materials for applications in impact protection, vibration damping, and energy-related structural systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-147611: Cryogenic Mechanical Properties of AISI 304 Stainless Steel for Hydrogen Storage

Abdisa Sisay Mekonnen

Department of Materials Technology, Faculty of Materials Engineering, Silesian University of Technology, Krasinskiego 8, 40-019 Katowice, Poland

Abstract

Physical-based hydrogen storage technologies are among the most promising pathways toward achieving global energy transition goals by 2050, particularly for transportation and large-scale energy infrastructure. Compressed gaseous and cryo-compressed hydrogen storage systems require structural materials capable of safely operating under high pressures, cryogenic temperatures, or a combination of both. In this context, the selection of advanced structural materials is critical to ensuring the safety, durability, and economic feasibility of hydrogen energy systems. Austenitic stainless steels (ASSs), especially AISI 304, are widely considered for hydrogen storage vessels and associated components due to their excellent corrosion resistance, resistance to hydrogen embrittlement, good weldability, and cost-effectiveness. The rapid advancement of hydrogen energy technologies necessitates a detailed understanding of material behavior under service-relevant extreme environments. Although AISI 304 is commonly used in hydrogen-related applications, its mechanical response at sub-ambient and cryogenic temperatures remains insufficiently characterized for reliable material selection and design of next-generation hydrogen infrastructure. This study systematically investigates the low-temperature mechanical behavior of AISI 304 austenitic stainless steel to evaluate its suitability for hydrogen storage and transport systems. Uniaxial tensile tests were performed at temperatures ranging from ambient room temperature (298 K) down to $-80\text{ }^{\circ}\text{C}$ (193 K) using a universal testing machine integrated with a controlled cooling chamber. A constant strain rate of 10^{-3} s^{-1} was applied to isolate the influence of temperature on the mechanical response. The results demonstrate a pronounced temperature dependence of strength and ductility. The ultimate tensile strength increased linearly from 785 MPa at 298 K to 1210 MPa at 193 K, corresponding to a 54.2% enhancement, while the yield strength showed a moderate increase from 690 MPa to 740 MPa (7.25%). Although uniform elongation decreased with decreasing temperature, fracture behavior remained predominantly ductile. Scanning electron microscopy (SEM) analysis of fracture surfaces revealed well-defined dimpled morphologies across all testing temperatures, including cryogenic conditions, indicating sustained energy absorption capability and resistance to brittle failure. These findings suggest that AISI 304 not only maintains but significantly enhances its strength at low temperatures while preserving acceptable ductility, a critical requirement for safe hydrogen storage systems. The novelty of this work lies in the systematic correlation of cryogenic tensile properties and fracture mechanisms of AISI 304 with the performance requirements of hydrogen energy infrastructure. The demonstrated combination of enhanced strength and retained toughness highlights the potential of AISI 304 as a reliable structural material for advanced hydrogen storage applications, contributing to the safe and efficient deployment of hydrogen technologies in future energy systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165555: Determining the Maximum Figure of Merit Using the Thermoelectric Material Parameter, Generalized Parameter, Universal Electrical Conductivity, and Reduced Electrical Conductivity of Cuprum and Nickel Based or Doped Compounds. The Compatibility Factor of these Materials

Irakli Nakhutsrishvil¹ and Christian Idogho^{2,*}

¹ Department of Optically Controlled Anisotropic Systems, Institute of Cybernetics of Georgian Technical University, Tbilisi, 0186, Georgia

² Department of Materials Science, University of Vermont, Burlington, VT 05405, USA

INTRODUCTION

Among the major industrial metals, copper and nickel occupy a prominent place. They are widely used both in pure form and in the form of alloys with each other and with other elements, in various branches of industry and everyday life. At the same time, alloying various materials with copper or nickel improves their thermoelectric characteristics. The figure of merit of these materials can take values $ZT > 2$ ($ZT = \sigma S^2 T / \lambda$, σ – specific electrical conductivity, S – Seebeck coefficient, λ – thermal conductivity, T – absolute temperature). This work studies the thermoelectric material (B) and generalized (B^*) parameters of copper and nickel-based or doped compounds. The compatibility factor (CF), the power and thermoelectric efficiency of some of the studied materials are also calculated.

METHOD To calculate the thermoelectric material and generalized parameters, the formulas $B = \sigma S^2 T / B_S \lambda_L$ [1] and $B^* = 1.551 \cdot 10^{-3} |S|_{\max} \lambda_L^{-1}$ [2] were used, respectively (B_S – scaled power factor, λ_L – lattice thermal conductivity). And the compatibility factor was calculated through ZT : $CF = [(1 + ZT)^{1/2} - 1] / (ST)$ [3,4]. Data from a large number of studies (for B) were used. In some of them, the temperature dependence of the Seebeck coefficient has an extreme point, which was used to calculate B^* .

RESULTS AND DISCUSSION

To determine parameter B , the electronic quality factor (B_E) was first calculated: $B_E = \sigma S^2 / B_S$, where B_S is the scaled power factor, and $S = 1.1605 \cdot 10^4$ is dimensionless reduced Seebeck coefficient. At $|S| = 210^{-4}$ V/K, B_S with high accuracy.) The temperature dependence of the electronic quality factor can be used to judge the presence of additional effects. Dependencies for Cu_2Se and $\text{Mg}_3\text{Sb}_{1.5}\text{B}_{0.5} + 0.3\text{Cu}$ are noteworthy (since in the ideal case B_E does not depend on temperature). Dependency for $\text{Cu}_{12}\text{Sb}_4\text{S}_3$ indicates the presence of additional scattering, and according to dependency for $\text{Cu}_2\text{Se} + 2\text{Ni}$, the latter adds band convergence and the bipolar effect.

The dependencies $(ZT)_{\max} - B$ and $(ZT)_{\max} - B^*$ are regular (almost rectilinear). This allows to evaluate $(ZT)_{\max}$ using B .

Values of the figure of merit allows us to determine the compatibility factor. It should be noted that for ideal thermoelectrics the compatibility factor should not (or little) change with temperature. $\text{Ti}_2\text{NiCoSnSb}$, $\text{CuAl}_{0.8}\text{Fe}_{0.2}\text{O}_2$, $\text{ZnNi}_{0.07}\text{Pb}_{0.38}\text{Sn}_{0.6}\text{Bi}_{0.03}$ and especially SiGe are the most favorable in this aspect. It is also evident that the $CF - T$ dependences for $\text{Cu}_{1.98}\text{S}$ and SiGe intersect at about 900K, and for $\text{CuAl}_{0.8}\text{Fe}_{0.2}\text{O}_2$ and SiGe at 750K. It is also evident that the $CF - T$ dependences for $\text{Mg}_3\text{Sb}_{1.5}\text{B}_{0.5} + 0.3\text{Cu}$ and $\text{ZnNi}_{0.07}\text{Pb}_{0.38}\text{Sn}_{0.6}\text{Bi}_{0.03}$ are the same at $T > 450$ K. The dependence for $\text{Ti}_2\text{NiCoSnSb}$ can intersect with them at about 900K. All this makes it possible to create segmented thermogenerators based on the indicated pairs.

For $\text{Cu}_{1.98}\text{S}$, $\text{Cu}_{12}\text{Sb}_4\text{S}_{13}$ and $\text{Zn}_{0.98}\text{Ni}_{0.02}\text{Sb}$ the power reaches 140 mW, and thermoelectric efficiency is (6-9)%. The latter is somewhat lower than that of benchmark materials such as $\text{Bi}_2\text{Te}_3/\text{Mg}_3(\text{Sb,Bi})_2$ and PbTe . Nevertheless, these values should be considered good.

CONCLUSION

For the studied materials, the dependences of the figure of merit on the material parameter and the generalized parameter are practically rectilinear. This allows to evaluate $(\text{ZT})_{\text{max}}$ using B. The compatibility factors of some materials coincide at certain temperatures. This allows segmented thermogenerators to be created from them. Power and thermoelectric efficiency have been calculated for some materials.

REFERENCES

1. X.Zhang, Z.Bu, X.Shi et al. Electronic quality factor for thermoelectric. *Sci. Adv.*, 2020, 6(46), eabc0726.
2. W.Liu, Z. Han, J.Ji et al. Uplimit $(\text{ZT})_{\text{max}}$ and effective merit parameter B^* of thermoelectric semiconductors. *Materials Today Phys.*, 2022, 31, 100989.
3. Nurachman, S. Permata, Ch. Idogho et al. Compatibility in thermoelectric material synthesis and thermal transport. *Unconvent. Resources*, 2025, 7, 100198.
4. Christian, E.O.Abah, J.E.Abel et al. Compatibility study of synthesized materials for thermal transport in thermoelectric power generation. *A.J. Innovat. Sci. and Engineering*, 2025, 4(1), 2158-7205.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-169845: DFT Study of Electronic Structure and Bonding in Carbide and Nitride Titanium MXenes toward Advanced Energy Materials

Md. Nurjaman Ridoy

Department of Computational Research, Nano Research Centre, Sylhet, 3114, Bangladesh

Introduction:

MXenes are a family of two-dimensional inorganic nanomaterials composed of transition-metal carbides and nitrides, well known for their high electrical conductivity, hydrophilic surfaces, and tunable surface chemistry, which make them promising candidates for advanced energy materials. These properties make them attractive in the next generation of energy storage and conversion equipment, including batteries and supercapacitors.

Methods:

In this study, density functional theory calculations are performed on finite cluster models of Ti_2C and Ti_2N MXenes to investigate their local electronic structure, bonding, and relative stability. The analysis is based on important electronic descriptors, namely total electronic energies, HOMO–LUMO gaps, charge distributions, dipole moments, symmetry properties, and differences in Ti–C and Ti–N bonding interactions.

Results:

The calculated results show clear contrasts between carbide and nitride MXenes. Ti_2C exhibits a total electronic energy of -47256.9008 eV with a HOMO–LUMO gap of 1.39 eV, indicating narrow-gap electronic behavior and favorable local electronic characteristics. In contrast, Ti_2N shows a lower total electronic energy of -47713.4497 eV, reflecting higher relative stability, along with spin-dependent HOMO–LUMO gaps of about 1.50 eV (α spin) and 1.72 eV (β spin). The Ti_2N cluster also has a finite dipole moment of 1.0858 Debye, fits within the CS point-group symmetry, and has a doublet spin state characteristic, indicating stronger polarization effects and stronger Ti–N bonding as compared to Ti–C. The systematically weakened HOMO–LUMO gaps and stronger interactions between the metals and nitrogen in the nitride MXenes indicate favorable electronic characteristics for energy applications and stronger bonding when compared to their carbide counterparts, which is also adjusted to parameters of thickness and composition.

Conclusions:

These findings show how first-principles electronic structure calculations can directly link atomic-scale bonding and electronic behavior to energy-relevant properties in MXenes. The results support the rational design of titanium carbide and nitride MXenes as advanced energy materials and underline the suitability of density functional theory-based electronic structure analysis for understanding and optimizing next-generation two-dimensional energy materials.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-161940: Enhanced Energy-Relevant and Multifunctional Properties of β -SiC/Polypropylene Nanocomposites for Advanced Energy Materials

Shafiga Safar Alakbarova^{1,*} and **Vusal Mammadov**²

¹ Nano Research Laboratory, Excellence Center, Baku State University, Z. Khalilov Street 23, Baku AZ1148, Azerbaijan

² Department of Physics, Baku State University, Baku, Azerbaijan

Polymer-based materials are attractive for energy applications due to their low density, mechanical flexibility, and ease of processing; however, their intrinsically low thermal conductivity, limited dielectric performance, and weak ultraviolet (UV) resistance restrict their functionality in advanced energy and electronic systems. To overcome these limitations, this study reports the development of β -silicon carbide (β -SiC) reinforced isotactic polypropylene (PP) nanocomposites designed to achieve enhanced multifunctional properties relevant to modern energy technologies and applications.

β - silicon carbide nanostructures were synthesized via high-temperature carbothermal methods and incorporated into the PP matrix at controlled filler loadings using melt blending followed by compression molding. This approach ensured uniform filler dispersion and strong interfacial interactions, which are critical for effective property enhancement, mechanical stability, and long-term performance. Structural characterization by X-ray diffraction confirmed the retention of the cubic β -SiC phase, while scanning electron microscopy revealed nanoscale filler distribution and good adhesion at the filler–matrix interface. Optical absorption measurements indicated a direct band gap of 5.76 eV for the nanocomposites, slightly higher than that of pristine β -SiC, suggesting modification of electronic states due to polymer–filler interactions and interfacial effects.

Dielectric measurements showed a notable increase in relative permittivity and energy storage capability compared to neat PP, attributed primarily to Maxwell–Wagner–Sillars interfacial polarization. Incorporation of β -SiC also improved thermal conductivity, supporting enhanced heat dissipation, and significantly increased UV absorption, demonstrating potential for solar shielding and protective energy applications.

The novelty of this work lies in the simultaneous improvement of dielectric, thermal, and optical functionalities within a lightweight polymer matrix, achieved through controlled interfacial engineering and conventional processing techniques. These multifunctional β -SiC/PP nanocomposites provide a versatile platform for dielectric films, thermal management layers, capacitive energy storage devices, and solar energy applications. Overall, this study offers new insights into designing high-performance, environmentally sustainable, and efficient polymer nanocomposites for advanced energy-related technologies.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170939: Experimental and computational insights into CO₂ adsorption in biomass-derived activated carbons

Jakkapan Kumsi^{1,2,*}, **Nikom Klomkliang**², **Kanagat Kishibayev**³ and **Jarosław Serafin**^{1,4}

¹ Department of Inorganic and Organic Chemistry, University of Barcelona, Martí i Franquès, 1-11, Barcelona 08028, Spain

² School of Chemical Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand

³ Center of Physical-Chemical Methods of Research and Analysis, Al-Farabi Kazakh National University, 96 A, Tole bi Street, Almaty 050012, Kazakhstan

⁴ ENPHOCAMAT Group, Institute of Nanoscience and Nanotechnology (IN2UB), University of Barcelona, Martí i Franquès, 1, 08028, Barcelona, Catalunya, Spain

Introduction

The unprecedented rise in atmospheric carbon dioxide (CO₂) concentration represents one of the most critical challenges for modern energy systems, directly impacting climate stability and energy sustainability [1, 2]. Carbon capture and storage (CCS) technologies are therefore indispensable for enabling low-carbon energy transitions. Among emerging solutions, porous carbons derived from biomass have attracted increasing attention due to their low environmental footprint, scalability, and structural tunability [3]. Grape seeds, a major waste stream of the wine industry, constitute an abundant lignocellulosic resource with untapped potential for advanced energy and environmental applications [4]. Despite growing interest in biomass-derived carbons, a fundamental understanding of how activation strategies govern pore architecture and CO₂ adsorption efficiency remains insufficient.

Methods

In this work, grape seed-derived activated carbons were synthesized via chemical and physical activation routes at temperatures between 600 and 800 °C to systematically evaluate structure–performance relationships. The materials were comprehensively characterized using XRD, Raman spectroscopy, XRF, SEM, and N₂ adsorption–desorption analyses to determine their crystallinity, chemical purity, morphology, and pore structure. To bridge macroscopic performance with microscopic mechanisms, Grand Canonical Monte Carlo (GCMC) simulations were employed to investigate CO₂ adsorption behavior [5], interaction energies, and isosteric heats of adsorption at the molecular level.

Results

Chemical activation yielded a highly developed porous carbon (AC-GC-C-800) with an exceptional specific surface area of 1968 m² g⁻¹ and a total pore volume of 1.22 cm³ g⁻¹. In contrast, physically activated carbons exhibited progressively reduced porosity and larger particle sizes with decreasing activation temperature. Structural analyses revealed that AC-GC-C-800 possessed the highest degree of structural disorder ($I_D/I_G = 0.75$), which strongly correlated with enhanced microporosity and superior CO₂ uptake. As a result, AC-GC-C-800 achieved a CO₂ adsorption capacity of 6.5 mmol g⁻¹ at 273 K and 4.8 mmol g⁻¹ at 298 K under 1 bar, outperforming physically activated counterparts by up to ~40%. Elemental analysis confirmed that KOH activation effectively removed inorganic impurities, resulting in a carbon purity of 92.5 wt%. GCMC simulations demonstrated that while surface area dominates adsorption at elevated pressures, CO₂ capture under low-pressure, post-combustion conditions is governed by the presence of narrowly distributed ultra-micropores [6, 7]. Simulation snapshots and energy analyses clearly showed stronger host–guest interactions in chemically activated carbons.

Conclusions

This study reveals that precise control of pore geometry, rather than surface area alone, is the decisive factor governing CO₂ capture efficiency in biomass-derived carbons. By combining advanced characterization with molecular-level simulations, this work provides a mechanistic framework for designing high-performance, sustainable adsorbents for CCS applications. The results highlight grape seed waste as a viable feedstock for advanced energy materials and

contribute to the rational development of carbon capture technologies aligned with circular economy and low-carbon energy strategies

Acknowledgments

This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant no. AP19679878—Conversion of plant biomass waste into microporous activated carbons to successfully capture and separate CO₂, N₂ and CH₄.)

References

1. Sangchoom, W. and R. Mokaya, Valorization of Lignin Waste: Carbons from Hydrothermal Carbonization of Renewable Lignin as Superior Sorbents for CO₂ and Hydrogen Storage. *ACS Sustainable Chemistry & Engineering*, 2015. 3(7): p. 1658-1667.
2. D'Alessandro, D.M., B. Smit, and J.R. Long, Carbon Dioxide Capture: Prospects for New Materials. *Angewandte Chemie International Edition*, 2010. 49(35): p. 6058-6082.
3. Priya, D.S., L.J. Kennedy, and G.T. Anand, Emerging trends in biomass-derived porous carbon materials for energy storage application: A critical review. *Materials Today Sustainability*, 2023. 21: p. 100320.
4. Montoya, V.H. and A. Bonilla-Petriciolet, Lignocellulosic precursors used in the synthesis of activated carbon: characterization techniques and applications in the wastewater treatment. 2012: BoD—Books on Demand.D. Frenkel, B.S., *Understanding Molecular Simulation: From Algorithms to Applications*. Elsevier, 2023. San Diego: Academic Press: p. 443.
5. Dziejarski, B., et al., Tailoring highly surface and microporous activated carbons (ACs) from biomass via KOH, K₂C₂O₄ and KOH/K₂C₂O₄ activation for efficient CO₂ capture and CO₂/N₂ selectivity: characterization, experimental and molecular simulation insights. *Chemical Engineering Journal*, 2025. 524: p. 169677.
6. Tiyawate, A., et al., Combined experimental and grand canonical Monte Carlo simulation study of CO₂ capture in nitrogen and sulfur co-doped biochar derived from biowaste: Cost analysis, kinetics, and equilibrium. *Journal of Environmental Chemical Engineering*, 2024. 12(5): p. 113991.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164181: Experimental Characterization of a Medium-Temperature Organic PCM Latent Thermal Storage for Residential Heat Pump Applications

Dario Guarda ¹, Claudio Zilio ¹, Giulia Righetti ^{1,*} and Simone Mancin ²

¹ Department of Management and Engineering, University of Padova, 36100, Vicenza, Italy

² Department of Industrial Engineering, University of Padova, Padova, Italy

The increasing penetration of photovoltaic generation in residential buildings has intensified the temporal mismatch between electricity availability and thermal demand, particularly in heat pump-based heating systems. Thermal energy storage represents a key enabling technology to increase on-site renewable energy self-consumption and system flexibility. Among available options, latent thermal energy storage (LTES) based on phase change materials (PCMs) offers high energy density and compact system layouts, which are especially attractive for space-constrained residential applications. Organic PCMs are of particular interest due to their chemical stability, predictable phase change behavior, and absence of supercooling-related issues. Nevertheless, the practical integration of PCM-based storage into real heat pump systems remains challenging due to heat transfer limitations and internal temperature non-uniformities. As a result, latent storage solutions cannot be considered plug-and-play components and require careful experimental validation under realistic operating conditions. Within this context, the LIFE ITS4ZEB project adopts an application-driven approach, focusing on industrially feasible configurations rather than idealized laboratory concepts.

This work presents the experimental characterization of a medium-temperature latent thermal storage unit based on an organic phase change material and integrated with a hydraulic loop representative of residential heat pump systems. The storage module consists of an aluminum tank with an internal volume of approximately 0.1 m³, filled with a commercial organic PCM with a phase change temperature suitable for space heating applications. The resulting nominal storage capacity is approximately 8 kWh. Heat exchange between the water loop and the PCM is provided by a commercial finned-tube heat exchanger adapted for latent storage use, representative of compact and cost-oriented industrial solutions. Charging and discharging tests were carried out by varying inlet water temperature differences (10–20 K) and volumetric flow rates (4–8 L/min), covering a range of operating conditions relevant to residential heat pump operation. Thermal power, cumulative stored and released energy, and internal temperature distribution were monitored using calibrated instrumentation. A distributed network of thermocouples enabled the analysis of thermal stratification and spatial temperature non-uniformities within the PCM volume.

The experimental results show that the performance of the organic PCM-based storage is strongly influenced by the imposed boundary conditions. Increasing the inlet temperature difference leads to higher peak thermal power and shorter charging and discharging times, while enabling a more effective utilization of the available storage capacity. At constant temperature difference, increasing the flow rate significantly boosts peak power but may reduce the total usable energy when an application-oriented power threshold is adopted to define the end of the process. Charging and discharging behaviors are largely symmetric, reflecting the stable and repeatable phase change characteristics of the organic PCM. Internal temperature measurements reveal the development of thermal stratification during both operating phases, with temperature gradients increasing under more aggressive conditions. Although such non-uniformities do not prevent correct operation, they influence charging and discharging dynamics and limit the uniform participation of the PCM volume in the phase change process.

The experimental investigation confirms that organic PCM-based latent thermal storage can deliver energy and power levels compatible with residential heat pump applications, albeit with a lower energy density compared to inorganic solutions. The absence of supercooling contributes to stable and predictable operation, but heat transfer limitations and thermal stratification remain

key design challenges. System performance is highly sensitive to operating conditions, and excessive emphasis on peak power may compromise temperature uniformity and effective energy utilization. These results demonstrate that, even for organic PCMs, latent thermal energy storage cannot be considered a plug-and-play solution. Careful system design, appropriate selection of operating conditions, and experimental validation under realistic boundary conditions are essential to achieve a balanced compromise between performance, robustness, and industrial feasibility. Within the ITS4ZEB framework, the investigated configuration represents a reliable and scalable solution for enhancing renewable energy self-consumption in residential heat pump systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170678: High-Performance Thermoelectric MXene/SWCNT Composites

Priyam Srivastava^{1,*}, Rani Rohini¹ and Beate Krause²

¹ Department of Materials Engineering, Indian Institute of Technology, Jammu, India

² Dept. Sustainable Polymer Structures, Leibniz-Institut für Polymerforschung Dresden e. V. | Leibniz Institute of Polymer Research Dresden, Germany

Polymer-based thermoelectric materials offer several advantages compared to conventional metal oxides [like bismuth telluride (Bi_2Te_3), lead telluride (PbTe), silicon germanium (SiGe), and bismuth antimony telluride (BiSbTe) alloys], including enhanced availability, cost efficiency, ease of processing, mechanical flexibility, low density, and reduced thermal conductivity. The incorporation of these materials into flexible and wearable electronics is a straightforward process that gives rise to the possibility of energy harvesting from body heat or other low-grade heat sources. If SWCNTs are combined with other materials, interfaces can scatter phonons and reduce heat conductivity which would be better for thermoelectric applications. The integration of SWCNT and MXene can provide more phonon scattering which causes reduced thermal conductivity however it also depends on the thickness of the material. Additionally, the various surface termination groups provide more options for modifying MXene, leading to combinations that possess the necessary capabilities. The inherent two-dimensional layered structure makes it possible to regulate properties practically and to assemble several layers. Due to these qualities, there are exciting prospects to adjust the electrical and thermal properties of MXene, which has promise in the field of thermoelectrics.

Herein, a thermoelectric device was fabricated using the bucky paper by combining single-walled carbon nanotubes (SWCNTs) and 2D MXene ($\text{Ti}_3\text{C}_2\text{T}_x$) sheets. This combination of materials helped to achieve a significantly lower heat conductivity by introducing phonon scattering into the system while simultaneously improving electrical conductivity. We accomplished this by creating a hollow three-dimensional structure that serves as a thermal insulator and by using energy filtering at the MXene/SWCNT interfaces to increase the Seebeck coefficient. The M90C10 bucky paper, composed of 90 wt.% MXene and 10 wt.% SWCNT, achieved a Seebeck coefficient of $50.45 \mu\text{V/K}$ and a power factor of $3.82 \mu\text{W}/(\text{m}\cdot\text{K}^2)$. A prototype thermoelectric device was fabricated with the same composition, having a Seebeck coefficient of $320.77 \mu\text{V/K}$ and a maximum output power of $0.053 \mu\text{W}$ to confirm its promise for high-performance and scalable thermoelectric applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171374: Interfacial Engineering and Upscaling Strategy for Aluminum Foil Substrates Flexible Perovskite Solar Cells

Yue Xian^{1,2,3,*}, Erica Magliano¹, Aldo Di Carlo^{1,2}, Paula Perez Rodriguez⁴, Arno Smets⁴ and Giorgio Scordo²

¹ Istituto di Struttura della Materia (CNR-ISM) National Research Council, Rome 00133, Italy

² CHOSE (Centre for Hybrid and Organic Solar Energy), Department of Electronic Engineering, Tor Vergata University of Rome, Rome 00118, Italy

³ Department of Applied Science and Technology, Politecnico di Torino, Turin 10129, Italy

⁴ Photovoltaic Materials and Devices group, Delft University of Technology, Delft 2628 CD, The Netherlands

Flexible perovskite solar cells (PSCs) combine high efficiency with sustainability, making them as a hot spot in green energy and a promising candidate for large-scale industrial production^{[1][2]}. While Al foil offers excellent moisture and oxygen barrier properties, high thermal tolerance, and mechanical robustness, it's the key point for the industrial roll-to-roll (R2R) production of lightweight, stable, and low-cost photovoltaic modules^[3]. However, its surface roughness and interfacial incompatibility with perovskite layers causes challenges to device performance and upscaling.

This work addresses these challenges through a multi-faceted approach combining substrate engineering, interfacial modification, and scalable deposition techniques. Within the framework of the Horizon Europe Luminosity project, successfully implement barrier/ITO stack on Al foil, which serves as a smooth, conductive, and chemically compatible base for perovskite deposition. Through the optimization of self-assembled monolayers (SAMs, e.g., MeO-4PACz) and interfacial passivation (e.g., PEACl) improved charge extraction and reduced hysteresis. The best performing flexible PSCs on Al/barrier/ITO substrates with semitransparent stack achieves power conversion efficiency (PCE) of 14.64%, with a low hysteresis index and operational stability. Comparative studies on semitransparent Glass/ITO references PCE up to 17.59%, showing the ongoing optimization pathway for Al substrate devices. Furthermore, we also report progress in laser patterning for monolithic module interconnection, which is the key step for R2R manufacturing.

This work demonstrates the feasibility of Aluminum substrates PSCs and highlights the crucial role of interface control in improving the efficiency and stability. By combining material innovation with industrially relevant processing routes, we provide a viable way for the commercialization of high-performance, durable, and sustainable perovskite photovoltaic modules.

[1] S. Aftab, M.Z. Iqbal, S. Hussain, H.H. Hegazy, M.A. Saeed, Nano Energy (2023), 108249.

[2] L. Yang, J. Feng, Z. Liu, Y. Duan, S. Zhan, S. Yang, K. He, Y. Li, Y. Zhou, N. Yuan, Adv. Mater. 34 (2022) 2201681.

[3] A. Kumar, S. Rani, D. S. Ghosh, Sol. Energy Mater. Sol. Cells. 268 (2024) 112737.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166354: Memcapacitive Devices Based on ZnO and Mg Thin Films: Toward Adaptive Energy Interfaces

Karen Ailed Neri-Espinoza^{1,*}, José Alberto Andraca-Adame¹, Diana Palma-Ramírez², Francisco Gutiérrez-Galicia³, Acela López-Benítez² and Ramón Peña-Sierra⁴

¹ Department of Nanomaterials, Unidad Profesional Interdisciplinaria de Ingeniería Campus Hidalgo (UPIIH), Instituto Politécnico Nacional (IPN), Hidalgo 42162, Mexico

² Department of Polymers and Nanomaterials, Unidad Profesional Interdisciplinaria de Ingeniería Campus Hidalgo (UPIIH), Instituto Politécnico Nacional (IPN), Hidalgo 42162, Mexico

³ Escuela Superior de Ingeniería y Arquitectura (ESIA), Instituto Politécnico Nacional (IPN), CDMX 07320, Mexico

⁴ Department of Electrical Engineering, Sección de Electrónica de Estado Sólido (SEES), Center for Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV-IPN), Mexico City 07360, Mexico

The fast evolution of smart and adaptive energy systems has intensified the demand for multifunctional materials capable of integrating energy storage, memory, and reconfigurable behavior within a single platform. Conventional capacitive devices, while effective for energy storage, lack the ability to retain information about their previous electrical states. In this context, memcapacitive systems have emerged as a promising class of components that combine capacitive functionality with memory effects, enabling adaptive and history-dependent responses.

In this work, we investigate memcapacitive behavior in thin-film devices based on zinc oxide (ZnO) and magnesium (Mg) [1] deposited on flexible polymer substrates. The use of polymeric substrates enables mechanical flexibility and lightweight architectures, while ZnO offers a wide bandgap, high dielectric stability, and defect-mediated charge transport properties. Magnesium is introduced as an active material to modulate dielectric response, defect density, and interfacial polarization through different structural configurations, including layered and mixed thin-film arrangements. All films were fabricated using sputtering techniques, allowing precise control over thickness and deposition parameters.

Electrical characterization was performed using current-voltage (I-V) measurements and frequency response analysis (FRA) over a broad frequency range. The devices exhibited nonlinear charge-voltage relationships, frequency-dependent capacitance, and hysteresis loops that cannot be described by conventional linear capacitors. These features are consistent with memcapacitive behavior, where the instantaneous capacitance depends on the history of the applied electrical stimulus. The incorporation of Mg was found to significantly influence the electrical response, suggesting tunability of memory retention and switching characteristics through material design.

Complementary structural and morphological analyses, including techniques such as X-ray diffraction (XRD), are employed to correlate electrical behavior with crystalline structure, film uniformity, and defect-related mechanisms. The observed memcapacitive effects are attributed to interfacial charge trapping, defect migration, and polarization processes within the ZnO-Mg thin-film system.

This study establishes a material-driven approach toward adaptive energy interfaces, where energy storage and memory functionalities coexist within flexible platforms. Such devices are highly relevant for low-power electronics, neuromorphic systems, wearable technologies, and intelligent energy-aware architectures. Future work will focus on optimizing ZnO-Mg configurations, improving device stability, and exploring scalable integration strategies for next-generation smart energy systems.

[1] Lv, Y., Guo, X., Li, X. *et al.* Coexistence of memristive and memcapacitive characteristics in Pt/MgO/ZnO metal-insulator-semiconductor heterostructure device. *Appl. Phys. A* **131**, 251 (2025). <https://doi.org/10.1007/s00339-025-08368-3>



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171282: Numerical Evaluation of Monolithic Aerogel as a Transparent Insulation Layer for Building-Integrated Natural Convection Solar Air Collectors

Yusuf Kepir^{1,*}, Holger Seidlitz², Lars Ulke-Winter¹ and Felix Kuke¹

¹ Chair of Polymer-based Lightweight Design, Brandenburg University of Technology Cottbus–Senftenberg (BTU), Cottbus, 03046, Germany

² Research Division Polymeric Materials and Composites PYCO, Fraunhofer Institute for Applied Polymer Research IAP, Wildau, Germany

Sustainable building design increasingly relies on passive solar thermal systems to reduce the carbon footprint of space heating. Among these technologies, building-integrated solar air collectors mounted on facades or roofs offer a cost-effective solution for fresh air preheating. However, the performance of natural convection collectors is inherently limited by the delicate balance between buoyancy-driven flow and heat loss through the glazing. This study presents a detailed three-dimensional numerical investigation into the thermal behavior of a passive solar air collector, comparing conventional glass covers with monolithic silica aerogel as a transparent insulation material.

The numerical model was developed within the Ansys Fluent environment, focusing on the thermosiphon effect, where the flow is entirely driven by buoyancy forces rather than external mechanical power. To accurately capture the physics of natural convection, the Boussinesq approximation or ideal gas density variations were employed in conjunction with the gravitational vector. A multi-band radiation modeling approach was implemented to decouple the incoming short-wave solar radiation from the long-wave thermal radiation emitted by the absorber. This allowed for a realistic assessment of the "greenhouse effect" and the radiative shielding provided by the aerogel layer in a vertical or inclined mounting configuration.

The findings reveal that monolithic aerogel acts as a transformative component for passive systems. In natural convection collectors, flow velocities are typically low, which usually leads to high stagnation temperatures and increased top heat losses in glass-covered units. The integration of aerogel, with its exceptionally low thermal conductivity and high infrared absorption, effectively suppresses these losses. Numerical results indicate that the aerogel-integrated collector maintains a significantly higher thermal equilibrium, leading to improved absorber surface temperatures and enhanced air delivery temperatures into the building interior. While the porous structure of the aerogel introduces a minor penalty in solar transmittance, the resultant enhancement in the stack effect—driven by higher internal temperatures—compensates for this by maintaining a stable and warm airflow. This research demonstrates that aerogel-based glazing is a superior alternative for the next generation of building-integrated passive solar systems, where thermal retention is the primary driver of overall seasonal efficiency.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-169562: Phase Change Materials in Energy Applications: Classification and Usually Evaluation Methods

Claudiu Gorea^{1,*} and Maria HARJA²

¹ Gheorghe Asachi Technical University of Iasi, Faculty of Chemical Engineering and Environmental Protection, Department of Chemical Engineering

² Department of Chemical Engineering, Faculty of Chemical Engineering and Environmental Protection, Gheorghe Asachi Technical University of Iasi, Iasi, 70050, D. Mangeron 73, street, Romania

Phase Change Materials (PCMs) are substances that store and release thermal energy through reversible solid-liquid phase transitions. In recent years, PCMs have received increased attention as effective components in thermal energy storage systems. Using PCMs across different technologies can improve thermal energy storage, reduce dependence on conventional energy sources, lower greenhouse gas emissions, and support global sustainability and energy efficiency objectives. These materials can maintain a stable temperature during phase transitions while absorbing or releasing latent heat. This characteristic enables PCMs to regulate temperature changes, making them suitable for applications such as passive thermal storage, solar energy systems, and building energy optimization. In building envelopes, they improve thermal inertia, reducing indoor temperature variations and heating or cooling demands. The same goes for solar energy systems; PCMs store excess solar heat during peak periods and release it when energy demand rises, improving overall system efficiency.

PCMs are classified into three main categories: organic, inorganic, and eutectic materials. Organic PCMs, like paraffins and fatty acids, are characterized by their chemical stability; they are non-corrosive and have congruent melting points, but they have low thermal conductivity and low latent heat in certain high-demanding applications. Inorganic PCMs, especially hydrated salts, offer high latent heat storage capacity and improved thermal conductivity. This particular aspect makes them attractive for medium- or high-temperature energy storage. Aside from these advantages, inorganic PCMs often have drawbacks such as phase separation, supercooling, or corrosive behavior. Eutectic PCMs combine two or more components to achieve specific melting temperatures and improved thermal stability, effectively merging the advantages of both organic and inorganic materials.

In this paper, a comparative study is presented about the most common studied inorganic hydrated salts, such as: magnesium nitrate hexahydrate ($\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$), lithium nitrate trihydrate ($\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$), sodium sulfate decahydrate ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$), calcium nitrate tetrahydrate ($\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$), calcium chloride hexahydrate ($\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$), magnesium chloride hexahydrate ($\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$), sodium acetate trihydrate ($\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$) and their eutectic mixtures. These materials exhibit melting temperatures ranging from 29 °C to over 100 °C, making them suitable for a wide range of thermal applications. For example, calcium chloride hexahydrate melts around 29 °C with a latent heat of approximately 190 kJ/kg but presents corrosion and supercooling issues. Sodium sulfate decahydrate offers a higher latent heat (about 230 J/g) and a melting range of 30–35 °C, though it is exposed to phase separation and leakage. Sodium acetate trihydrate has a melting temperature of approximately 58 °C and a high latent heat of 264 kJ/kg, but can exhibit supercooling and segregation phenomena. Magnesium-based hydrated salts, such as magnesium nitrate and magnesium chloride hexahydrates, operate over a wider temperature range and provide improved thermal storage capacity, although supercooling remains a significant limitation.

Improving property stabilization is a common method used for phase change material systems. Expanded graphite used as an additive was reported to improve thermal stability and heat transfer performance. Microencapsulation is a method used to prevent leakage during phase transitions and to improve thermal reliability.

To establish the properties of the considered hydrate salts, this paper analyzed: DSC for determining melting temperatures and latent heat values; TGA for thermal stability and

degradation behavior; SEM for structural and morphological analysis; and XRD and FTIR to confirm chemical composition and compatibility between the PCM cores and the encapsulated materials.

In conclusion, inorganic hydrated salts and their eutectics have significant potential for thermal energy storage and energy efficiency applications due to their high latent heat and favorable thermal properties. Single or eutectic formulations presented in this paper represent an important research focus for enhancing their performance and enabling the implementation of PCMs in sustainable energy systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171389: Photocatalytic Methanol Reforming over Cs_2RuX_6 ($\text{X} = \text{Cl}, \text{Br}$) Double Perovskites: H_2 Evolution and Carbon-Containing Gas Formation

Kevin Mego^{1,2,*}, Pedro Ruiz-Campos², Pedro Atienzar¹ and Herme G. Baldoví³

¹ Instituto de Tecnología Química, Consejo Superior de Investigaciones Científicas, Universitat Politècnica de València, Avenida de los Naranjos s/n, 46022 Valencia, Spain

² Universidad Científica del Sur, Panamericana Sur Km 19, 150142 Lima, Perú

³ Departamento de Química, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain

Photocatalytic methanol reforming offers a low-temperature route to hydrogen production, yet controlling product selectivity remains a key challenge. Here, we evaluate Cs_2RuX_6 ($\text{X} = \text{Cl}, \text{Br}$) double-perovskite photocatalysts for methanol reforming under mild conditions (2 mg catalyst, 25 °C, 1.0 bar Ar, 130 $\text{mW}\cdot\text{cm}^{-2}$ irradiation, 3 h), tracking time-resolved gas evolution to elucidate substrate-loading effects and halide-dependent behaviour. Methanol addition markedly enhances H_2 generation compared with methanol-free conditions for both catalysts. Cs_2RuCl_6 shows the highest H_2 productivity at intermediate methanol loading, reaching $\sim 10 \text{ mmol}\cdot\text{g}_{\text{cat}}^{-1}$ after 3 h at $\sim 39.6 \text{ mmol}$ methanol, while Cs_2RuBr_6 attains $\sim 7\text{--}8 \text{ mmol}\cdot\text{g}_{\text{cat}}^{-1}$ under the same loading. Increasing methanol to higher levels (e.g., $\sim 98.9 \text{ mmol}$) reduces H_2 output for both materials, indicating an optimum substrate range rather than a monotonic dependence.

O_2 evolution exhibits a contrasting trend: the presence of methanol generally suppresses O_2 formation, most clearly for Cs_2RuBr_6 , consistent with competitive consumption of oxidative equivalents in the reforming network. In parallel, carbon-containing gaseous products are co-generated, revealing strong selectivity changes with methanol loading and catalyst halide. CH_4 formation increases with time and is maximised at intermediate methanol loadings (e.g., $\sim 8 \text{ mmol}\cdot\text{g}_{\text{cat}}^{-1}$ for Cs_2RuCl_6 at $\sim 39.6 \text{ mmol}$ after 3 h; lower maxima for Cs_2RuBr_6). CO production is also favoured at moderate methanol amounts (up to $\sim 3\text{--}4 \text{ mmol}\cdot\text{g}_{\text{cat}}^{-1}$ for Cs_2RuCl_6 around $\sim 21.9 \text{ mmol}$), whereas higher methanol loading diminishes CO yields. Notably, C_2H_4 emerges as a dominant carbon product on both catalysts, reaching $\sim 350 \mu\text{mol}\cdot\text{g}_{\text{cat}}^{-1}$ for Cs_2RuCl_6 and $\sim 270 \mu\text{mol}\cdot\text{g}_{\text{cat}}^{-1}$ for Cs_2RuBr_6 at $\sim 39.6 \text{ mmol}$ methanol after 3 h, highlighting a pronounced substrate-dependent shift towards C–C containing products.

Overall, these results demonstrate that Cs_2RuX_6 perovskites enable methanol reforming at ambient temperature with substantial hydrogen evolution and tunable multi-gas selectivity. The combined halide comparison and substrate-loading optimisation provide practical guidelines for balancing H_2 productivity against carbonaceous by-products in perovskite-based reforming systems.

Looking ahead, the demonstrated loading-dependent trade-off between hydrogen productivity and carbonaceous by-product formation offers a clear lever for process tuning. By identifying an optimum methanol range and highlighting distinct selectivity patterns for Cl versus Br, this study sets a baseline for rational catalyst and reactor optimisation. Future work will couple in situ spectroscopy with mass-balance analysis to map reaction pathways and to suppress undesired products, enabling more efficient solar-to-chemical conversion using perovskite reforming platforms under ambient conditions relevant to deployment.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171224: Simulation and study of Cd-free SnS-based solar cells with a ZnSe buffer layer using SCAPS-1D

Moussa Simassa *, Redouane El Bakkali, Youssef El Mrini and Mounir Fahoume

Materials Physics and Subatomic Laboratory, Department of Physics, Faculty of Science, Ibn Tofail University, Kenitra, Morocco

Introduction:

Thin-film solar cells based on CdTe, CIGS, and perovskites have achieved high efficiencies, but their large-scale industrialization remains limited by toxicity issues related to cadmium or lead and by the scarcity of critical elements such as indium, gallium, and tellurium. In this context, tin monosulfide (SnS) has emerged as a promising absorber material because of the abundance and non-toxicity of its constituents, its direct band gap close to 1.3 eV, and its high absorption coefficient, which makes it suitable for thin-layer solar cells. However, the conventional SnS/CdS architecture still suffers from important limitations, including parasitic absorption in the blue-UV region by the CdS layer, unfavorable band alignment at the interface, enhanced recombination, and consequent degradation of the open-circuit voltage (Voc), short-circuit current density (Jsc), and fill factor (FF).

Methods:

To address these limitations, this work proposes a detailed numerical study of cadmium-free SnS solar cells using SCAPS-1D. The study first considers replacing the CdS buffer layer with alternative Cd-free materials, particularly zinc selenide (ZnSe) and molybdenum disulfide (MoS₂), in order to optimize the conduction band offset at the interface with the absorber and reduce recombination losses. In parallel, the effect of introducing back surface field (BSF) or hole transport layers (HTL), such as NiO and Cu₂O, between the SnS absorber and the rear metal contact is analyzed, with the aim of blocking electrons, facilitating selective hole extraction, and lowering rear-interface recombination. Different combinations of buffer and BSF/HTL layers are systematically examined together with their physical and electrical parameters, including thickness, doping, band gap, and defect density.

Results:

The numerical analysis is intended to identify device architectures offering the best compromise between band alignment, recombination reduction, and simultaneous improvement of Voc, Jsc, and FF. The comparison focuses on Cd-free configurations based on ZnSe or MoS₂ buffer layers combined with NiO or Cu₂O as BSF/HTL layers, relative to the reference SnS/CdS structure.

Conclusions:

This study aims to identify a truly Cd-free SnS solar-cell structure with improved conversion efficiency compared with the conventional SnS/CdS configuration. It also seeks to provide practical guidance for the experimental implementation of environmentally friendly and efficient SnS-based solar cells.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170263: Space-Charge Effects in Lithium Garnet Solid Electrolytes: A Continuum Modeling Study Using the Poisson–Nernst–Planck Framework

Akash Kanji

Department of Metallurgical and Material Engineering, Jadavpur University, Kolkata, 700032, India

Lithium garnet solid electrolytes such as $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$ (LLZO) are widely regarded as promising candidates for next-generation all-solid-state lithium batteries owing to their high ionic conductivity, wide electrochemical stability window, and superior mechanical stiffness against lithium dendrite penetration. These attributes position LLZO as a key advanced energy material for enabling safe, high-energy-density storage technologies critical to electrified transportation and renewable energy integration. However, despite frequently being approximated as purely Ohmic ionic conductors, growing experimental evidence indicates that transport in LLZO can deviate significantly from ideal electroneutral behavior. In particular, interfacial resistance, thickness-dependent conductivity, and current-induced polarization effects have been reported to limit rate capability and power performance in practical cells.

In this work, we develop a continuum-scale theoretical framework to systematically investigate lithium-ion transport in LLZO under externally applied electric fields. The model is formulated using the coupled Poisson–Nernst–Planck (PNP) equations, capturing the interplay between ionic diffusion, migration, and electrostatic potential evolution. The governing equations are nondimensionalized using physically motivated scaling parameters, revealing that the transport response is governed primarily by a single dimensionless group corresponding to the squared ratio of the Debye screening length to the electrolyte thickness. This scaling provides direct physical insight into when space-charge effects become non-negligible in solid electrolytes.

To resolve the resulting nonlinear boundary-value problem, numerical solutions are obtained using a fully implicit Newton–Raphson scheme, enabling stable and accurate resolution of steep potential gradients and space-charge layers near blocking or reactive interfaces. The simulations reveal pronounced deviations from classical Ohmic conduction in thin electrolytes and under high applied voltages, manifested through charge accumulation, field localization, and nonlinear current–voltage characteristics. These findings demonstrate that polarization losses in LLZO cannot always be attributed solely to microstructural defects or grain boundary resistance but may arise intrinsically from continuum electrostatic effects.

The developed framework establishes a quantitative basis for interpreting experimental impedance and polarization data and provides design guidelines for thickness optimization, interfacial engineering, and composite electrolyte architectures. More broadly, this study highlights the importance of coupled electrochemical–electrostatic modeling in advancing solid-state battery performance and reliability.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165650: Spectrally Resolved OCVD Investigation of Surface and Bulk Recombination in Silicon Photovoltaic Materials

Yacine Kouhlane^{1,*}, **Béchir Dridi REZGUID**², **Djoudi BOUHAFA**³, **Nabil KHELIFAT KHELIFATI**³ and **Mohamed MAOUDJ**³

¹ L.A.S.M.A Laboratory, Department of Physics, Faculty of Sciences, University Badji Mokhtar -Annaba, B.P.12, Annaba, 23000, Algeria

² Laboratoire de Photovoltaïque, Centre de Recherches et des Technologies de l'Energie, Technopôle de Borj-Cédria, BP 95, Hammam-Lif, 2050 Tunis, Tunisia

³ Centre de Recherche en Technologie des Semiconducteurs pour l'Energétique (CRTSE), Alger, Algeria, 2 Bd Frantz Fanon BP n° 140 - 7 Merveilles

1. Introduction

Advanced energy materials play a critical role in the continued development of photovoltaic technologies, particularly crystalline silicon solar cells, which continue to dominate the global renewable energy market [1]. Despite their high degree of technological maturity, the performance of silicon photovoltaic devices remains fundamentally limited by non-radiative recombination losses occurring at surfaces, interfaces, and within defect-rich bulk regions. These recombination pathways directly reduce the achievable open-circuit voltage and, consequently, the overall power conversion efficiency.

Among the various surface engineering strategies, hydrogenated silicon nitride ($\text{SiN}_x\text{:H}$) has emerged as a key passivation layer due to its dual functionality: chemical passivation of dangling bonds and field-effect passivation arising from fixed charges within the dielectric layer [2]. Nevertheless, further improvements in passivation quality require characterization techniques capable of resolving recombination dynamics with both temporal and spectral selectivity.

Spectrally selective open-circuit voltage decay (OCVD) analysis represents an advanced transient diagnostic method that is particularly well suited for probing charge carrier recombination in silicon photovoltaic energy materials [3,4]. By exploiting the wavelength-dependent absorption coefficient of silicon, this technique enables depth-resolved investigation of recombination processes, offering direct insight into the relative contributions of surface, emitter, and bulk regions.

2. Methods

A spectrally selective OCVD system was developed to investigate recombination dynamics in monocrystalline (c-Si) and multicrystalline (mc-Si) silicon photovoltaic energy materials. Industrial p-type Al-BSF solar cells fabricated using standard industrial processes were examined in both full-area devices ($10 \times 10 \text{ cm}^2$) and mini-cell configurations ($2 \times 2 \text{ cm}^2$) in order to capture global as well as localized recombination behavior.

Pulsed optical excitation was provided by light-emitting diodes operating at discrete wavelengths of 458, 524, 633, and 864 nm. These wavelengths were selected to enable depth-resolved carrier generation, ranging from near-surface excitation to bulk-dominated absorption, in accordance with the spectral absorption characteristics of silicon. Pulse generation, timing, and synchronization were controlled using an Arduino-based system interfaced with MATLAB/Simulink, providing microsecond-scale temporal resolution.

To assess the impact of passivation on recombination dynamics, a low-temperature thermal annealing treatment at 115 °C for 3 minutes was applied. The resulting OCVD transients were analyzed using exponential fitting procedures, allowing extraction of characteristic decay times corresponding to the effective minority carrier lifetime under different excitation conditions.

3. Results

The spectrally selective OCVD analysis reveals pronounced differences in recombination dynamics between monocrystalline and multicrystalline silicon solar cells. Under broad-area, high-injection excitation, full-size c-Si devices exhibited voltage decay times exceeding 15 ms, indicative of superior crystalline quality and reduced bulk defect density. In contrast, localized

excitation in mini-cell configurations resulted in decay times in the microsecond regime, highlighting the strong influence of injection level and probing scale on recombination kinetics.

Short-wavelength excitation at 458 nm, which predominantly probes the near-surface and emitter regions, produced a marked increase in both open-circuit voltage and decay time following thermal annealing. This behavior confirms the effectiveness of hydrogen-related defect passivation in reducing surface recombination velocity. Conversely, near-infrared excitation at 864 nm, which is primarily sensitive to bulk recombination processes, showed minimal change after annealing, particularly in multicrystalline silicon. This observation indicates the persistence of bulk defect-related recombination associated with grain boundaries and extended defects.

Excitation at intermediate wavelengths exhibited coupled surface–bulk recombination behavior, further validating the depth-resolved capability of the spectrally selective OCVD approach.

4. Conclusions

This work demonstrates that spectrally selective OCVD analysis is a powerful, non-destructive characterization technique for investigating recombination dynamics in silicon photovoltaic energy materials. By enabling clear separation of surface and bulk recombination mechanisms, the method provides direct insight into the effectiveness of passivation treatments. The results confirm that low-temperature thermal annealing primarily enhances surface passivation, with a more pronounced impact on monocrystalline silicon compared to multicrystalline material. Through the integration of wavelength-resolved excitation and high temporal resolution, the proposed approach offers a robust pathway for guiding material optimization and passivation engineering in next-generation high-efficiency silicon photovoltaic technologies.

References

1. M. A. Green *et al.*, « Solar Cell Efficiency Tables (Version 66) », *Progress in Photovoltaics*, vol. 33, n° 7, p. 795-810, juill. 2025, doi: 10.1002/pip.3919.
2. S. P. Muduli et P. Kale, « State-of-the-art passivation strategies of c-Si for photovoltaic applications: A review », *Materials Science in Semiconductor Processing*, vol. 154, p. 107202, févr. 2023, doi: 10.1016/j.mssp.2022.107202.
3. J. Vollbrecht et V. V. Brus, « Effects of Recombination Order on Open-Circuit Voltage Decay Measurements of Organic and Perovskite Solar Cells », *Energies*, vol. 14, n° 16, p. 4800, août 2021, doi: 10.3390/en14164800.
4. K. Joardar et D. K. Schroder, « Analysis of the small-signal voltage decay technique in the characterization of Si concentrator solar cells », *IEEE Trans. Electron Devices*, vol. 39, n° 7, p. 1622-1632, juill. 1992, doi: 10.1109/16.141227.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165774: Structurally Engineered EDOT–Porphyrin Electropolymers for Stable and High-Performance Pseudocapacitive Energy Storage

Jahir Leon Jaramillo¹, Edwin Gonzalez Lopez², Daniel Heredia³, Miguel Gervaldo¹, Luis Otero¹ and Javier E. Durantini^{1,*}

¹ IITEMA-CONICET, Departamento de Química, Facultad de Ciencias Exactas Físico-Químicas y Naturales, Universidad Nacional de Río Cuarto, Agencia Postal Nro. 3, X5804BYA Río Cuarto, Córdoba, Argentina.

² School of Molecular Sciences, Arizona State University, Tempe, Arizona 85287, United States

³ IDAS-CONICET, Departamento de Química, Facultad de Ciencias Exactas Físico-Químicas y Naturales, Universidad Nacional de Río Cuarto, Agencia Postal Nro. 3, X5804BYA Río Cuarto, Córdoba, Argentina.

Introduction

The development of advanced electrode materials capable of delivering high energy and power densities while maintaining long-term operational stability remains a central challenge in electrochemical energy storage. Organic pseudocapacitive materials have emerged as promising candidates in this context, as they offer fast redox kinetics, molecular-level tunability, mechanical flexibility, and compatibility with low-energy, solution-based fabrication processes. In particular, electropolymerized conjugated polymers enable direct, binder-free growth of electroactive films on conductive substrates, ensuring intimate electrical contact and precise control over film thickness and morphology, features that are highly desirable for advanced energy materials.

Porphyrins constitute a unique class of redox-active molecular scaffolds owing to their extended π -conjugation, multielectron redox chemistry, and exceptional chemical robustness. Fully fluorinated porphyrins are especially attractive building blocks, as their strongly electron-withdrawing substitution pattern confers outstanding electrochemical stability and enhanced resistance toward oxidative degradation. When functionalized with polymerizable conjugated substituents, porphyrins can be integrated into extended polymer networks that combine molecular redox activity with efficient charge transport and structural durability. However, the electropolymerization of porphyrin derivatives remains nontrivial, and subtle variations in molecular architecture (such as the number and nature of polymerizable units) can critically influence polymer growth, electrochemical stability, and long-term pseudocapacitive performance. Establishing clear structure–property–performance relationships is therefore essential for advancing porphyrin-based electropolymers toward practical energy storage applications.

Herein, we present a comparative study of two structurally related fluorinated porphyrin monomers, **P-4E**, bearing four 3,4-ethylenedioxythiophene (EDOT) units, and **P-3E-BDT**, incorporating three EDOT units and one benzothiadiazole substituent, which were used as precursors for the electropolymerized films **p-P-4E** and **p-P-3E-BDT**, respectively. These polymer systems provide an ideal platform to elucidate how the nature and distribution of conjugated substituents influence electrochemical stability, rate capability, and pseudocapacitive behavior.

Methods

Electropolymerization of the porphyrin monomers was performed by oxidative cyclic voltammetry using a conventional three-electrode configuration. Glassy carbon (GC), platinum, and indium tin oxide (ITO) electrodes were employed as working electrodes, with a platinum wire counter electrode and a silver wire quasi-reference electrode. Polymer growth was carried out in dichloromethane solutions containing 0.10 M tetrabutylammonium hexafluorophosphate (TBAPF₆) as the supporting electrolyte, applying consecutive potential cycles at a scan rate of 0.1 V s⁻¹ within the anodic window required to promote EDOT coupling. After deposition, the electrodes were rinsed and transferred to monomer-free electrolyte solutions for electrochemical characterization.

Spectroelectrochemical measurements were conducted using polymer-coated ITO electrodes in a UV–Vis transparent electrochemical cell. Film morphology and surface texture were investigated by scanning electron microscopy (SEM) and atomic force microscopy (AFM).

Electrochemical impedance spectroscopy (EIS) measurements were performed using a 5 mV AC perturbation amplitude over a frequency range of 100 kHz to 0.1 Hz. Galvanostatic charge–discharge (GCD) measurements at different current densities were used to evaluate gravimetric capacitance, rate capability, and cycling stability, including extended cycling tests.

Results

Both fluorinated porphyrin monomers were efficiently electropolymerized, yielding uniform and strongly adherent films on GC and ITO substrates. Cyclic voltammetry revealed reversible redox processes associated with both the porphyrin macrocycle and the conjugated EDOT backbone, indicating effective electronic communication within the polymer network.

p-P-4E exhibited a highly reproducible electrochemical response upon extended cycling, whereas **p-P-3E-BDT** displayed more pronounced changes over repeated cycles. GCD measurements confirmed pseudocapacitive behavior for both materials, with nearly linear discharge profiles within the selected potential windows. Spectroelectrochemical measurements revealed reversible, potential-dependent spectral changes consistent with the formation of radical species during oxidation, involving both the EDOT backbone and the porphyrin macrocycle and confirming preservation of the porphyrinic framework during cycling.

At a current density of 5 A g⁻¹, **p-P-3E-BDT** delivered a gravimetric capacitance of approximately 240 F g⁻¹, whereas **p-P-4E** reached higher values of around 320 F g⁻¹ under identical conditions. Moreover, **p-P-4E** showed improved capacitance retention with increasing current density and retained ~90% of its initial capacitance after 3000 charge–discharge cycles, demonstrating excellent durability. Capacitance values derived from GCD were independently corroborated by EIS. SEM and AFM analyses revealed more porous and textured morphologies for **p-P-4E**, consistent with its superior electrochemical performance.

Conclusions

This work demonstrates that molecular engineering of fluorinated porphyrin electropolymers provides an effective approach to access stable and high-performance pseudocapacitive materials. The investigated EDOT–porphyrin polymer networks exhibit reversible redox activity, efficient charge storage, and robust electrochemical behavior over extended cycling. While both systems display pseudocapacitive characteristics, the polymer incorporating a larger number of EDOT units (**p-P-4E**) exhibits enhanced gravimetric capacitance and cycle stability within the investigated current-density range. The combined analysis of galvanostatic charge–discharge and electrochemical impedance spectroscopy confirms a consistent pseudocapacitive response. These results highlight the importance of molecular architecture in porphyrin-based electropolymers and establish fluorinated EDOT–porphyrin systems as promising candidates for advanced organic electrode materials in electrochemical energy storage.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166170: Synergistic Nano-Doping of Ternary Diesel-Coconut Methyl Ester-Ethanol Matrices: Assessing the Interfacial Influence of ZnO and TiO₂ Nanoparticles on Combustion Dynamics, Brake Thermal Efficiency, and Heterogeneous Emission Abatement

Andrey Denelle Arboleda¹, Roberto II Miras¹, Simoun Kille Torres¹, Ruy Vicente Rubi^{2,3}, Allan Soriano⁴, Nathaniel Dugos⁴ and Rich Jhon Paul Latiza^{5,*}

¹ Chemical Engineering Department, College of Engineering, Adamson University, 900 San Marcelino St. Ermita Manila, Philippines

² Chemical Engineering Department, College of Engineering, Adamson University, 900 San Marcelino St., Ermita, 1000, Manila, Philippines

³ Adamson University Laboratory of Biomass, Energy and Nanotechnology (ALBEN), Adamson University, 900 San Marcelino St., Ermita, 1000, Manila, Philippines

⁴ Department of Chemical Engineering, Gokongwei College of Engineering, De La Salle University, Manila, Philippines

⁵ Chemical Engineering Department, College of Engineering, Adamson University

The ubiquity of conventional petroleum diesel in the global transport and industrial sectors has precipitated a critical environmental crisis characterized by the excessive discharge of hazardous pollutants such as nitrogen oxides, particulate matter, and carbon-based greenhouse gases. Despite the current energy transition emphasizes the adoption of bio-based oxygenates like coconut methyl ester (CME) and ethanol to dilute the carbon intensity of fossil fuels, these biological additives often present challenges regarding lower energy density and altered combustion kinetics that can lead to suboptimal engine performance. To address these limitations, the present study proposes the development of a technologically advanced and marketable eco-friendly diesel alternative through the strategic integration of zinc oxide (ZnO) and titanium dioxide (TiO₂) nanoparticles as high-performance fuel additives to stabilize and enhance ternary blends. The experimental methodology involved the formulation of a base mixture consisting of 10% coco methyl ester and 5% ethanol, which was subsequently homogenized with ZnO and TiO₂ at precise concentrations of 10, 20, and 30 parts per million (ppm) using magnetic stirring techniques. This nano-doped matrix was then integrated into 85% pure diesel using a high-shear mixer to ensure uniform particle distribution. Following ASTM-standardized protocols, five distinct samples underwent comprehensive physicochemical property testing to evaluate the impact of nano-augmentation. The results and discussion highlighted a significant enhancement in thermophysical characteristics, particularly for the D85B10E5ZnO20TiO220 blend, which exhibited the highest calorific value recorded at 6702.51 cal/g, notably outperforming binary variants. Engine performance diagnostics revealed that the 20 ppm dual-nanoparticle configuration achieved a brake thermal efficiency of 24.25% and demonstrated a 12.85% increase in brake specific fuel consumption. Crucially, emission analysis revealed profound reductions in carbon dioxide (414.94%) and carbon monoxide (145.58%) compared to baseline D100 diesel. In conclusion, the study underscores the decisive advantages of nanoparticle inclusion in multi-component fuel systems for optimizing combustion efficiency and atmospheric safety. It is recommended that this formulation be further scaled for commercial viability as a sustainable alternative to pure fossil fuels.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-168022: Synthesis and Electrochemical Performance of Mn-ZIF-67 for Faradaic Supercapacitor Applications

Ady Frenly Simanullang^{1,*}, Erna Frida¹, Syahrul Humaidi¹, Ni Luh Wulan Septiani² and Nazwa Hudaiby³

¹ Department of Physics, Universitas Sumatera Utara, Medan 20155, Indonesia

² Electronic and Informatics Research Organization- the National Research and Innovation Agency (BRIN), Samain Science and Technology Area, Bandung City 40135, Indonesia

³ Master's Program in Nanotechnology, Graduate School of Multidisciplinary Science and Technology, Institute of Technology in Bandung (ITB), Bandung City, 40132, West Jawa, Indonesia

The increasing demand for sustainable and renewable energy technologies necessitates the development of efficient, durable, and high-performance energy storage systems to support modern electronic devices and renewable power integration. Among various energy storage technologies, supercapacitors have attracted significant attention due to their high power density, rapid charge–discharge capability, and long cycle life, operating through a combination of electric double-layer capacitance (EDLC) and faradaic redox mechanisms. However, the performance of supercapacitors is strongly governed by the properties of electrode materials, including surface area, electrical conductivity, and electrochemical activity. Metal–organic frameworks (MOFs) have emerged as promising electrode materials owing to their high surface area, tunable porosity, and well-defined crystalline structures. Nevertheless, their practical application is often limited by intrinsically low electrical conductivity and insufficient redox-active sites. ZIF-67, constructed from Co^{2+} ions and 2-methylimidazole ligands, represents a representative MOF material that can be further engineered to improve its electrochemical performance. In particular, partial metal substitution with Mn^{2+} to form bimetallic Mn-ZIF-67 is expected to enhance redox activity, provide additional active sites, and facilitate charge-transfer processes. In this work, Mn-ZIF-67 was successfully synthesized via a facile room-temperature coprecipitation route using mixed Co^{2+} and Mn^{2+} precursors with 2-methylimidazole as the organic linker. The as-prepared material was dried and subsequently characterized to confirm phase formation, crystallinity, and morphological features. Structural and morphological analyses were performed using X-ray diffraction (XRD) and scanning electron microscopy (SEM), revealing the preservation of the ZIF framework and a uniform polyhedral morphology. The electrochemical performance of the Mn-ZIF-67 electrode was systematically evaluated in a three-electrode configuration by cyclic voltammetry (CV), galvanostatic charge–discharge (GCD), electrochemical impedance spectroscopy (EIS), and long-term cycling stability tests. The Mn-ZIF-67 electrode delivered a specific capacitance of 11.1 F g^{-1} at a current density of 1 A g^{-1} , indicating a distinct contribution from faradaic charge storage processes associated with the redox activity of Co and Mn centers. Furthermore, the electrode retained approximately 83% of its initial capacitance after 5000 charge–discharge cycles, demonstrating satisfactory structural stability and electrochemical durability. The stable impedance response further suggests preserved charge-transfer characteristics during prolonged cycling. Overall, these results highlight the feasibility of Mn-modified ZIF-67 as a bimetallic MOF-based electrode material for faradaic supercapacitors and provide valuable insight into the rational design of MOF architectures for next-generation sustainable energy storage applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165029: The hydrogen storage performance and catalytic mechanisms of the $\text{MgH}_2\text{-ZrF}_4$ composite system

Mohammad Ismail

Energy Storage Research Group, Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

1. Introduction

Magnesium hydride (MgH_2) is regarded as a solid-state hydrogen storage material with high potential. Its advantages include low cost, excellent reversibility of release/uptake of hydrogen and abundance on earth compared to other solid-state hydrogen storage materials. Unfortunately, MgH_2 released hydrogen at very high temperatures ($> 400\text{ }^\circ\text{C}$ for the pure MgH_2), sluggishly absorbed and desorbed hydrogen, and stable thermodynamic properties restricted commercialization of MgH_2 for hydrogen storage applications. To overcome this problem, many approaches have been studied, such as using high-energy ball milling to synthesize nanoparticles of MgH_2 using catalysts or additives that lower the energy barrier for Mg-H bond breaking and shorten hydrogen diffusion pathways, and mixing with other metals or hydrides (destabilized concept) that will alter the thermodynamic properties of MgH_2 .

2. Methods

This study examines the impact of zirconium fluoride (ZrF_4) addition on the MgH_2 synthesized using ball milling to improve hydrogen storage properties. The prepared 10 wt.% ZrF_4 -doped MgH_2 sample was characterized by X-ray diffraction, pressure-composition-temperature (PCT) curves and differential scanning calorimetry (DSC).

3. Results

From the PCT characterization, the 10 wt.% ZrF_4 -doped MgH_2 sample demonstrated improved hydrogen storage properties relative to as-milled MgH_2 , with the onset decomposition temperature reduced from $340\text{ }^\circ\text{C}$ to $220\text{ }^\circ\text{C}$. The absorption/desorption kinetics measurements proved that the sample of 10 wt.% ZrF_4 -doped MgH_2 can release and uptake hydrogen much faster than the pure as-milled MgH_2 . From the DSC measurement at different heating rates, the apparent activation energy for hydrogen release from 10 wt.% ZrF_4 -doped MgH_2 is reduced significantly compared to the undoped MgH_2 .

4. Conclusions

The improved hydrogen storage properties of MgH_2 in the presence of ZrF_4 are thought to be due to the function of in situ produced active species that form during the dehydrogenation process. This active species plays a critical role in catalyzing the hydrogen release and uptake in the ZrF_4 -doped MgH_2 composite system.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-153423: Theoretical study of hybrid architectures combining graphene substrate with single-molecule magnets

Manel Mabrouk * and Jacek A. Majewski

University of Warsaw, Faculty of Physics, Pasteura 5, 02-093 Warsaw, Poland

We explore the fascinating features of unique hybrid structures composed of single-molecule magnets (SMMs) integrated with two-dimensional nanomaterials, such as graphene. These hybrid systems exhibit novel magnetic, electronic, and quantum properties arising from the synergistic interaction between the molecular magnets and the two-dimensional substrate. The combination enhances functionalities like magnetic anisotropy, spin coherence, and charge transport, opening new avenues for applications in quantum computing, spintronics, and advanced nanoelectronics. The fascinating features of the unique hybrid structures made of single molecule magnets (SMMs) and two-dimensional nano-materials (like graphene) have drawn the attention of experimental researchers. Such systems might eventually form a reconfigurable array of magnetic nano-objects and give rise to cutting-edge spin-based technology like spin quantum memory. The stability of these hybrid structures and the kinds of interactions between the localized spin in SMM and the 2D material to which the molecule is grafted are examined in detail theoretically, and results are presented here. Our theoretical investigation is supported by density functional theory based on ab initio computations. We pay close attention to how to properly describe magnetism and van der Waals dispersive forces. In addition, we looked at a few types of SMMs (molecules with tetrahedrally coordinated Fe and Cr bound to two double bis(methanesulfonamido) benzene ligands), and we examined their adsorption to a graphene monolayer. In addition, we address the crucial topic of how structural defects in graphene (such as vacancies, N-dopants, etc.) affect the adhesion and magnetic characteristics of SMMs.

This work provides valuable insights into the design of graphene-SMM hybrid materials, emphasizing the role of molecular coordination and ligand architecture in achieving stable and functional interfaces. The findings pave the way for future exploration of SMM-graphene composites in nanoscale magnetic sensors, data storage, and quantum computing technologies, where the integration of magnetic molecules with two-dimensional materials could offer unprecedented control over spin-dependent phenomena.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166150: Thermally-Optimized Synthesis of *Arenga pinnata* Nut-Derived Bio-Carbon Cathodes for Enhanced Ion-Transport Dynamics in Battery Electrode Deionization (BDI) Architectures

Jewel Rose Barbon¹, Andrei Matias¹, Abigail Monis¹, John Paul Parani¹, Paul JenRae Samson¹, Coleen Moira Sarmiento¹, Jerry Olay^{1,2}, Rugi Vicente Rubi^{1,2} and Rich Jhon Paul Latiza^{1,2,*}

¹ Chemical Engineering Department, College of Engineering, Adamson University, 900 San Marcelino St., Ermita, 1000, Manila, Philippines

² Adamson University Laboratory of Biomass, Energy and Nanotechnology (ALBEN), Adamson University, 900 San Marcelino St., Ermita, 1000, Manila, Philippines

The escalating global water-energy nexus crisis necessitates the urgent development of resource-efficient desalination technologies that bypass the carbon-intensive footprints of traditional thermal and membrane-based processes. Current electrochemical deionization frameworks, such as Capacitive Deionization (CDI) and Battery Electrode Deionization (BDI), are often hindered by the high synthesis costs and environmental liabilities associated with synthetic, petroleum-derived electrode materials, which frequently exhibit suboptimal ion-transport kinetics under varying operational regimes. To address these critical bottlenecks, this research explores the pyrolytic transformation of *Arenga pinnata* (Kaong) nutshells—an abundant agricultural byproduct—into a high-performance, bio-based porous carbon cathode for integration into advanced BDI architectures. The study focuses on leveraging the inherent lignocellulosic microstructure of the Kaong precursor to synthesize a hierarchically porous membrane capable of efficient NaCl sequestration. The experimental methodology involved the systematic evaluation of the synthesized cathode's performance metrics, specifically focusing on ion removal efficiency, effluent stream concentration profiles, and Salt Absorption Capacity (SAC). A multi-parametric analysis was conducted to examine the influence of hydrodynamic and thermodynamic variables, namely volumetric flow rates and system temperatures, on the electrosorption phenomena. Statistical validation was rigorously performed using Analysis of Variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) tests to ensure the reproducibility and significance of the observed data. The results reveal a significant inverse relationship between operational temperature, flow velocity, and SAC; specifically, lower thermal environments were found to significantly enhance electrode wettability and ion-trapping stability. The optimal performance threshold was identified at a temperature of 15 °C and a flow rate of 5 mL/min, conditions which facilitated maximum desalination efficiency through improved interfacial contact and reduced ionic mobility resistance. Ultimately, the findings highlight the viability of *Arenga pinnata*-derived bio-carbons as sustainable, cost-effective alternatives to conventional electrodes, promoting a circular economy model within the water-energy sector. This study provides a foundational blueprint for future innovations in long-term electrode stability and the application of bio-electrochemical systems in treating diverse feed water sources, contributing to the advancement of sustainable materials in the global transition toward smart energy management.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166186: TiSiO_4 as a Catalytic Dopant for Lowering the Decomposition Temperature and Improve Kinetics of AlH_3 for Solid-State Hydrogen Storage

Ayob Zanberi * and Mohammad Ismail

Energy Storage Research Group, Faculty Of Ocean Engineering Technology, University Malaysia Terengganu, Kuala Terengganu, Malaysia

Aluminium hydride (AlH_3) is a promising solid-state hydrogen storage material due to its high theoretical capacity of 10.1 wt.% H_2 . However, its practical use is limited by a high decomposition onset temperature and slow desorption kinetics. This study introduces titanium silicate (TiSiO_4) as a novel catalytic dopant to address these challenges. A composite of 10 wt.% TiSiO_4 - AlH_3 was prepared via planetary ball milling under an argon atmosphere. The dehydrogenation behavior was systematically investigated using temperature-programmed desorption (TPD), isothermal kinetics measurements, differential scanning calorimetry (DSC), X-ray diffraction (XRD), and scanning electron microscopy (SEM). The incorporation of TiSiO_4 profoundly enhanced the dehydrogenation performance. TPD revealed that the onset temperature for hydrogen release dropped from 127 °C for milled AlH_3 to below 50 °C—a reduction exceeding 77 °C. Isothermal desorption at 60 °C showed that the doped composite released about 2.1 wt.% H_2 within the first hour, while the undoped material was nearly inert. Kissinger analysis of DSC data indicated a substantial decrease in the apparent activation energy by 46.6 kJ/mol, confirming a lowered kinetic barrier. Mechanistic studies revealed a synergistic two-part effect of TiSiO_4 . Although not directly detected by XRD due to its low content and possible amorphous nature, TiSiO_4 is proposed to electronically polarize and weaken Al-H bonds at the surface, facilitating initial bond cleavage. Simultaneously, SEM and XRD evidence indicates that TiSiO_4 acts as a nanostructuring agent, dispersing AlH_3 into finer particles during milling and heating. This creates a nanoconfinement effect that shortens hydrogen diffusion paths, suppresses agglomeration of AlH_3 and metallic Al during decomposition, and provides nucleation sites for Al formation—a critical step in the decomposition pathway. In summary, TiSiO_4 doping introduces a dual catalytic and nanoconfinement mechanism that destabilizes AlH_3 , significantly lowers its decomposition temperature, and accelerates hydrogen release kinetics. This work not only identifies TiSiO_4 as an effective catalyst for AlH_3 but also provides a mechanistic framework that highlights the value of composite design in advancing metal hydrides for practical hydrogen storage.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Session 6. Electrical Power Systems

sciforum-165378: A Resilient Multi-Objective MOABC–NSGA-II Optimization approach for Fault Location and Restoration Time Reduction in Wind-integrated Power Grid Networks

Abhishek Bajirao Katkar

Electrical Engineering, Lecturer, Government Polytechnic, Kolhapur, Maharashtra, 416004, India

The increasing penetration of renewable resources, particularly wind generation, introduces considerable stochasticity into modern transmission networks, thereby complicating system monitoring, fault diagnosis, and post-disturbance restoration. Sudden fluctuations in wind power injections can distort network states, reduce observability, and hinder the accuracy of conventional protection schemes. As a result, the ability to accurately locate faults and minimize restoration time has become a critical requirement for achieving resilient power system operation. Motivated by these evolving challenges, this paper proposes a comprehensive multi-objective optimization framework for **simultaneous fault location and restoration time minimization** in a **modified IEEE 39-Bus transmission system** that incorporates both thermal generating units and probabilistic wind-energy resources.

The proposed methodology extends the OPF-embedded fault-location paradigm established in earlier research by formulating fault resistance, faulted-bus index, and corrective operational decisions as optimization variables. Wind uncertainty is represented using probabilistic forecast distributions, ensuring that the model realistically captures variability in renewable injections. The multi-objective problem is solved using a **hybrid MOABC–NSGA-II metaheuristic**, chosen for its complementary strengths: the Multi-Objective Artificial Bee Colony (MOABC) algorithm contributes strong global exploration and adaptability under non-convex OPF landscapes, while NSGA-II provides efficient non-dominated sorting, diversity preservation, and convergence control. Together, these capabilities allow the hybrid framework to effectively navigate the intricate solution space induced by fault scenarios and renewable variability. The optimization simultaneously minimizes two conflicting objectives: (i) **fault-location mismatch**, defined as the error between the measured system quantities and the OPF-estimated post-fault responses; and (ii) **restoration time**, expressed as a composite of switching, feeder reconfiguration, generator rescheduling, and ramping delays.

The resulting Pareto front reveals the trade-offs inherent in achieving high diagnostic accuracy while reducing operational downtime. Simulation studies were carried out across multiple wind-power uncertainty cases, enabling a robust performance assessment under realistic stochastic operating conditions. Results indicate that the hybrid MOABC–NSGA-II approach consistently outperforms standalone MOABC and NSGA-II algorithms across all tested scenarios. The hybrid formulation achieves smoother, denser Pareto fronts with enhanced convergence behavior and improved solution diversity. Notably, the method demonstrates superior robustness under large wind-power fluctuations, maintaining both accurate fault localization and minimal restoration times even in the presence of significant uncertainty. In addition, the framework exhibits computational scalability suitable for real-world transmission-level applications.

Overall, the proposed hybrid multi-objective OPF-based strategy advances the state of the art in fault management for renewable-integrated grids. By unifying fault localization and restoration optimization within a probabilistically informed decision-support mechanism, the framework provides power system operators with a powerful tool for improving situational awareness and accelerating service recovery. The results underscore the potential of metaheuristic hybridization and uncertainty-aware OPF modeling to strengthen grid resilience and operational reliability in an emerging era of high renewable penetration.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170611: Non-Iterative Lagrange Multiplier Approach for Maximum Power Point Tracking in Photovoltaic Systems

Mohamed Louzazni^{1,*}, Wardi Fatima¹, Oussama Khouili² and Hafsa Khayrane¹

¹ Science Engineer Laboratory for Energy, National School of Applied Sciences, Chouaib Doukkali University, El Jadida 24000, Morocco

² LTI Laboratory, National School of Applied Sciences, Chouaib Doukkali University, El Jadida 24000, Morocco

Accurate and effective optimization of photovoltaic (PV) systems is still a challenging task because solar cell current-voltage (I-V) characteristics are strongly sensitive to environmental conditions, which behave nonlinearly. This paper presents an analytical, non-iterative method to achieve the global maximum power point (MPPT) of PV cells and panels based on the Lagrange Multiplier Method (LMM). Compared with traditional iterative and empirical methods, the proposed method can obtain a mathematical optimization solution directly for output power maximization of PV systems in terms of single-diode and double-diode equivalent circuit models with series and parallel resistances.

An objective function and a constraint are set up for the optimization problem, consisting of the desired output power and nonlinear current-voltage solar cell equation. The problem becomes a matter of a reduced analytical approach by normalizing the variables with respect to current and voltage, which leads to the application of constrained optimization theory. Then, the Lagrange Multiplier Method is used under standard regularity and optimality conditions such as the KKT, Fritz John, Mangasarian-Fromovitz (MFCQ), or Linear Independence Constraint Qualification. These statements ensure that there is an optimal solution, which further means that the condition of optimality is satisfied.

Regarding the single-diode model, an analytical solution results in a second-order polynomial equation that describes the efficiency gap against the current density [12], which is of third-order type for the double-diode model. The optimal current, voltage, and load resistance corresponding to the maximum power point are analytically obtained in closed forms. The physical meaning of the Lagrange multiplier is also presented, emphasizing its connection with the characteristic resistance of the solar cell at the maximum power point.

To assess the efficiency and applicability of the proposed method, a series of simulations are performed based on experimental data recorded from R.T.C France (silicon solar cell) and Photowatt-PWP 201 (photovoltaic module). Further validation is carried out on the different PV technologies, such as monocrystalline silicon, polycrystalline silicon, amorphous silicon, and copper indium diselenide (CIS) modules. The results indicate that the analytically calculated maximum power point corresponds well with experimental current-voltage and power-voltage characteristics for various operating temperatures and technologies.

The Lagrange-based optimization is an effective, fast, and low-cost approach compared to the conventional heuristic search techniques of AI for MPPT. Its non-iterative nature, analytical transparency, and versatility make it especially well-suited for real-time PV analysis, system sizing, and performance estimation tasks, as well serving as a bridge from optimization environments to larger PV plant and system hybrids.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164414: A Two-Stage Random Forest Analysis Framework for Electricity Price Forecasting and Spike Driver Interpretation

Wei Lu^{1,*}, Jay Wang¹ and Caiyi Song²

¹ School of Engineering, Computer & Mathematical Sciences, Auckland University of Technology, Auckland 1010, New Zealand

² Green Gold Energy Pty Ltd, Adelaide SA 5063, Australia

Introduction:

Electricity price forecasting in power markets is critical for energy trading, grid dispatch, and risk management. However, traditional forecasting models often focus on improving accuracy while lacking the ability to explain the underlying drivers of predictions, especially during key scenarios such as price spikes. To address this challenge, this study focuses on the high volatility and pronounced price spikes observed in the Australian National Electricity Market (NEM). It proposes a two-stage integrated framework that combines time-series feature engineering with interpretability analysis. The framework is designed to achieve both high predictive accuracy and strong interpretability, providing decision-makers in this market with analytical tools that offer both robust performance and meaningful insight.

Methods:

This study focuses on a systematic two-stage random forest analysis framework, empirically validated using historical operational data from the Australian NEM. The first stage involves dynamic feature engineering, constructing a multi-dimensional feature pool that includes original variables, lagged features (1–24 hours, 48 hours, 168 hours), rolling statistics (mean, standard deviation, extreme values), time indicators (hour, day of week, month, etc.), interaction terms, differentials and change rates, and statistical features, generating over a hundred candidate features in total. The second stage focuses on feature selection and modelling: first, feature importance is evaluated based on out-of-bag error increment from the random forest, selecting key features that either cumulatively account for more than 95% of importance or the top 30 features; subsequently, a final random forest model is trained using the selected features. To further enhance model interpretability, the framework integrates SHapley Additive exPlanations (SHAP) analysis, obtaining feature contribution values through simplified calculations, with special attention given to identifying driving factors during the Australian market's electricity price spike periods.

Results:

Testing results show that the proposed framework achieves prediction performance on the validation set with a root mean square error (RMSE) of 10.1626, a mean absolute error (MAE) of 3.8179, and a mean absolute percentage error (MAPE) of 33.36%. Compared to the baseline model using only original features, both RMSE and MAPE are significantly reduced. Compared to the model using all features without selection, RMSE improves by 1.01% and MAPE by 12.56%, indicating that feature selection effectively enhances the model's generalization capability and robustness. Interpretability analysis further reveals that interaction features (such as price–demand interaction terms), price rolling statistics, and key variables among the original features contribute most significantly to predictions. Among the 209 identified Australian market electricity price spike moments, SHAP analysis clearly points out the main driving factors influencing spike formation, providing a quantitative basis for understanding extreme price volatility in this market.

Conclusion:

The integrated framework of time-series feature engineering and interpretability analysis proposed in this study not only improves the accuracy of Australian electricity market price forecasting through a two-stage feature selection mechanism, but also achieves transparency and interpretability in model decision-making via the SHAP method. This framework can effectively identify key causes of this market's electricity price spikes, providing electricity market

operators, traders, and policymakers with an analytical tool that combines predictive performance with mechanistic explanation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166367: A Universal ECM Parameter Estimation Algorithm Developed from Multi-C-Rate Modified HPPC Tests

Martina Totaro^{1,2,*}, **Davide Aloisio**², **Orazio Barbera**², **Giacomo Risitano**¹, **Francesco Sergi**² and **Giosuè Giacompo**²

¹ Department of Engineering, University of Messina, Contrada di Dio (S. Agata), 98166 Messina, Italy

² National Research Council - Institute of Advanced Technologies for Energy "Nicola Giordano" (CNR-ITAE), Salita S. Lucia Sopra Contesse, 5, 98126 Messina, Italy

Introduction

In recent years, Equivalent Circuit Models (ECMs) have been extensively investigated in the literature as effective tools to accurately predict the current-voltage performance of lithium-ion cells. Battery performance is highly influenced by operating conditions: temperature, load current and state of charge (SOC). To characterize the circuit elements of ECMs, Hybrid Pulse Power Characterization (HPPC) tests are commonly employed. This study proposes the characterization of Panasonic NCR18650B lithium-ion batteries as a function of SOC and C-rate at constant temperature, using a modified HPPC-based methodology aimed at reducing testing time while preserving the completeness of the battery characterization: instead of performing separate HPPC tests for each C-rate, the proposed approach integrates multiple C-rates within a single dynamic test profile. A key contribution of this work is the development of a parameter estimation algorithm derived from MATLAB fitting functions originally meant for traditional HPPC tests, generalized to achieve universal applicability to both conventional and modified HPPC test profiles. Based on the identified parameters, a two-parallel ECM battery model is developed in a Simulink/Simscape environment using the Battery Equivalent Circuit block. The model accuracy is finally evaluated by comparing simulated and experimental voltage responses.

Methods

In this work, the model circuit consists of a dc voltage source, a series resistance and two RC parallel networks. The dc voltage source is used to represent the open circuit voltage of battery (E_{ocv}), series resistance (R_s) is used to represent the internal dc resistance and RC parallel branches (R_1 , C_1 , R_2 , C_2) are used to characterize the transient response of voltage. The model input is the applied current profile (i_{in}) and the output is the terminal voltage V_t ; the parameters are dependent on SOC and current, while temperature dependence is neglected with tests performed at fixed 25 °C. The model is developed in MATLAB/Simulink using the Simscape Battery Equivalent Circuit block. Parameters are identified from experimental measurements obtained through a modified Hybrid Pulse Power Characterization (HPPC) test. Unlike conventional approaches, where model parameters are identified through separate HPPC tests for each C-rate, the proposed methodology unifies all current levels within a single experimental test in which four different C-rates (0.25C, 0.5C, 0.75C, and 1C) are applied at each SOC level, with SOC ranging from 100% to 0% in 5% intervals. The open-circuit voltage is estimated as the voltage value immediately preceding each current pulses series in each soc value. The ohmic resistance and RC branches parameters are identified using MATLAB's *fitECM* function. Since this function is originally intended for standard HPPC datasets, dedicated pre-processing algorithms have been developed to adapt it to the modified test structure. These algorithms automatically detect, classify and extract current pulses directly from the experimental data by associating each pulse with its corresponding C-rate based on the structure of the applied current profile. Pulses belonging to the same current level are grouped and stored in dedicated *pulseData* objects. Each *pulseData* object is then used as input to the *fitECM* routine to estimate the ECM parameters corresponding to the specific operating condition. The identified parameters are finally organized into two-dimensional lookup tables as functions of SOC and current, which are used to parameterize the Simscape ECM block.

Results

The comparison between experimental and simulated voltage profiles shows that the model successfully reproduces dynamic voltage, confirming the effectiveness of the proposed parameter identification strategy. Discrepancies become more evident at low SOC values, where the simulated voltage slightly deviates from the experimental measurements. These errors highlight intrinsic limitations of the chosen second-order ECM in representing complex electrochemical behavior (i. e. nonlinear dynamics caused by phenomena like electrolyte lithium-ion depletion and solid-phase diffusion limitations close to the cell's working limits). This nonlinearity is reflected in the open-circuit voltage (specifically the 'knee' of the OCV curve) and significant parameter variation, which collectively degrade model performance. Nevertheless, the overall accuracy remains suitable for system-level simulations and control-oriented applications.

Conclusions

This study demonstrates that a pulse extraction and MATLAB-based parameter fitting algorithm enable efficient identification of ECM parameters as functions of both SOC and C-rate from a single modified HPPC dataset. The proposed methodology not only reduces experimental effort but also provides a fast and universally applicable tool for ECM parameter estimation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170895: Accurate small-signal dynamic modeling of Symmetrical SOGI-PLL (SSOGI-PLL) structure

Muhammad Armughan Shakeel^{1,*}, Jose Matas¹, Keval Prakash Desai¹ and Josep Maria Guerrero²

¹ Electric Engineering Department, Polytechnic University of Catalonia (EEBE-UPC), Barcelona, 08019, Spain

² Center for Research on Microgrids, Huanjiang Lab, Zhejiang University, Zhuji, Shaoxing, Zhejiang, 311800, China.

With the increasing complexity of modern power systems, grid synchronization has become more challenging due to the presence of DC offsets, subharmonics, and voltage distortions. One of the recent approaches capable of fully addressing these issues single-handedly is the symmetrical second-order generalized integrator phase-locked loop (SSOGI-PLL). It uses a low-pass filter (LPF) tuned to the system frequency to make the quadrature output of the SOGI function like a band-pass filter (BPF). As a result, the system can operate effectively in the presence of subharmonics and DC-offset. Moreover, the low-pass filter (LPF), tuned to the grid frequency, facilitates accurate measurement of the total harmonic distortion (THD) in the grid voltage. Although the small-signal model of the SSOGI-PLL has been developed, certain dynamic parameters, particularly the third pole introduced by internal filtering and control dynamics, are approximated using empirical assumptions. These approximations, often expressed as multiples of the fundamental frequency, result in uncertainty in modeling accuracy and limit the reliability of the analysis.

This paper focuses on the systematic refinement of the existing small-signal model of the SSOGI-PLL by identifying the most accurate location of the third pole. Starting from the established analytical model, multiple candidate representations are formulated by assigning different values to the uncertain pole, such as 2.5, 2.8, and 3 times the fundamental angular frequency. The dynamic behavior of these models is evaluated through time-domain and frequency-domain analysis and compared with the response of the nonlinear SSOGI-PLL system.

Extensive validation is performed using MATLAB/Simulink simulations under various grid disturbance scenarios, including voltage sag and swell, harmonic and subharmonic distortion, frequency deviations, and phase-jump perturbations. The comparative results demonstrate that the proposed methodology enables accurate identification of the third pole and significantly improves the agreement between the small-signal model and the nonlinear system behavior.

The refined model provides a reliable analytical foundation for stability assessment and performance evaluation of SSOGI-PLL-based synchronization systems. By resolving the uncertainty associated with the third pole, this work enhances the credibility of small-signal analysis and supports more reliable design and optimization for this grid synchronization scheme.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170397: Comparative Study of SOGI-Based Structures for Fault Diagnosis in EV Charging Pile Rectifiers with Typhoon Validation.

Keval Prakash Desai^{1*}, Jose Matas¹, Muhammad Armughan Shakeel² and Josep M. Guerrero³

¹ Barcelona East School of Engineering (EEBE), Polytechnic University of Catalonia—BarcelonaTech (UPC), 08034 Barcelona, Spain

² Polytechnic University of Catalonia—BarcelonaTech (UPC), 08034 Barcelona, Spain

³ Center for Research on Microgrids (CROM), Zhejiang University, Hangzhou 310027, China

The rapid expansion of electric vehicle (EV) fast-charging infrastructure has increased the demand for reliable and real-time fault diagnosis techniques in power electronic converters. The Vienna rectifier and the DC/DC converter are widely adopted in DC charging stations due to their high efficiency, low harmonic distortion, and reduced component count; however, they remain vulnerable to open-circuit and short-circuit faults in semiconductor devices and DC-link components. Signal-based diagnostic methods that rely on grid-synchronized estimators have gained attention due to their low computational burden and suitability for real-time implementation. Among these, Second-Order Generalized Integrator (SOGI)-based Frequency-Locked Loop (FLL) structures can be used for frequency, amplitude, and harmonic estimation. Despite their widespread use in synchronization and power quality monitoring, a systematic comparison of different SOGI-based structures for converter fault diagnosis—particularly under real-time operating conditions—has not yet been reported. This work addresses this gap by comparatively evaluating multiple SOGI-FLL variants for fault diagnosis in rectifiers used in EV DC charging applications.

This paper will present a comparative analysis of different SOGI-based grid estimation structures. Each structure is integrated into an identical fault diagnosis framework based on total harmonic distortion (THD) estimation, frequency deviation, and amplitude variation of the measured signals. The diagnostic method is applied to a three-phase Vienna rectifier model subjected to representative open-circuit and short-circuit fault scenarios affecting switching devices and DC-link components. To ensure a fair comparison, all SOGI variants are tuned using equivalent nominal parameters and evaluated under identical operating conditions. Performance metrics include fault detection time, sensitivity to fault severity, robustness to noise and grid disturbances, and computational complexity. To validate real-time feasibility and practical applicability, the proposed framework is implemented and experimentally tested using a Typhoon Hardware-in-the-Loop (HIL) simulation platform, enabling realistic fault injection, switching behavior, and sensor non-idealities.

The comparative results demonstrate that all investigated SOGI-based structures are capable of detecting converter faults using THD-based indicators; however, significant differences are observed in detection speed, noise immunity, and stability under distorted grid conditions. Hardware-in-the-Loop experiments confirm the simulation findings and validate the real-time operation of the diagnostic algorithms, with detection delays remaining within a few tens of milliseconds for all studied fault cases.

This study provides a systematic and experimentally validated comparison of SOGI structures for fault diagnosis in Vienna rectifiers. The results highlight clear trade-offs between estimation accuracy, robustness, and computational complexity, offering practical design guidelines for selecting suitable SOGI configurations in real-time diagnostic applications. The successful implementation on a Typhoon HIL platform confirms the feasibility of SOGI-based THD estimation as a reliable and interpretable diagnostic tool for EV DC charging systems. The findings support the extension of this methodology to other converter topologies and real-world charging infrastructure.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171170: Design and Development of a Low-Cost Power Harmonics Monitoring Device for LED Lighting Systems: An Experimental Case Study

Paul John Plaza Infante * and Edward Querikiol

School of Engineering, University of San Carlos, Cebu City, 6000, Philippines

A light-emitting diode, also known as an LED, is a modern lighting technology that consumes 70% to 85% less energy than other lighting technologies. However, an LED is a nonlinear load that generates harmonic distortion, thereby distorting the sinusoidal waveforms. A larger number of LED installations in buildings may lead to severe power quality issues, and there is a lack of research on LED harmonic monitoring and laboratory testing, with underdeveloped innovation in practical power harmonic monitoring of LED lamps. To monitor the harmonic level in the system, the study aimed to design and develop a low-cost power-harmonic monitoring device for LED systems. The comparison of the Fluke 1736 power logger with a prototype using a low-cost ESP32 microcontroller with current and voltage sensors involved an experimental setup comprising a single LED and 18 LED tubes operated in a low-voltage, also known as an LV network, single-phase, 60Hz. The Total Harmonic Distortion or THD measurement method was applied, and the harmonic results were validated against specific IEC standards. It was observed that a single FSL T8 18W LED had a 236.3V and a 0.14A, with 0.51 pf, 94.7% total current harmonic distortion (THDi), and 1.5% total voltage harmonic distortion (THDv). For the 18 LED tube orientation, it produced 242.7V and 2.2A, with 0.56 pf, 133.8% THDi, and 1.7% THDv. The absolute error of the prototype is $\pm 0.5V$ and $\pm 0.02A$, with THDi and THDv at $\pm 1.35\%$ and $\pm 0.04\%$, respectively, which are within acceptable error limits of the IEC standards for low-cost instrumentation Class II and S. The findings showed that the FSL T8 18W LED has a poor power factor with a high THD content. The current harmonic distortion is directly related to the number of LED installations. The study revealed that it is essential to monitor power harmonics in modern lighting technology, and this can be achieved with a low-cost power-harmonic monitoring device.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-168993: From Conventional to Digital Substations: A Systematic Review of Migration Strategies, Standards, and Emerging Technologies

Diego Ticona Mamani^{1,*} and Fahad Saleh Al-Ismaïl²

¹ Electrical Engineering Department, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran, Saudi Arabia

² Interdisciplinary Research Center for Sustainable Energy Systems (IRC-SES), KFUPM, Dhahran, Saudi Arabia

The transition from conventional air-insulated substations (AISs) to hybrid and fully digital substations constitutes a structural transformation in power system architecture, communication infrastructure, protection philosophy, and asset management practices. This transition redefines not only primary and secondary equipment interfaces but also engineering workflows, interoperability requirements, and operational performance expectations. Although numerous studies address specific technologies and pilot implementations, a comprehensive and methodologically rigorous synthesis of migration strategies, enabling standards, and deployment challenges remains limited. This paper presents a systematic literature review aimed at identifying dominant technological pathways, implementation barriers, reported benefits, and emerging research directions associated with digital substation transformation.

The review was conducted following a structured systematic review protocol inspired by PRISMA guidelines to ensure transparency and reproducibility. A comprehensive search was performed in IEEE Xplore and ScienceDirect for peer-reviewed publications published between 2005 and 2025. Predefined Boolean search strings combined terms such as “digital substation,” “IEC 61850,” “process bus,” “station bus,” “substation automation,” and “protection and control modernization.” After duplicate removal, titles and abstracts were screened against explicit inclusion criteria (peer-reviewed journal articles and conference papers addressing substation architecture, communication infrastructure, protection and control integration, or migration strategies) and exclusion criteria (non-technical reports, non-English publications, and studies lacking architectural or implementation relevance). Full-text assessment was subsequently conducted, and the final set of eligible studies underwent structured data extraction using predefined classification variables. All screening stages and eligibility decisions were documented to guarantee methodological consistency.

The selected studies were systematically categorized according to substation architecture level (conventional, hybrid, fully digital), communication layer (station bus, process bus, or combined), measurement interface type (conventional CT/VT versus Non-Conventional Instrument Transformers), scope of protection and control integration, and migration strategy (incremental retrofit, phased modernization, or greenfield deployment). A comparative synthesis was performed to evaluate architectural features, interoperability performance, communication determinism, time synchronization requirements, engineering complexity, cybersecurity implications, and reported operational performance indicators.

The review confirms that IEC 61850-based architectures—particularly the coordinated implementation of station bus and process bus—represent the dominant technological foundation of digital substations. The deployment of Intelligent Electronic Devices (IEDs), Merging Units (MUs), and communication mechanisms based on Sampled Values (SV) and GOOSE messaging is consistently identified as the core enabler of interoperability and functional integration. Reported benefits include substantial reduction of copper wiring, improved measurement fidelity, enhanced personnel safety through elimination of high-energy secondary circuits, faster and more selective protection response, and improved system observability and asset diagnostics capabilities.

Despite these advantages, large-scale adoption remains constrained by several technical and organizational challenges. These include multi-vendor interoperability limitations, strict latency and synchronization requirements for process-bus applications, increased engineering and configuration complexity, testing and commissioning difficulties, workforce skill gaps, and

heightened cybersecurity exposure in highly interconnected digital environments. Furthermore, heterogeneous implementation practices and limited standardization in validation procedures continue to restrict widespread deployment.

Significant research gaps are identified in long-term reliability and availability assessment, standardized interoperability validation frameworks, systematic cyber-resilience evaluation methodologies, and documented large-scale field deployment experiences. Emerging research directions include the integration of digital twins for real-time simulation and decision support, artificial intelligence for engineering automation and predictive maintenance, cloud- and edge-based automation platforms, and software-defined protection architectures.

By explicitly defining a transparent and reproducible review protocol, this work provides a structured reference framework to support utilities, manufacturers, system integrators, and researchers in the systematic evaluation and implementation of reliable, cost-effective, and resilient migration strategies toward fully digital substations.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-148192: FSM-Guided Adaptive MPC for Robust Fault-Tolerant Control of PV Inverters

Muzammil Ahmed

Department of Electronics and Electrical Engineering, IIT Guwahati, Assam, India

The rapid growth of photovoltaic (PV) systems has made them a central component of renewable energy integration. However, PV inverters, which are responsible for converting direct current (DC) into alternating current (AC) for grid compatibility, remain highly vulnerable to faults. Issues such as sensor offsets, partial shading, and grid disturbances can cause performance degradation, instability, and even disconnection from the grid. These challenges pose significant risks to system reliability. Conventional control strategies, including proportional-integral-derivative (PID) controllers, often fail to adapt dynamically to such disturbances. Similarly, standard Model Predictive Control (MPC) approaches with fixed parameters may be ineffective under fault conditions. This has created the need for advanced fault-tolerant control (FTC) methods.

Recent studies have explored residual-based fault detection, where discrepancies between expected and actual outputs are monitored to identify faults, as well as finite-state-machine (FSM)-based frameworks to govern system behavior under different operating conditions. However, integrating these approaches directly into MPC for real-time adaptation has been relatively unexplored, particularly for PV inverters.

This work introduces a novel FSM-guided adaptive MPC framework aimed at detecting faults and adjusting control strategies on the fly. The proposed scheme is designed not only to identify fault conditions but also to reconfigure its optimization priorities to maintain stability and performance despite variations in operating conditions and reference signals. The approach is validated using a detailed discrete-time simulation of a PV inverter, where fault offsets and varying reference signals are introduced to stress the system.

The FSM operates with two modes: normal and faulty. Fault detection relies on monitoring the residual, which measures the deviation between the system's actual and nominal outputs. When the residual surpasses a threshold, the controller switches to the faulty mode, assigning greater importance to minimizing output errors while allowing for sharper control actions. Once the residual returns below a recovery threshold, the FSM transitions back to the normal mode with smoother control behavior.

Simulation results over 350 time steps show that the proposed adaptive MPC effectively maintains stability and tracking performance under fault conditions. When a disturbance is applied, the FSM correctly identifies the fault and transitions the controller to a more aggressive setting. This reduces tracking error compared to the normal operating mode and ensures the inverter output closely follows the reference despite the disturbance. Once the disturbance subsides, the controller smoothly transitions back to its original configuration. Additional analyses, such as state trajectories, phase plots, and control cost evaluations, confirm both the stability and robustness of the system.

Overall, the FSM-adaptive MPC framework improves fault tolerance in PV inverters by combining residual-based detection with dynamic tuning of control parameters. The method shows significant improvement in tracking accuracy during faults while maintaining overall system stability. Beyond its strong simulation performance, this framework addresses pressing reliability challenges in renewable energy integration. Future work will focus on expanding the FSM to multiple states, refining fault detection thresholds, and conducting hardware-in-the-loop experiments to demonstrate its practicality for real-world grid-connected PV systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171279: Optimal Reactive Power Dispatch Management of Renewable Energy integration Using Improved Salp Swarm Algorithm

Himmat Singh * and Umesh Kumar Saket

Electrical Engineering Department, Madhav Institute of Technology& Science, Gwalior, Pin-: 474005, Madhya Pradesh, India

The increasing penetration of renewable energy resources such as solar photovoltaic and wind power has introduced significant challenges in the operation and control of modern power systems. One of the critical issues is maintaining voltage stability and minimizing power losses while ensuring efficient reactive power management. Optimal Reactive Power Dispatch (ORPD) plays a vital role in enhancing the operational performance of power systems by optimally controlling reactive power sources, transformer tap settings, and voltage magnitudes of generators. However, the nonlinear, nonconvex, and highly constrained nature of the ORPD problem makes it difficult to solve using conventional optimization techniques.

This study presents an Improved Salp Swarm Algorithm (ISSA) for solving the optimal reactive power dispatch management problem in power systems integrated with renewable energy resources. The proposed ISSA is an enhanced version of the Salp Swarm Algorithm inspired by the swarming behavior of salps in the ocean. The algorithm improves the exploration and exploitation capability of the conventional SSA by incorporating adaptive control parameters, improved leader-follower updating strategies, and enhanced convergence mechanisms. These modifications help avoid premature convergence and improve global search ability when solving complex power system optimization problems.

In the proposed framework, renewable energy sources such as solar and wind generation units are integrated into the distribution network, and their uncertainties are considered during optimization. The ORPD problem is formulated as a multi-objective optimization problem with the primary goals of minimizing active power losses, improving voltage profile, and maintaining voltage stability across the system. Control variables include generator voltages, transformer tap positions, and reactive power compensation devices such as shunt capacitors. System constraints such as power balance equations, generator limits, voltage limits, and reactive power limits are also incorporated into the optimization model.

To validate the effectiveness of the proposed method, the Improved Salp Swarm Algorithm is applied to standard benchmark test systems including the IEEE 33-bus, IEEE 69-bus, and IEEE 85-bus distribution networks with renewable energy integration. Load flow analysis is performed using the backward-forward sweep method suitable for radial distribution networks. The results obtained using ISSA are compared with several well-known optimization algorithms such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Orangutan Optimization Algorithm (OOA). Simulation results demonstrate that the proposed ISSA achieves superior performance in terms of reducing power losses, improving voltage profiles, and achieving faster convergence compared to conventional algorithms.

The numerical results show that the ISSA-based reactive power dispatch strategy significantly enhances system performance under renewable energy integration scenarios. Furthermore, the algorithm provides stable and reliable solutions even under varying load conditions and renewable energy uncertainties. The improved convergence characteristics and robustness of the proposed approach make it a promising tool for solving complex optimization problems in modern smart grids.

Overall, this research highlights the potential of the Improved Salp Swarm Algorithm for efficient reactive power management in renewable energy-based power systems. The proposed approach can assist power system operators in maintaining voltage stability, reducing power losses, and improving overall system efficiency in future smart grid environments with high renewable energy penetration



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164870: Population-Based Genetic Algorithm for Loss and CO₂ Emission Reduction in AC Microgrids with Distributed Energy Resources

Daniel Sanin-Villa^{1,*}, Luis Fernando Grisales-Noreña² and Oscar Danilo Montoya³

¹ Área de Industria, Materiales y Energía, Universidad EAFIT, Medellín 050022, Colombia

² Grupo de Investigación en Alta Tensión---GRALTA, Escuela de Ingeniería Eléctrica y Electrónica, Facultad de Ingeniería, Universidad del Valle, Cali 760015, Colombia

³ Grupo de Compatibilidad e Interferencia Electromagnética (GCEM), Facultad de Ingeniería, Universidad Distrital Francisco José de Caldas, Bogotá 110231, Colombia

Introduction.

The accelerated integration of distributed energy resources into alternating current microgrids has increased the complexity of operational planning, particularly in reducing electrical energy losses and carbon dioxide emissions associated with slack-node power supply. These challenges are intensified by the intermittent nature of photovoltaic generation and the dynamic operation of battery energy storage systems. Population-based metaheuristic optimization methods have shown strong potential for addressing such nonlinear and constrained problems. Nevertheless, quantitative, statistically robust comparisons among algorithms remain limited, especially when technical and environmental objectives are treated independently.

Methods.

An intelligent energy management framework for AC microgrids is assessed, where the coordinated dispatch of photovoltaic units, battery energy storage systems, and D-STATCOMs is formulated as a nonlinear optimization problem. Two independent mono-objective functions are considered: minimizing total daily energy losses and minimizing total daily CO₂ emissions. A master-slave structure is adopted, in which candidate solutions are generated by population-based algorithms and evaluated using hourly power flow via successive approximations. The Population-Based Genetic Algorithm and Particle Swarm Optimization are implemented under identical tuning parameters and operational constraints, including nodal voltage limits, line loading limits, power balance equations, and battery state-of-charge bounds. The framework is tested on an IEEE 33-node AC microgrid with distributed energy resources over a 24-hour horizon with 30-minute resolution. To ensure statistical significance, each algorithm is executed 100 independent times for each objective function and operating mode.

Results.

The performance of the Population-Based Genetic Algorithm and Particle Swarm Optimization was assessed through 100 independent executions for each objective function and operating mode, enabling a statistically consistent comparison.

Under grid-connected operation, loss-minimization results show that the Genetic Algorithm achieves a best solution of 1,825.6 kW and a worst solution of 1,834.4 kW, with a mean of 1,829.6 kW and a standard deviation of 0.0965%. In contrast, PSO attains a best solution of 2,515.7 kW and a worst solution of 2,868.0 kW, yielding a mean of 2,673.9 kW and a significantly higher standard deviation of 3.2277%. The average computational time per execution is 150.0 s for the Genetic Algorithm and 216.1 s for PSO, resulting in total runtimes of 4.17 h and 6.00 h for the complete statistical assessment, respectively.

For CO₂ emission minimization in grid-connected mode, the Genetic Algorithm produces best and worst solutions of 13.5855 tCO₂ and 13.6112 tCO₂, with a mean value of 13.5989 tCO₂ and a standard deviation of 0.0442%. PSO yields a best solution of 15.1910 tCO₂ and a worst solution of 16.2613 tCO₂, with a mean of 15.7686 tCO₂ and a standard deviation of 1.5987%. The corresponding average execution times are 148.0 s for the Genetic Algorithm and 218.1 s for PSO, indicating a lower computational burden for the GA under these operating conditions.

In islanded operation, similar trends are observed. For loss minimization, the Genetic Algorithm reaches a best solution of 1,857.3 kW and a worst solution of 1,868.2 kW, with a mean of 1,862.4 kW and a standard deviation of 0.1347%. PSO presents a best value of 3,030.0 kW and a

worst value of 3,320.0 kW, with a mean of 3,148.5 kW and a standard deviation of 1.5778%. Due to the increased computational complexity of islanded operation, the average execution time rises to 1,093.5 s for the Genetic Algorithm and 665.7 s for PSO, corresponding to total runtimes of 30.37 h and 18.49 h for the 100-run analysis.

For CO₂ emission minimization in islanded mode, the Genetic Algorithm achieves best and worst solutions of 22.5306 tCO₂ and 22.5939 tCO₂, with a mean of 22.5630 tCO₂ and a standard deviation of 0.0526%. PSO attains a best solution of 25.6710 tCO₂ and a worst solution of 27.9578 tCO₂, resulting in a mean of 26.8340 tCO₂ and a standard deviation of 1.6421%. The average execution times are 1,075.7 s for the Genetic Algorithm and 680.6 s for PSO, confirming that GA maintains lower variability and tighter convergence despite increased computational effort.

Conclusions.

The results demonstrate that both GA and PSO can reduce energy losses and CO₂ emissions in AC microgrids through coordinated management of distributed energy resources. However, based on extensive statistical testing with 100 independent runs per objective, the Population-Based Genetic Algorithm consistently achieves superior solution quality, significantly lower variability, and more stable convergence behavior than PSO. These findings provide statistically grounded evidence supporting the suitability of GA-based strategies for sustainable and reliable microgrid energy management.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164527: Robust Inner-Loop Control Design for a Single-Stage Single-Phase Onboard EV Charger with Uncertain Grid Impedance

Sokvan In *, Menghorng Sy, Chhaytep Born, Siren Seven and Chivon Choeung

Faculty of Electricity, National Polytechnic Institute of Cambodia, Phnom Penh, Cambodia

Single-stage single-phase onboard electric vehicle chargers have been widely adopted because of their compact structure and high efficiency. However, the performance of the grid-connected operation is highly sensitive to variations in grid impedance, and this may badly compromise stability and current regulation performance. In practice, the distribution networks have uncertain and timevarying grid impedance, which, along with the charger's L-filter impedance, presents significant challenges to conventional controller designs based on nominal system parameters. This paper presents a robust inner-loop current control strategy for the single-stage single-phase onboard EV charger that explicitly takes into account both L-filter dynamics and uncertain grid impedance. The uncertain grid impedance is incorporated into the plant representation by a small-signal model of the charger, and then, based on this model, an LMI-based robust control framework is employed to synthesize the inner-loop controller in such a way that closed-loop stability and robust performance are guaranteed over a prescribed range of grid conditions, without online estimation of grid impedance or any adaptive mechanisms. To enable implementation in the synchronous rotating reference frame, an all-pass filter is adopted to generate an artificial orthogonal (β) signal from single-phase grid voltage and current signals, and thus facilitate dq-frame transformation and control. The proposed approach now meets a systematic design methodology for reducing the sensitivity to parameter variations while maintaining implementation simplicity. Additionally, the robust control synthesis is performed by enforcing linear matrix inequality constraints at all vertices of the polytopic uncertainty model. Specifically, sixteen vertex systems, corresponding to different combinations of L-filter parameter variations and grid impedance uncertainty, are incorporated into the LMI-based optimization, where the optimization objective is to minimize the convergence time while guaranteeing closed-loop stability and robust performance over the entire uncertainty domain. Simulation results under various grid impedance conditions confirm stable operation and reliable current tracking performance, demonstrating the effectiveness of the proposed dq-frame LMI-based robust control strategy for single-stage single-phase onboard EV chargers operating under uncertain grid conditions.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Session 7. Energy Economics and Policy (Thermo-Economics, Exergy Economics)

sciforum-159926: Assessing the Public Acceptance of Large-Scale Solar Projects in Southern Indiana

Thomas Brelage¹ and Gilbert Michaud^{2,*}

¹ Loyola University Chicago, Chicago 60660, USA

² School of Environmental Sustainability, Loyola University Chicago, Chicago 60660, USA

The Inflation Reduction Act (IRA) introduced the Energy Community Tax Credit Bonus, providing an additional 10% investment tax credit for renewable energy projects located in designated “energy communities” with a legacy of coal mining and coal-fired power generation. While this policy aims to accelerate clean energy investment and economic revitalization in historically fossil fuel dependent regions, less is known about how these communities are responding to new renewable development on the ground. This study examines local responses to large-scale solar projects in Southern Indiana, a state characterized by strong local siting authority and county-level control over energy project approval. We conducted 22 semi-structured telephone interviews with county commissioners and local officials across 32 counties between January and March 2025, including 13 interviews in counties designated as energy communities due to coal mine or coal plant retirements, and 9 interviews in adjacent counties without energy community status. Our findings indicate that coal’s legacy continues to shape local identity, political culture, and economic narratives, with 86% of respondents citing its historic importance through tax revenues, employment, industrial attraction, and community stability. At the same time, economic considerations were central to solar energy acceptance, as 73% of respondents emphasized tax revenue, landowner lease income, and local economic activity as key benefits of solar development. However, despite these perceived advantages and the added incentives from the IRA, officials consistently identified constituent pressure and local political dynamics as the primary factors influencing project approvals and denials, often superseding technical siting criteria or economic rationale. These results suggest that federal place-based incentives alone are insufficient to ensure local acceptance of renewable energy projects in post-coal regions, as historical energy identities, land use values, and political contexts mediate how such policies are interpreted and implemented at the local level. The findings also point to the potential role of clearer state-level siting guidance, and early, sustained community engagement in improving the prospects for large-scale solar deployment in these areas. By situating county-level decision-making within broader federal decarbonization policy and regional energy transition dynamics, this study contributes to emerging scholarship on post-coal transitions, place-based policy, and the governance challenges surrounding utility-scale renewable energy development.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-164379: A Thermo-Economic and Exergy-Based Analysis of Sustainable Aviation Fuel Production in Brazil: Policy, Efficiency, and Decarbonization Pathways

Silmara Furtado da Silva^{1*} and Maria Letícia Murta Valle²

¹ Department of Chemical and Materials Engineering, Pontifical Catholic University of Rio de Janeiro (PUC-Rio), Rio de Janeiro, 22451-900, Brazil

² Department of Organic Processes, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

The global aviation sector faces mounting pressure to decarbonize, with sustainable aviation fuels (SAFs) representing a critical transitional solution. Brazil, endowed with abundant biomass resources and a mature biofuel industry, holds significant potential for SAF production. However, the economic viability, energy efficiency, and environmental impact of SAF pathways remain underexplored through integrative energy economics frameworks. This study applies principles of thermo-economics and exergy economics to evaluate the technical, economic, and policy dimensions of SAF production in Brazil. By examining the exergetic efficiency and life-cycle costs of key production routes, such as HEFA, ATJ, Fischer-Tropsch, and SIP, we aim to identify optimal pathways for scaling SAF within Brazil's energy and climate policy landscape.

The methodology integrates a systematic review of Brazilian SAF initiatives, regulatory frameworks, and production technologies with thermo-economic and exergy analyses. Data were drawn from government publications, technical reports, academic literature, and industry roadmaps (2010–2025). Exergy analysis was applied to quantify the useful energy potential and irreversibilities of each SAF conversion pathway. Thermo-economic models were developed to assess the cost of exergy destruction and the trade-offs between capital investment, operating costs, and thermodynamic performance. Policy instruments such as RenovaBio, the Fuel of the Future Program, and tax incentives were evaluated for their impact on the exergy-economic competitiveness of SAFs relative to conventional aviation kerosene.

The analysis reveals that while Brazil possesses sufficient feedstock potential (particularly from sugarcane residues, wood waste, and used cooking oil), the exergy efficiency of SAF production varies significantly across technologies. Fischer-Tropsch and ATJ routes showed higher exergetic performance for lignocellulosic feedstocks, whereas HEFA exhibited lower exergy losses but faced feedstock limitations and higher hydrogen demand. Thermo-economic assessment indicated that SAF production costs remain 20–80% above fossil kerosene, largely due to exergy inefficiencies in conversion and upgrading stages. The study also highlights regulatory gaps, including the absence of a SAF-specific mandate, complex environmental licensing, and post-blending taxation issues, which collectively hinder investment and scale-up. The integration of exergy-based metrics into policy design could prioritize high-efficiency pathways and align incentives with decarbonization goals.

To accelerate SAF deployment, Brazil must adopt an integrated energy policy approach that combines thermo-economic optimization with supportive regulation. The principal recommendations include (1) introducing exergy-based subsidies to reward high-efficiency SAF pathways; (2) simplifying environmental licensing through multi-level governance coordination; (3) establishing an SAF blending mandate linked to carbon intensity reduction; and (4) fostering public-private partnerships for R&D in exergy-efficient conversion technologies. This study demonstrates that thermo-economic and exergy analyses provide a robust framework for guiding SAF policy, enabling Brazil to leverage its bioenergy potential while advancing toward its climate commitments under the Paris Agreement.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166217: CO₂ Emissions Mitigation Through Renewable Energy in West Africa: Evidence from Bilateral Green Finance

Bini Koffi Achille Bouo * and Yanmin Shao

School of Economics and Management, University of Science and Technology Beijing, Beijing, 100083, China

This study examines whether bilateral green finance (BGF) can successfully reduce carbon dioxide emissions in West Africa by promoting the growth of renewable energy sources and enhancing energy efficiency. The study estimates linear panel models for lagged per-capita CO₂ emissions using an unbalanced panel of 15 West African nations from 2000 to 2023. To account for contemporaneous correlation and heteroskedasticity, correlated panel-corrected standard errors and Driscoll-Kraay corrections are used. Lagged BGF is the primary explanatory variable, which is supplemented by foreign direct investment, energy intensity, trade openness, methane emissions, total renewable energy consumption, access to electricity in urban areas, renewable electricity output, and an SDG 7b infrastructure indicator that captures installed renewable capacity.

According to preliminary estimates, BGF is positively and significantly correlated with lagged CO₂ emissions, suggesting that West Africa's current green finance allocation patterns are not yet translating into complete decarbonization. Reductions in per-capita CO₂ emissions are also strongly correlated with higher percentages of renewable electricity output and lower energy intensity, underscoring the significance of allocating green finance to projects that improve efficiency and decarbonize the power sector. On the other hand, there is a positive correlation between emissions and both total renewable energy consumption and increased access to electricity, which is indicative of the region's rapid electrification, structural change, and economic growth.

By using quantile regressions to compare mean and distributional effects, the study demonstrates that the positive correlation between BGF and emissions is stronger at the median and upper quantiles of the emissions distribution. Building on these results, the study develops and evaluates a mediation hypothesis according to which energy efficiency and the deployment of renewable energy act as transmission channels through which BGF could, in theory, lower emissions, even if the reduced-form BGF-CO₂ relationship is currently positive. The findings offer policy-relevant insights for redesigning bilateral green finance instruments to better support West Africa's low-carbon transition by leveraging efficiency gains and renewable energy.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165739: Coping with Grid Failure: An Economic Analysis of Household Inverter Adoption as a Proxy for Future Storage Demand in Rural India

Srikant Shaw * and Santosh Kumar Sahu

Department of Humanities and Social Sciences, Indian Institute of Technology Madras, Chennai 600036, Tamil Nadu, India

This study investigates the socio-economic determinants of household inverter adoption in rural India, positioning it as a critical proxy for understanding future distributed energy storage transitions. As India accelerates its renewable energy deployment, integrating storage technologies at the household level will be crucial for maintaining grid stability and ensuring energy security. However, there is little empirical evidence on what drives the early adoption of storage-like technologies in developing economies. Leveraging nationally representative panel data from the Access to Clean Cooking Energy and Electricity Survey (2015–2018) across six states, we employ random-effects and rare-events logistic regression models to address the inherent econometric challenges of analysing low-probability adoption events. Our analysis reveals that, despite the widespread unreliability of the grid, only 4–5% of households own inverters, with these devices primarily concentrated among affluent, literate, and grid-connected individuals. This pattern indicates a significant socio-economic stratification in the early stages of storage adoption. Key findings challenge conventional expectations: Grid connection is a strong positive predictor, confirming its role as a reliability-coping mechanism. In contrast, renewable energy sources show no significant complementarity, indicating a market disconnect between standalone solar adoption and storage integration. A striking and consistent result is the significantly lower adoption rates among male-headed households, suggesting important gendered differences in reliability valuation, financial prioritisation, or intra-household decision-making dynamics.

The persistence of these patterns across model specifications underscores that inverters are not merely backup devices but represent a household's first capital-intensive investment in energy security. We argue that current inverter adopters constitute a clearly identifiable “storage-ready” segment, providing a behavioural and economic baseline for forecasting the adoption of more advanced storage technologies, such as lithium-ion battery systems. The study concludes with urgent policy implications: without targeted financing mechanisms, enhanced grid reliability initiatives, and gender-sensitive energy planning, the transition to distributed storage risks reinforcing existing energy inequities. These insights are vital for designing inclusive energy policies that can bridge the reliability gap, prevent a “storage divide,” and accelerate India's sustainable energy transition.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171426: Analysis of the Free Energy Market Opening for Low-Voltage Consumers in Brazil: A Critical Approach and International Comparative Study

Lucas Vidal Porciuncula¹, Ricardo de Lara Pinto Filho^{2,3,*}, Hédio Tatizawa¹ and Danilo Ferreira de Souza^{1,2,3,4}

¹ Energy and Environment Institute (IEE), University of São Paulo (USP), São Paulo, 05508-900, Brazil

² Department of Electrical Engineering, Federal University of Mato Grosso (UFMT), Cuiabá, 78068-600, Brazil

³ Interdisciplinary Center for Studies in Energy Planning (Niepe), Federal University of Mato Grosso (UFMT), Cuiabá, 78068-600, Brazil

⁴ Brazilian Association for Awareness of the Dangers of Electricity (Abracopel), Salto, 13326-140, Brazil

Introduction: The Brazilian electricity sector has undergone a gradual liberalization process since 1995, successfully granting freedom of choice to high-voltage consumers. However, the vast majority of the consumer base, residential users and small businesses, remain captive to local distributors, prevented from negotiating directly with suppliers. Despite recent regulatory moves, such as the proposal for full market opening by 2026, there is a significant gap in research on the socioeconomic risks of this transition. Specifically, there is little evidence on how to balance increased competition with the need for social equity and the financial sustainability of distributors. Therefore, this study aims to assess the prospect of full market opening in Brazil, drawing lessons from international benchmarks and modeling the potential economic impacts on the national regulated market.

Methods: The research methodology begins with a systematic literature review in global databases to identify success and failure factors in the international liberalization of low-voltage electricity. This review provides the basis for a critical contextualization of the Brazilian scenario, comparing the historical constraints of the captive market with the proposed liberalization goals. For the quantitative phase, the study replicates established forecasting protocols, applying models to Brazilian historical data (2004–2024) to project demand and costs until 2035.

Results: Preliminary analysis of international experiences reveals several structural challenges: Germany exhibits significant market rigidity due to high switching costs and consumer inertia; France maintains price stability through state redistribution of nuclear energy profits; Japan recently experienced a "reverse phenomenon," in which market prices exceeded regulated prices after the 2022 energy crisis, leading to a contraction in the free market share; and the United Kingdom demonstrates that high consumer satisfaction (81%) can coexist with record levels of household energy debt (£3.85 billion). For the Brazilian context, initial simulations indicate that regulated tariffs may increase between 2% and 11% during the migration phase. This pressure is disproportionately high for smaller distributors, where loss of scale threatens solvency and may force the remaining captive consumers, including 67% of low-income users, to absorb the fixed costs of the distribution network.

Conclusions: The study concludes that while liberalization can boost efficiency and innovation, its successful implementation in Brazil depends on robust regulatory safeguards. To avoid deepening social inequalities, the transition should include a gradual management of legacy contracts, investments in smart metering infrastructure, and comprehensive energy education programs to protect vulnerable users. Furthermore, the research suggests that an abrupt and sudden opening could be detrimental to the financial health of regional utilities. Instead, a gradual approach is recommended, ensuring that gains in competitiveness are not achieved at the expense of tariff affordability for those who remain in the regulated market.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171363: Distributed Generation in Mexico's Energy Transition: Regulatory Change, Institutional Tensions and Policy Implications

Gabriel Alberto Rosas Sánchez^{1,2}

¹ Center for Policy Research, FuturoLab/The Oxford – Mexico Industrial Policy Co-Lab, Mexico City, 03600, Mexico

² Department of Economics, Autonomous Metropolitan University, Mexico City, 09340, Mexico

Introduction

Mexico's electricity sector has undergone significant regulatory shifts in recent months. Amendments to the Electricity Sector Law, the publication of its implementing regulations, the update of the Ministry of Energy's Sectoral Plan (SENER), and the release of the country's third Nationally Determined Contributions (NDC 3.0) have together reshaped the incentives, boundaries, and constraints governing the integration of clean technologies into the national grid.

Within this evolving landscape, distributed generation (DG) has gained strategic relevance for Mexico's energy transition. By enabling the decentralization of electricity production, supporting the incorporation of renewable sources, and broadening community participation, DG holds the potential to strengthen energy democracy (Moroni, 2024). It also offers a pathway to simultaneously advance decarbonization, energy security, and capacity expansion while reducing transmission losses and diversifying the energy mix.

This paper aims to assess the internal coherence of the new regulatory framework and to identify the structural factors that either enable or constrain the expansion of DG. In doing so, it seeks to provide analytical inputs that can inform the design of public policies more consistent with the country's energy transition objectives.

Methods

The study draws on a qualitative analysis of Mexico's updated energy regulatory framework, a review of specialized technical reports, and semi-structured interviews with key stakeholders across the national energy ecosystem. Findings are organized through the Multi-Level Perspective proposed by Geels (2024), which distinguishes between macro, meso, and micro dynamics of sociotechnical transitions.

The research systematically examines recent amendments to the Electricity Sector Law, its corresponding regulations, the Energy Sectoral Plan, and the NDC 3.0, with particular attention paid to provisions bearing on distributed generation, renewable energy integration, and grid modernization. A public policy analysis lens is applied to identify areas of regulatory coherence, existing gaps, and implementation mechanisms. The study is further grounded in recent data on installed DG capacity and market trends, alongside specialized literature on energy transitions and regulatory governance.

Results

The analysis reveals tensions across all three levels of the Multi-Level Perspective. At the meso level, a central finding is the limited articulation between the new electricity regulatory framework and the NDC 3.0. Persistent gaps are evident in institutional coordination, access to financing, and technical support, alongside an uneven distribution of implementation capacities across the country. These tensions are illustrated by the marked geographic and technological concentration of DG activity: 37% of interconnection requests are concentrated in just two states—Jalisco and Nuevo León—and 96% correspond to photovoltaic systems.

At the macro level, national energy policy has prioritized energy sovereignty through the consolidation of state-owned enterprises, particularly Petróleos Mexicanos (PEMEX) and the Comisión Federal de Electricidad (CFE). The recently launched Plan México further reinforces this orientation by designating petrochemicals—a gas-intensive industry reliant on hydraulic fracturing—as a strategic productive sector.

At the micro level, existing instruments tend to focus on residential and community-scale DG, primarily within rural electrification programs such as those operating in Baja California Sur. This

suggests a policy logic oriented toward expanding energy access rather than driving systemic scaling. The situation is further complicated by inadequate household infrastructure in low-income regions, particularly across the northeast, south, and southeast of the country, which limits the viability of DG projects in areas where they may be most needed.

Conclusions

Distributed generation occupies a relevant, if still constrained, position within Mexico's emerging energy framework, with genuine potential to contribute to matrix diversification and system resilience. Yet the findings point to a fragmented development trajectory, one shaped more by a logic of containment than by structural promotion. Advancing DG's role in the energy transition will require stronger alignment between climate commitments and energy policy, improved institutional coordination, and the design of mechanisms capable of scaling DG in an inclusive, equitable, and territorially balanced manner.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-163807: Global Assessment of Low-Cost Green Hydrogen Production Potential Using Machine Learning Models

Suresh Baral

School of Engineering, Pokhara University, Pokhara, Nepal

Green hydrogen produced via renewable-powered electrolysis is a key pathway for global decarbonization; however, its large-scale deployment remains limited by high costs and regional variability in renewable resources and infrastructure. To address the limitations of conventional deterministic techno-economic models, this study presents a machine learning-based framework that integrates spatial datasets, including renewable energy potential, electricity tariffs, and electrolyzer techno-economic parameters, across various regions of the world. A Random Forest model predicts the levelized cost of hydrogen with a test root mean square error of \$0.28 per kg and an R^2 value of 0.94, significantly outperforming a simple linear regression model, which achieved an R^2 of 0.71. The main factors influencing cost are electricity price, availability of renewable energy, electrolyzer cost, and system efficiency. The model identifies the lowest-cost production areas, with hydrogen projected to cost between \$1.8 and \$2.5 per kg, in regions combining high solar and wind resources with stable infrastructure, such as North Africa, the Middle East, and Australia. This approach can inform policy, investment, and planning for cost-effective green hydrogen deployment.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-169456: Global Energy Security at Risk: Maritime Piracy and Supply Chain Disruptions in the Context of Middle East Conflict (2026)

Sonia Rozbiewska

Doctoral School, Maritime University of Szczecin, Szczecin, 70-500, Poland

The contemporary global energy system relies heavily on maritime transportation for the delivery of critical energy resources, including crude oil, liquefied natural gas (LNG), and refined petroleum products. Approximately 80–90% of global trade is transported by sea, while around 20% of the world's oil supply transits through key maritime chokepoints such as the Strait of Hormuz. As a result, the security and reliability of major maritime routes play a fundamental role in ensuring the continuity of energy supply and the stability of energy markets worldwide. While technological, environmental, and geopolitical risks affecting energy systems are widely discussed, maritime piracy remains an underexamined yet persistent non-technical threat to global energy security.

The primary objective of this study is to assess the impact of maritime piracy on energy security through disruptions in global maritime energy supply chains. The analysis adopts a global perspective while using the Middle East as a case study, particularly in the context of heightened geopolitical tensions in 2026 affecting strategic routes such as the Strait of Hormuz and Bab el-Mandeb. The study is based on piracy incident data (e.g., International Maritime Bureau reports), AIS-derived maritime traffic data, and spatial analysis of key energy shipping routes.

The study highlights that the consequences of maritime piracy extend well beyond direct material losses or immediate threats to vessel crews. Piracy incidents frequently result in delays in energy deliveries, forced rerouting of vessels, increased fuel consumption, and higher greenhouse gas emissions due to longer shipping distances. Rerouting tankers around the Cape of Good Hope instead of transiting through high-risk areas can significantly increase voyage distance and fuel costs. Moreover, heightened piracy risk leads to increased insurance premiums, higher freight rates, and additional security expenditures, which may raise shipping costs by several to over a dozen percent in high-risk regions.

These costs are ultimately transferred to energy markets, influencing energy prices and increasing volatility, particularly in import-dependent regions. In the context of the 2026 Middle East tensions, additional disruptions and perceived risks in critical maritime corridors further amplify these effects, contributing to concerns over fuel availability and market stability.

In addition, the paper discusses the implications of maritime piracy for energy policy and long-term investment decisions. Persistent security risks in maritime transport corridors may discourage investment in energy infrastructure, alter trade patterns, and undermine efforts to build resilient and sustainable energy systems. The role of modern technological solutions, including satellite surveillance, Automatic Identification System (AIS) data analysis, and artificial intelligence-based risk assessment tools, is examined as a means of mitigating piracy-related risks and enhancing the resilience of maritime energy supply chains.

The findings of this study indicate that maritime piracy remains a significant and often underestimated threat to global energy security. The paper contributes to the literature by integrating maritime security risks into energy economics and energy security analyses, which have traditionally focused on technical and geopolitical factors. Addressing piracy through coordinated international security measures, technological innovation, and integrated energy and maritime policies may improve the stability and resilience of global energy supply systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-168167: Infrastructure Reliability as a Gatekeeper for Productive Electricity Use—Evidence from Rural Nigeria and Policy Implications

Mulikat Abdulrahman

Graduate School of Innovation and Technology Management, Yamaguchi University, Ube, 755-0097, Japan

Abstract

Introduction:

Rural electrification policy in Sub-Saharan Africa (SSA) increasingly prioritizes the productive use of electricity (PUE) to generate income and sustain decentralized energy systems. However, prevailing intervention models assume that financing, skills, and market access are the primary barriers to adoption. This study tests that assumption by examining whether infrastructure reliability functions not merely as one constraint among many, but as a gatekeeping mechanism that determines whether other factors can operate at all. Using evidence from rural Nigeria, where grid supply averages 2–4 hours daily and mini-grid sustainability is fragile, we test the hypothesis that below a critical reliability threshold, standard determinants of PUE adoption cease to predict behavior.

Methods:

In July 2025, we conducted a cross-sectional household survey (n=249) in two contrasting communities in southwestern Nigeria: one grid-connected with an unreliable supply (Ila-Orangun), and one where the community solar mini-grid had collapsed (Gbamu-Gbamu). Data were analyzed using descriptive statistics, logistic regression, and threshold modeling to examine (1) the magnitude of the underutilization of electricity or access–utilization gap, (2) the predictive power of income, education, and social capital under reliability constraints, (3) the hierarchy of adoption barriers, and (4) household adaptation strategies following infrastructure failure.

Results:

Analysis showed that only 32.4% of electrified households used electricity productively, resulting in a 67.6% access–utilization gap. Above 10–11 hours of daily supply, PUE adoption doubled to 57.7% (OR=7.6, p0.001); below this threshold, adoption stagnated at 27–30%, and household characteristics (income, education, social capital) showed no significant predictive power. The barrier hierarchy inverted relative to Asian contexts: 76% of non-adopters cited unreliable supply as the primary barrier, versus 24% citing financing. Following mini-grid collapse in Gbamu-Gbamu, we see that adaptation strategies were stratified sharply by wealth: the poorest quintile experienced a 47.8% de-electrification rate, compared to 20% in the wealthiest quintile, revealing a 27.8 percentage-point equity gap.

Conclusions:

Findings support a conditional model of PUE adoption: standard determinants operate only above reliability thresholds. In severely constrained environments, infrastructure quality acts as a gatekeeper, rendering demand-side interventions (equipment subsidies, credit, training) ineffective unless reliability is first assured. Policy implications are as follows: (1) sequence interventions by prioritizing reliability improvements before deploying demand-side support; (2) redefine success metrics to reflect tier-specific reliability within frameworks like the Multi-Tier Framework; and (3) treat infrastructure sustainability as an equity imperative, given that system collapse disproportionately harms poor households. This study urges a reorientation of energy policy from access provision to quality-assured service delivery as a prerequisite for productive use and inclusive development.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170717: Mapping Energy Governance in the Global Energy Transition: An Evidence-Based Topic Modeling Approach

Javier Antonio De la Hoz ¹, Victor José Olivero ^{1,*}, John Alexander Taborda ¹, Carlos Arturo Robles ¹ and Laura Alejandra Chia Pinto ²

¹ Facultad de Ingeniería, Universidad del Magdalena, Calle 29H3 No 22 - 01, 470004, Santa Marta D.T.C.H., Colombia

² Vicepresidencia Técnica, Agencia Nacional de Hidrocarburos (ANH), Avenida Calle 26 N° 59 - 65 Piso 2, Bogotá, Colombia

The global energy transition is reshaping energy systems through profound technological, economic, and institutional transformations, intensifying the need for coherent governance frameworks capable of aligning energy sources, market mechanisms, and long-term policy objectives. While energy governance has gained increasing scholarly attention, the literature remains conceptually fragmented, making it difficult to extract systematic, evidence-based insights relevant to Energy Economics and Policy. This study provides a structured and quantitative mapping of global research on energy governance within the energy transition context.

The analysis integrates bibliometric techniques with Latent Dirichlet Allocation (LDA) topic modeling applied to a curated corpus of 312 peer-reviewed journal articles indexed in Scopus and Web of Science between 2014 and 2025. Although focused in scope, the dataset was deliberately constructed using strict inclusion criteria to capture publications explicitly addressing governance dimensions within energy transition debates, thereby ensuring thematic coherence rather than broad bibliometric coverage. Bibliometric indicators reveal an average annual growth rate exceeding 20% in governance-related transition research over the past decade, with a clear post-2018 acceleration. LDA modeling (optimal solution: 10 topics, coherence score = 0.51) identifies dominant thematic clusters centered on energy policy frameworks (22% topic prevalence), renewable energy governance and deployment mechanisms (18%), market regulation and investment dynamics (15%), and multi-level institutional coordination (13%). Emerging but rapidly growing themes include energy justice and participation (9%) and distributional impacts of transition policies (7%).

Temporal trend analysis shows a statistically significant increase ($p < 0.05$) in governance- and policy-oriented topics after 2019, alongside a relative decline in purely technology-centric discussions. Citation network metrics indicate increasing cross-referencing between governance, market design, and renewable energy deployment studies, suggesting progressive integration of technical and economic-policy dimensions. The findings also highlight persistent tensions between fossil fuel governance regimes and renewable energy policy pathways, particularly regarding regulatory stability, investment risk allocation, and market signaling mechanisms.

While bibliometric and LDA approaches are widely used in energy research, the contribution of this study lies in its focused and quantitative examination of governance as the mediating layer between energy sources and economic policy instruments in the transition process. By providing explicit topic prevalence measures, temporal dynamics, and network-based evidence, the study strengthens the empirical basis for governance-centered energy policy analysis.

The results underscore the growing centrality of governance in shaping energy economics outcomes and support the development of integrated, evidence-informed policy frameworks that enhance coherence between regulatory instruments, market structures, and decarbonization objectives. This work contributes to advancing systematic, data-driven approaches to understanding governance dynamics in global energy transitions and provides a replicable analytical framework for future research in Energy Economics and Policy.

This research was made possible thanks to the financial support of the Agencia Nacional de Hidrocarburos (ANH), through its Vicepresidencia Técnica, within the framework of Contract No. 618 of 2025 executed between the ANH and the Universidad del Magdalena. The authors gratefully acknowledge this institutional support, which enabled the development of the analyses

presented in this study and contributed to strengthening evidence-based research on energy governance and the energy transition.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-153363: Market Security Index (MSI): A pioneering framework for measuring and enhancing EU energy market resilience

Michał Thlon

Department of Applied Economics, Krakow University of Economics, Krakow 31-510, Poland

The European Union's electricity markets face escalating volatility due to the rapid expansion of variable renewable energy sources (RES), deeper cross-border integration, and technology-driven demand flexibility. These dynamics increase extreme price events, elevate balancing costs, and challenge system stability. To address this, we propose the Market Security Index (MSI), an author-developed, composite metric to quantify market security (higher MSI = greater resilience) across EU bidding zones. MSI tracks resilience, benchmarks heterogeneous systems, and guides investments in flexibility, aligning with IOCE 2026's focus on sustainable energy systems, smart grids, and AI applications. Concept and Construction: The MSI integrates three pillars capturing short-term risk, operational stress, and system buffers: (i) Price risk—frequency and intensity of extreme price episodes and volatility in day-ahead (DA) and intraday (ID) markets; (ii) Balancing stress—costs of reserve activation and imbalance settlement relative to system load; (iii) Buffer capacity—availability of interconnectors (net transfer capacity-to-load ratio), storage (batteries, pumped hydro), and demand-side response (DSR) activation during peak stress. Indicators are normalized, directionally aligned, and aggregated using equal weights, with robustness validated via principal component analysis and constrained optimization. Data and Empirical Strategy: We construct a multi-year, monthly panel dataset from ENTSO-E, ACER/CEER, and national transmission system operators, covering EU bidding zones. Control variables include RES shares, network constraints, interconnector outages, and weather (heating/cooling degree days, wind/solar output). Fixed-effects panel models estimate associations between MSI and market outcomes (balancing costs, extreme price incidence), while quantile regressions test stability across distributions. Case studies, such as the 2025 Iberian blackout, validate MSI's responsiveness to shocks, serving as plausibility checks. Findings: Higher MSI consistently correlates with lower balancing costs and fewer extreme price events. Key insights include the following: (i) Zones with higher interconnector capacity (NTC-to-load) mitigate price shock transmission to balancing costs, supporting cross-border buffering (H3); (ii) DSR activation narrows DA-ID price spreads and reduces imbalances, especially in high-RES systems (H4); and (iii) Storage attenuates positive price spikes, with stronger effects in RES-heavy zones (H5). These findings are robust to alternative normalizations and weather/network controls, with shock-period MSI behavior aligning with operational narratives. Policy Implications: MSI serves as a policy dashboard to benchmark zones, identify vulnerabilities (e.g., low buffers in RES-dominated systems), and prioritize cost-effective interventions like interconnector upgrades, storage deployment, or DSR expansion. It complements regulatory assessments of CfD/PPA schemes by highlighting the need for physical flexibility to stabilize short-term operations, supporting the EU's Fit for 55 decarbonization goals. AI-Enabled Extensions: MSI incorporates random forest models to forecast demand and RES generation errors, enhancing MSI-F, a forward-looking variant for probabilistic imbalance risk and tail price event prediction. This aligns with IOCE 2026's AI focus, enabling scenario analysis for RES penetration and DSR adoption. Limitations and Future Work: The MSI is descriptive, not causal, requiring future quasi-experimental validation. Planned extensions include integrating electric vehicle flexibility, hydrogen storage, and network-aware spatial models. Contribution: The MSI offers a transparent, modular tool bridging market analytics and system operations. It enables regulators and operators to track resilience, compare zones, and allocate flexibility investments for maximum stability, advancing the EU's sustainable energy transition.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166249: Renewable Energy Cooperatives in the Just Transition in Greece: Barriers and possibilities

Georgios Anagnostopoulos

Department of Social Policy, Panteion University of Social and Political Sciences, Athens, Greece

Introduction

The just transition agenda has become prominent in European Union energy policy but remains contested (Sabato, 2024). The research agenda on just transition and energy poverty alleviation is marked by a technical-economic bias and a neglect of socio-political questions (Bouzarovski, 2022). Moreover, there is a lack of empirical data on how just transition policies are implemented in fiscally constrained, southern European contexts. This study investigates Renewable Energy Communities (RECs) in Greece as promising eco-social and just transition policy tools (De Vidovich, 2024) and hybrid institutional spaces at the intersection of energy justice, social policy, and participatory energy governance frameworks. It employs a comparative analysis of a rural, top-down, municipality-initiated REC and an urban, bottom-up, citizen-initiated RECs which undertake actions to address energy poverty. This approach elucidates the relationships, interactions and interdependencies that determine how participatory energy policies and just transition agendas are mobilized and actualized within a local and structural context. This study thus highlights energy poverty not as a merely technical issue of resource distribution, but as a central just transition policy question entangled in broader questions over welfare distribution, recognition, and citizenship. The just transition is shown as a socio-technical issue that is spatially bound and embedded in pre-existing institutional contexts.

Methodology

This study asks whether and under what conditions RECs can deliver just transition policy goals such as energy poverty alleviation in resource-constrained environments. Utilizing a qualitative methodology, it reveals through semi-structured interviews and document analysis the taken-for-granted assumptions within the discourses and practices of the RECs. The interviews included 15 stakeholders from various backgrounds, such as REC members, civil society representatives, municipal government officeholders, and academic experts. Policy documents were analyzed from a variety of state, non-state, transnational and national institutions, enabling a broad coverage of discourses. The institutional context of Greece was also examined through careful analysis of the policies, laws, and discourses on the just transition and the role of RECs at the national level. This interdiscursive triangulation helps uncover the interlinkages between systemic, institutional, and subject-formation-level processes.

Results

This study highlights the tensions between inclusion and exclusion, market-logic and community governance, and philanthropy and solidarity in RECs seeking to achieve just transition goals. This exposes the pervasiveness of market logics within decentralized initiatives showing an institutional tension between market-based integration and community-based governance. Both initiatives are constrained by unfavorable grid access policies, lack of institutional support, and regulatory instability. Both initiatives respond to these constraints by implementing needs-based, residual redistribution for energy-poor households while excluding broader community members.

The governance formation and geography of the initiative influence their effectiveness in achieving just transition policy objectives. The top-down initiative is shown to more closely replicate the dominant policy paradigm of privatized energy, but local visibility gives rise to democratizing tendencies and claims-making based on citizenship, particularly from excluded island residents. Even though the top-down nature of the REC ensured adequate resources to cover all residents' needs, initial mistrust led to low participation and uneven allocation of membership shares. As a result, the REC maintains 150 outstanding applications leading to tensions between included and excluded residents. The perceived injustice over access to the

project and the distribution of benefits leads to lower stakeholder engagement threatening the project's long-term social sustainability. The bottom-up initiative showcases discursive imaginaries oriented towards collective democratic control of energy and access to energy as a right but is tempered in practice by operational constraints including a lack of resources and consideration of beneficiaries' anonymity, thus implementing technical-economic solutions for energy poverty. These operational constraints and regulatory instability have prompted fears over the cooperative's financial viability leading to the project's stagnation and inability to include more members.

Conclusion

The comparative approach allowed for the exploration of the effect of different governance structures (top-down bottom-up) and geography (urban-rural) on the success of just transition, community-based policies. This spatializes the just transition agenda, elucidating the translation of EU policy into national and local contexts. The results indicate the need for further empirical exploration of RECs and their potential to achieve just transition objectives as mediated by local contexts. It also highlights the need to not assume the success of community-based initiatives but rather to implement carefully designed policies that ensure adequate institutional support at the national and supranational level while accounting for local specificities. Energy transition policies aiming at strengthening decentralized production need to move beyond "one-size-fits-all" approaches and implement tailor-made solutions that empower local communities to achieve just transition objectives. Finally, this study underlines RECs as compensatory mechanisms for highly concentrated energy markets and inadequate redistribution policies in fiscally constrained southern-European policy environments.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171297: Techno-Economic Comparison of Carbon Capture Technologies with Exhaust Gas Recirculation in NGCC Power Plants

Hulkar Abdusalomova¹, Azizbek Kamolov^{1,*}, Adham Norkobilov², Zafar Turakulov¹ and Botir Usmonov¹

¹ Department of Automation and Digital Control, Tashkent Institute of Chemical Technology, Tashkent, Uzbekistan

² Department of Engineering Technologies, Shahrissabz Branch of Tashkent Chemical-Technological Institute, Shahrissabz, Uzbekistan

Natural gas combined cycle (NGCC) power plants are expected to remain a critical component of global electricity generation due to their high efficiency, operational flexibility, and comparatively lower specific carbon dioxide (CO₂) emissions than coal-fired power plants. However, achieving long-term climate targets requires deep decarbonization of gas-fired generation through the integration of carbon capture, storage, and utilization (CCSU) technologies. Post-combustion amine absorption is currently the most mature capture technology, while membrane separation represents a promising emerging alternative with potential advantages in modularity and operational simplicity. In parallel, process intensification strategies such as exhaust gas recirculation (EGR) have recently attracted growing attention due to their ability to increase CO₂ concentration in flue gas and reduce the energy penalty associated with capture processes. Despite significant progress, comprehensive techno-economic comparisons of absorption, membrane, and hybrid capture systems under EGR-integrated NGCC configurations remain limited.

This study presents an integrated techno-economic assessment of multiple CO₂ capture configurations applied to a 450 MW NGCC power plant. Detailed process simulations were developed using Aspen Plus and Aspen Custom Modeler to evaluate absorption-based, membrane-based, and hybrid capture systems combined with selective and non-selective EGR strategies. The modelling framework includes full process integration with the steam cycle, enabling consistent evaluation of energy consumption, efficiency penalties, and key economic indicators. The assessment focuses on net plant efficiency, energy penalty, levelized cost of electricity (LCOE), and CO₂ avoidance cost, providing a consistent basis for comparing capture options.

Results indicate that integrating EGR substantially enhances the performance of carbon capture in NGCC systems. In particular, selective EGR combined with amine absorption demonstrates the most favourable performance, reducing the energy penalty by more than 30% compared with standalone absorption and by over 70% relative to membrane separation. The selective EGR-absorption configuration achieves an estimated LCOE of approximately 72 USD/MWh and a CO₂ avoidance cost of about 39 USD/tCO₂, outperforming the selective EGR-membrane configuration, which yields approximately 77 USD/MWh and 51 USD/tCO₂. These results highlight the strong influence of flue gas composition and process integration on the overall economic viability of carbon capture.

The findings demonstrate that combining process intensification with established capture technologies can significantly improve the feasibility of CCSU deployment in NGCC power plants. This work provides insights into cost-effective decarbonization pathways for gas-fired power generation and supports ongoing efforts toward large-scale implementation of carbon capture technologies in the transition to low-carbon energy systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170937: Thermodynamic-based perspectives on critical raw materials in photovoltaic energy production: the Italian case

Giulia Grisolia

Department of Environment, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Turin, Italy

Introduction Global decarbonization efforts have accelerated the deployment of renewable infrastructures, particularly photovoltaic (PV) systems, due to their scalability and cost-efficiency. However, this transition increases demand for Critical Raw Materials (CRMs), which often involve energy-intensive extraction and refining processes with high greenhouse gas emissions [1]. While traditional assessments focus on material demand, supply risks, and economic security, they frequently overlook the physical quality of resources and the thermodynamic irreversibility of their transformation. Specifically, high-purity refining entails significant exergy losses, indicating material degradation. This study explores existing methodological frameworks to discuss how a thermodynamic perspective could offer a physics-based, complementary metric to socio-economic and environmental analyses, better characterising the long-term sustainability of material-intensive technologies.

Methods This study integrates a quantitative material demand assessment for PV technologies with an exploratory analysis of thermodynamic and thermoeconomic methods addressing resource quality. Using the Italian National Energy and Climate Plan (PNIEC) as a 2030 reference scenario, we estimate cumulative requirements for PV systems, specifically silicon, silver, copper, aluminium, steel, and concrete, and we use their potential environmental impacts are associated using Carbon Footprint (CF) ranges from the JRC report [2]. In this context, it can be useful to complement these quantities with an overview of exergy-based and thermoeconomic approaches and metrics [3, 4] to explicitly address resource quality. The analysis focuses on the conceptual relevance of these physical indicators and their capacity to inform sustainability assessments for material-intensive technologies.

Results and Discussions PNIEC-based assessments confirm that large-scale PV deployment requires substantial bulk and highly refined materials. Projections on future energy demand can be used to calculate the future CO_{2eq} emissions linked to PV technologies (or their CF). While this metric clarifies climate impacts, it offers a primarily environmental perspective. Integrating thermodynamic frameworks can enhance resource characterization by addressing physical aspects that emission-based indicators overlook, such as resource quality and degradation. Frameworks such as cumulative exergy demand, exergy replacement costs, exergy footprint, and thermodynamic rarity explicitly account for irreversibility and resource quality degradation, e.g., the thermodynamic rarity (ex_{TR}) accounts for the “amount of exergy resources needed to obtain a mineral commodity from an accessible common rock, using the best prevailing technology” with respect to a reference state, in which the minerals are too dispersed in the crust. This quantity includes a physical cost, meaning the exergy resources needed to convert a mineral into a commodity (embodied exergy, or exergy cost), and a non-visible cost, which accounts for the “natural” cost (exergy replacement cost) of the actual concentrations of ores in mines instead of being dispersed in the crust. It takes into account both the scarcity in the crust together with ore degradation, but also the technology improvements that can be introduced. As concerns the case study, PNIEC PV-related cumulative 2020-2030 demand has been evaluated as: 147-240 kt of PV-grade silicon, 450 kt of aluminium, 276 kt for copper, and 600 t of silver. CF values of PV systems range from 10.8 to 44.0 $g_{CO_{2eq}}/kWh$, driven by silicon manufacturing electricity mixes, material intensity, and structural components. Technology lifetime further influences emission intensity per unit of energy. Meanwhile, the thermodynamic rarity values, ex_{TR} [$GJ\ kg^{-1}$], of the main elements used in PV technologies can vary a lot: Silicon (77.0), Aluminium (681.7), Copper (348.7), Silver (8937.6). This allows to obtain a complementary thermodynamic quantity, related to the

second law and to the degradation of resources, that can be further used to assess the resources' sustainability. Consequently, these approaches can offer a thermodynamic foundation for assessing the long-term sustainability of material-intensive technologies, although such methodologies are rarely applied in CRM-oriented policy analyses or systemic evaluations of green technologies.

Conclusions While material demand and *CF* indicators are essential, they overlook the physical implications of resource transformation. Thermodynamic approaches complement these metrics by addressing resource quality and irreversibility, fostering a systemic sustainability evaluation of material-intensive technologies.

References

1. International Energy Agency. *Global Critical Minerals Outlook 2024*. Paris: IEA; 2024.
2. European Commission, JRC. Harmonised rules for the calculation of the *CF* of PV modules in the context of the EU Ecodesign Directive. Luxembourg: Publications Office of the European Union; 2025.
3. Szargut J. *Exergy Method: Technical and Ecological Applications*. Southampton: WIT Press; 2005.
4. Sciubba, E. A Thermodynamic Measure of Sustainability. *Frontiers in Sustainability* 2021, 2, 739395. DOI: 10.3389/frsus.2021.739395
5. Iglesias-Émbil et al. Raw material use in a battery electric car - a thermodynamic rarity assessment. *Resources, Conservation & Recycling* 2020, 158, 104820. DOI: 10.1016/j.resconrec.2020.104820



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166145: When Do Credit Prices Drive Decarbonization? Credit-Price Thresholds and EV Charging Infrastructure in Oregon's Clean Fuels Program

Chukwuemeka Valentine Okolo * and Andres Susaeta

Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, 97331, United States

Low-carbon fuel standards (LCFS) such as Oregon's Clean Fuels Program (CFP) rely on market-based credit prices to motivate reductions in the lifecycle carbon intensity (CI) of transportation fuels. In practice, those price signals operate alongside the physical build-out of low-carbon infrastructure, especially electric vehicle (EV) charging networks, which may amplify or dampen the extent to which regulated parties respond to credit-market incentives. Yet it remains unclear whether higher credit prices consistently produce proportionate CI reductions, or whether the credit price–CI relationship changes once prices cross key “turning points,” and whether those turning points depend on the level of EV charging infrastructure in place. This study tests for threshold behavior in the relationship between CFP credit prices, EV charging deployment, and ethanol CI. Using monthly data from January 2018 through December 2024 drawn primarily from Oregon CFP public reports and related market sources, the analysis focuses on ethanol CI ($\text{gCO}_2\text{e/MJ}$) as the outcome variable and the average CFP credit price as the main policy variable. Additional controls include B5 and E10 cost indices, measures of EV charging deployment, and lagged CI dynamics.

Empirically, the study applies threshold regression methods in the spirit of Hansen's endogenous threshold model. The core specifications allow the marginal effect of credit prices on ethanol CI to differ across regimes defined by one or more estimated credit-price thresholds, selected by searching over candidate values and choosing thresholds that improve model fit (e.g., minimizing residual variance and improving AIC/BIC). Linear and quadratic models serve as benchmarks for comparison. The working hypothesis is that the credit price–CI relationship is piecewise: responses may be muted at low prices, strengthened in an intermediate range as incentives become binding, and weakened at very high prices as low-cost abatement options are exhausted. The study further tests whether EV charging infrastructure shifts these regimes by allowing charging variables and their interaction with credit prices to vary across threshold-defined regimes. Robustness checks examine alternative threshold variables and sensitivity to the lag structure and specification. By identifying where credit prices and EV infrastructure most strongly influence CI, the results aim to inform LCFS/CFP design choices, including benchmark setting, banking rules, and cost-containment mechanisms that shape where credit prices tend to fall relative to the most effective range for driving decarbonization.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Session 8. AI Applications to Energy Conversion Systems

sciforum-168327: Adaptive State of Energy Estimation for Lithium-Ion Batteries Using an Improved Sage–Husa Extended Kalman Filter

Sulyman Taofeeq Opeyemi^{1,*}, Umar Musa¹, Ibrahim Abdullahi Shehu¹, Ramani Kannan² and Aminu Jibrin Aliyu^{1,2}

¹ Department of Electrical Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.

² Department of Electrical and Electronics Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, 32610, Perak, Malaysia

Accurate State of Energy (SOE) estimation is a critical prerequisite for ensuring the safety, reliability, and optimal performance of lithium-ion batteries (LIBs) in modern Battery Management Systems (BMSs). While model-based approaches, such as the standard Extended Kalman Filter (EKF), are widely utilized in industrial applications, their precision is fundamentally compromised by a reliance on static, pre-defined noise covariance matrices (Q and R). These static parameters often fail to account for the highly non-linear, time-variant electrochemical behavior of LIBs under dynamic operating conditions, frequently leading to filter divergence and estimation lag. This research presents an enhanced state estimation framework utilizing an Improved Sage–Husa Extended Kalman Filter (SHEKF) to address these limitations. A second-order (2RC) equivalent circuit model (ECM) is chosen in this research for its optimal balance between computational efficiency and high-fidelity representation of battery dynamics. To ensure a precise model foundation, internal parameters including ohmic resistance, charge transfer, and mass transfer effects, were identified through offline analysis of Hybrid Pulse Power Characterization (HPPC) test data. The non-linear relationship between Open-Circuit Voltage (OCV) and SOE was further refined using a sixth-order polynomial fit to minimize model-induced errors. The proposed SHEKF algorithm incorporates a recursive adaptive mechanism that utilizes filter innovation to estimate and update process and measurement noise statistics in real time. This eliminates the need for manual parameter tuning and allows the estimator to maintain stability across varying current rates and drive cycles. The robustness of the SHEKF was rigorously validated through a comparative analysis against baseline EKF and Strong Tracking EKF (STEKF) algorithms. Evaluations were conducted using standardized dynamic datasets, specifically the Federal Urban Driving Schedule (FUDS) and the Urban Dynamometer Driving Schedule (UDDS). Results obtained demonstrate that the SHEKF significantly outperforms traditional estimators, achieving a 75% reduction in Root Mean Square Error (RMSE) for both SOE and terminal voltage estimation compared to the baseline EKF. Specifically, the SHEKF maintained an exceptionally low SOE RMSE of 0.58% and a Maximum Absolute Error (MAE) below 0.84%, even under the volatile current profiles of the UDDS cycle. These findings confirm that the adaptive Sage–Husa mechanism provides a superior, self-correcting solution for high-precision battery state monitoring in real-world electric vehicle applications.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165679: Benchmarking Deep Learning Techniques for Photovoltaic Output Prediction: A Case Study of PV Systems in China

Oussama Khouili^{1,*}, Youssef ELMRINI², Fatima Wardi³, Hafsa Khayrane³, Mohamed Louzazni³ and Mohamed Hanine¹

¹ LTI Laboratory, National School of Applied Sciences, Chouaib Doukkali University, El Jadida 24000, Morocco

² Materials and Subatomic Physics Laboratory, Faculty of Sciences, Ibn Tofail University, Kenitra, Morocco

³ labsipe, National School of Applied Sciences, Chouaib Doukkali University, El Jadida 24000, Morocco

Accurate forecasting of photovoltaic (PV) power output plays a critical role in the reliable integration of solar energy into modern power grids and in the optimal operation and management of renewable energy systems. Nevertheless, achieving high prediction accuracy remains challenging due to the inherent variability and stochastic nature of meteorological conditions, including solar irradiance, ambient temperature, and atmospheric dynamics. These uncertainties significantly affect PV power generation and necessitate the use of advanced data-driven modeling techniques capable of capturing complex nonlinear and temporal relationships. In this study, a comprehensive benchmarking analysis of four widely used deep learning architectures, Multilayer Perceptron (MLP), Convolutional Neural Network (CNN), Long Short-Term Memory (LSTM), and Gated Recurrent Unit (GRU), is conducted for photovoltaic power forecasting. The evaluated models represent both feedforward and recurrent learning paradigms, allowing for a systematic comparison of their predictive capabilities in modeling PV power dynamics. The models are trained and tested using real-world operational data collected from a grid-connected PV plant in China, comprising meteorological variables and historical PV power output measurements. Prior to model training, appropriate data preprocessing and normalization steps are applied to ensure consistency and robustness. PV power output is predicted at time t using a supervised learning framework, enabling short-term forecasting under real operating conditions. Furthermore, the proposed framework is inherently flexible and can be extended to medium-term forecasting horizons of up to 15 days by integrating Numerical Weather Prediction (NWP) data as external inputs. Model performance is quantitatively assessed using widely accepted evaluation metrics, including Root Mean Squared Error (RMSE), Mean Absolute Percentage Error (MAPE), and the coefficient of determination (R^2), ensuring a fair and transparent comparison across all architectures. The experimental results clearly indicate that recurrent neural network-based models, particularly the LSTM architecture, consistently outperform feedforward and convolutional models. This superior performance is attributed to their ability to effectively capture temporal dependencies and long-term patterns in PV power time series data. Compared with existing comparative studies, this work provides a unified and rigorous benchmarking framework in which all models are evaluated under identical datasets, forecasting settings, and validation criteria. The findings offer valuable practical insights into the selection and deployment of deep learning models for real-world PV power forecasting applications and support informed decision-making for grid operators and energy planners.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171504: Machine Learning–Based Predictive Maintenance Framework for Performance Degradation Detection in Energy Conversion Systems

Prashant Steele * and Alka Bani Agrawal

Department of Mechanical Engineering, University Institute of Technology Rajiv Gandhi Proudhyogiki Vishwavidyalaya, Bhopal, India

Energy conversion systems, such as refrigeration units, electric motors, compressors, and thermal management systems, are very important in the use of energy in both industry and ordinary households. Performance degradation and component failure of energy conversion systems lead to both unexpected equipment downtime and a significant loss of energy efficiency. The typical method of maintaining these systems is either reactive or scheduled maintenance, and does not provide the tools for early detection of the degradation. In this paper, we will present an artificial intelligence-based predictive maintenance framework designed for monitoring and diagnosing Energy Conversion Systems (ECS) and using multiple sensor-generated operational data. The proposed methodology integrates a variety of parameters, including temperature, vibration, current, and environmental parameters, to develop a model of the health of ECS operating under normal conditions. Machine learning is then applied to the obtained data to identify anomalies, identify early fault signatures, and predict likely future failures prior to a major breakdown. The framework helps achieve both fault prevention and optimising energy efficiency through correlating equipment health indicators with energy performance metrics. Through experimental analyses of predictive maintenance, the findings show that not only does predictive maintenance reduce unplanned downtime, but it also exhibits verifiable improvements in system efficiency and operational stability. According to the study, the use of machine learning algorithms in predictive maintenance provides a robust framework for improving the reliability and energy efficiency of energy conversion systems. A framework that continuously learns from multi-sensor operational data allows for the identification and thus, maintenance of both the early stages of performance degradation and early identification of potential failure modes. The framework's combination of health indicators and energy performance metrics makes it possible to provide a quantitative evaluation of the total amount of efficiency loss due to deterioration in energy conversion systems. With these results, it is possible to see the potential for AI-based maintenance to facilitate sustainable energy management, decrease operational losses, and build the resiliency of systems in today's smart and connected energy conversion systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165421: A Hybrid Artificial Bee Colony with Adaptive Neighborhood Search and Gaussian Perturbation Integrated NSGA-II for Multi-Objective Probabilistic Optimal Power Flow Considering Solar, Wind, Electric Vehicles, and FACTS Devices

Abhishek Bajirao Katkar

Electrical Engineering, Lecturer, Government Polytechnic, Kolhapur, Maharashtra, 416004, India

The large-scale integration of renewable energy sources (RESs) and electric vehicles (EVs) has significantly increased the operational uncertainty, nonlinearity, and dimensionality of modern power systems, thereby challenging the effectiveness of conventional deterministic optimal power flow (OPF) techniques. To address these challenges, probabilistic optimal power flow (POPF) has emerged as a reliable framework capable of explicitly modeling the stochastic behavior of renewable generation and flexible EV loads while ensuring secure and economical system operation. In this paper, a novel hybrid multi-objective POPF framework is proposed by coupling an Artificial Bee Colony (ABC) algorithm enhanced with Adaptive Neighborhood Search (ANS) and Gaussian Perturbation (GP) strategies with the Non-dominated Sorting Genetic Algorithm II (NSGA-II). The proposed framework simultaneously minimizes total fuel cost and pollutant emissions under AC power flow equality constraints and practical operational limits. Uncertainties associated with wind speed, solar irradiance, and EV charging/discharging behaviors are modeled using appropriate probability density functions, enabling a realistic representation of intermittency and demand-side flexibility. In addition, Flexible AC Transmission System (FACTS) devices, namely the Thyristor Controlled Series Compensator (TCSC) and Thyristor Controlled Phase Shifter (TCPS), are optimally incorporated to enhance voltage regulation, reduce transmission congestion, and improve overall system security. The hybrid ABC-ANS-GP mechanism strengthens global exploration through adaptive neighborhood control, while Gaussian perturbations effectively mitigate premature convergence in high-dimensional search spaces. The embedded NSGA-II ensures robust Pareto dominance ranking and diversity preservation, resulting in well-distributed and convergent trade-off solutions. The effectiveness of the proposed approach is evaluated on the IEEE 57-bus test system under three study scenarios: conventional POPF, POPF with RES and EV integration, and POPF with combined RES, EV, and FACTS deployment. Comparative analyses against the recently reported Quasi-Optimistic Artificial Hummingbird Algorithm (QOAHA) demonstrate that the proposed framework achieves an average reduction of **7–10% in total generation cost**, a **9–13% emission reduction**, and a **15–25% improvement in convergence speed**. Furthermore, statistical assessments over multiple independent trials reveal a **35–45% reduction in solution dispersion**, confirming superior robustness and consistency under uncertainty. These results validate the proposed framework as a scalable and effective solution for large-scale, uncertainty-aware, multi-objective power system optimization.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170676: A Machine Learning Regression Model for Early-Stage Prediction of Biogas Production

Jasmina Elmurodova *, Zafar Turakulov and Jaloliddin Eshbobaev

Department of Automation and Digital Control, Tashkent Institute of Chemical Technology, Tashkent, Uzbekistan

Biogas production from organic waste is widely recognized as an effective option for renewable energy generation and sustainable waste management. At the same time, accurate estimation of biogas yield remains difficult because the process is influenced by several interrelated factors, including feedstock type, moisture content, and general operating conditions. These factors interact in a nonlinear manner, which limits the applicability of conventional empirical correlations and simplified mathematical models. This limitation is particularly important at the early stages of biogas project development, where quick and reasonably accurate yield estimation is required, while detailed kinetic or operational data are often unavailable. In this study, a machine-learning-based regression model is developed to predict biogas production using experimental data reported in the literature. The dataset is formed from previously published anaerobic digestion studies and includes a range of organic substrates and operating conditions. To ensure practical applicability, only a small number of commonly reported input variables are considered, mainly related to substrate composition and basic process characteristics. This choice reflects the typical level of information available during preliminary design and feasibility assessment. The data are divided into training and testing subsets using a standard train-test split in order to evaluate the predictive capability of the model for unseen data. The performance of the proposed model is evaluated using statistical indicators, with the coefficient of determination (R^2) used as the main metric. The results show good agreement between predicted and experimental biogas production values. For the test dataset, the R^2 value is close to 0.9, indicating that the model is able to explain a large portion of the variability observed in the experimental data. These results suggest that the main relationships affecting biogas generation can be captured using a single regression-based machine learning model, without the need for complex model structures or extensive input data. The obtained results highlight the potential of data-driven regression approaches as practical tools for early-stage analysis of biogas systems. While the proposed model does not replace detailed process modeling or experimental studies, it can support preliminary feasibility analysis, comparison of different feedstocks, and initial technology assessment. Due to its simplicity and modest data requirements, the model may be useful for engineers and researchers involved in the early planning and evaluation of biogas-based renewable energy projects.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170951: AI-Driven Multi-Modal Integration for Structural Health Monitoring of Photovoltaic Systems: A Nigerian Context

Blessed Olalekan Oyebola^{1,2,*} and Emmanuel S. Babatunde³

¹ Department of Electrical/Electronic Engineering, Lead City University, Ibadan, Nigeria

² Department of Computer Engineering Technology, Gateway (ICT) Polytechnic Saapade, Ogun State, Nigeria

³ Department of Electrical and Information Engineering, Achievers University, Owo, Nigeria

Introduction

Structural Health Monitoring (SHM) is essential for maintaining the reliability and long-term performance of photovoltaic (PV) systems, particularly in regions exposed to harsh environmental conditions. Photovoltaic installations in Nigeria operate under high solar irradiance, elevated ambient temperatures, dust accumulation, and limited maintenance accessibility, which accelerate structural degradation such as cell cracking, delamination, thermal hotspots, and shading losses. Existing SHM research is largely dominated by laboratory-based electroluminescence (EL) inspection and single-metric performance evaluation, limiting scalability and field applicability. To address these limitations, this study proposes a structured AI-driven multi-modal SHM evaluation framework that integrates unmanned aerial vehicle (UAV) imaging, thermal and RGB sensing, and deep learning diagnostics. Unlike experimental studies focused on single datasets, this work develops a systematic analytical framework that synthesizes and evaluates published photovoltaic diagnostic pipelines using objective multi-criteria decision analysis, enabling consistent cross-study comparison under field-relevant deployment conditions.

Methods

A literature-supported analytical framework was developed using Multi-Criteria Decision Theory (MCDT) to evaluate competing AI-hardware SHM pipelines. Eight representative AI-hardware alternatives were selected from peer-reviewed photovoltaic diagnostic studies using strict inclusion thresholds ($\geq 90\%$ Accuracy/F1/AUC or low regression error metrics) and verified field applicability. Performance indicators included Accuracy, F1-score, Area Under the Curve (AUC), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and coefficient of determination (R^2). To ensure methodological consistency across heterogeneous studies, performance metrics were normalized and objectively weighted using the CRITIC (Criteria Importance Through Intercriteria Correlation) method. Robustness-sensitive criteria received the highest weights (AUC = 0.2782; RMSE = 0.1978; MAE = 0.1835; R^2 = 0.1844), while Accuracy received a minimal weight (0.0071) due to uniformly high reporting across studies. The weighted decision matrix was subsequently ranked using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to identify field-optimal SHM pipelines.

Results

TOPSIS ranking identified CNN combined with thermal imaging as the most effective SHM solution (Closeness Coefficient C_i = 0.567), followed by CNN + UAV (RGB/Thermal) (C_i = 0.505) and Hybrid CNN + Sensors/IoT + UAV systems (C_i = 0.497). CNN-thermal pipelines consistently demonstrated high diagnostic performance ($\approx 95\text{--}96\%$ accuracy) and strong AUC values (~ 0.96), while maintaining operational scalability for large photovoltaic farms. UAV-enabled CNN frameworks further improved inspection coverage by enabling non-contact, large-scale monitoring of distributed PV arrays. In contrast, EL-based CNN methods ranked lower (C_i = 0.370) due to laboratory constraints, while classical machine-learning approaches such as SVM and ensemble tree models exhibited weaker generalization and incomplete metric reporting (C_i = 0.032–0.258). Hierarchical clustering analysis further confirmed that UAV-thermal CNN pipelines form a high-performance family of SHM solutions optimized for real-world deployment environments.

Conclusion

This study provides a methodologically consistent, literature-derived multi-criteria evaluation framework for AI-based photovoltaic structural health monitoring pipelines. The results indicate that UAV-mounted thermal CNN workflows offer the most robust and scalable SHM solution for photovoltaic installations operating under Nigerian environmental conditions. By integrating multi-modal sensing with objective decision analysis, the proposed framework enables systematic selection of field-deployable PV diagnostic technologies and bridges the gap between laboratory-based research and practical solar farm monitoring in sub-Saharan Africa. The framework also establishes a foundation for future experimental validation using field-acquired UAV and thermal datasets.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-168669: AI-Driven Neuro-Fuzzy (ANFIS) Control for Small-Scale DC Wind Turbine Systems in Uzbekistan

Botir Usmonov¹, Ulugbek Muinov¹, Komil Usmanov^{2,*} and Nigina Muinova³

¹ Department of Automation and Control, Tashkent Chemical Technological Institute, 100011, Tashkent, Uzbekistan

² Department of Automation and Digital Control, Tashkent Chemical-Technological Institute, Tashkent 100011, Uzbekistan

³ Department of Cellulose and Woodworking Technology, Tashkent Chemical-Technological Institute, Tashkent 100011, Uzbekistan

Small-scale wind turbines (SWTs) are a hopeful way to bring stable energy to Uzbekistan's remote towns. Many rural homes are still only poorly connected to the national grid or not connected at all. In these kinds of systems, proportional–integral (PI) control is not enough to make sure of tight DC-bus regulation because the wind is not always the same, the turbine and generator do not always move in the same way, and the DC loads change all the time. This paper suggests an intelligent, metaheuristic-optimized driver for a small-scale DC wind energy conversion system. The goal is to achieve a stable 48 V, 1 kW DC supply for bringing electricity to rural areas. The setup that was looked at has a horizontal-axis SWT connected to a permanent-magnet DC generator and a DC–DC buck converter that supplies a 48 V DC bus. The aerodynamic, electrical, and power electronic subsystems are modeled in MATLAB/Simulink using real wind data from the Bukhara region in 2024 (NASA POWER), along with hub-height adjustment and IEC 61400-1 Kaimal-spectrum turbulence reconstruction to show how the wind really changes speed at high frequencies. Using an ANFIS-based SWT model that has already been proven to work in rural Uzbekistan, this study adds a Grey Wolf Optimizer-tuned Adaptive Neuro-Fuzzy Inference System (GWO–ANFIS) controller that works better and is more stable than a well-tuned PI controller. The suggested controller uses an ANFIS structure that has two inputs, the DC voltage of the generator and the power of the turbine, and a single output, the buck converter's duty-cycle command. Generalized bell-shaped membership functions and a Sugeno-type rule base can also be used. The Grey Wolf Optimizer does a global search over the premise and consequent parameters. To obtain the best results, the optimization reduces a mixed objective function that includes DC-bus voltage tracking error, settling time, and RMS voltage noise. This builds power-quality standards directly into the learning process. The controller's performance is tested with step changes in wind speed, IEC-compliant unstable wind profiles, and step-changing DC loads that are typical of what people use in rural areas.

The simulations show that the GWO–ANFIS controller performs a lot better than the PI controller in all situations. GWO–ANFIS demonstrates faster settling and smaller delay when wind speed changes and it keeps the 48 V reference over a wide input voltage range (about 168–530 V). When there is a lot of wind, the improved driver cuts down on DC-bus voltage noise and improves disturbance avoidance. During load steps, the DC voltage stays very stable, and the output current follows the power demand without oscillating.

These results show that using neuro-fuzzy control along with metaheuristic optimization based on nature creates a strong AI-driven control strategy for small-scale DC wind energy systems. The suggested GWO–ANFIS processor improves the voltage, responds more quickly, and is more reliable without adding to the complexity of the hardware. This makes it a good choice for a low-cost, stable DC micro-power source in rural Uzbekistan and other places with low to medium wind.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-161154: AI-Optimized Pyrolysis: A Machine Learning Framework for Predictive Waste-to-Energy Conversion

Kelvin Godwin Anaman¹ and Sanjith Balamurali^{2,*}

¹ Presbyterian Boys Secondary School, Pulse Organization, Accra, 00233, Ghana

² Metea Valley High School, Pulse Organization, Aurora, Illinois, 60502, United States

Abstract

Introduction:

Global municipal solid waste (MSW) generation is projected to reach 3.4 billion tons annually by 2050. While pyrolysis offers a sustainable waste-to-energy alternative to landfilling, its industrial application is hindered by the complexity of heterogeneous feedstocks and the limited availability of reliable predictive optimization tools. This research addresses these challenges by developing a scalable, data-driven framework that integrates artificial intelligence with thermochemical principles.

Methods:

Using a dataset of 619 experimentally validated scenarios across 75 feedstock types, we benchmarked XGBoost against Random Forest (RF), Support Vector Regression (SVR), and Multi-Layer Perceptron (MLP) models. Model selection was based on predictive accuracy (R^2), robustness across diverse feedstocks, and stability under cross-validation. XGBoost was chosen due to its superior performance in capturing non-linear relationships in high-dimensional chemical data. The dataset was split using an 80/20 train-test scheme, ensuring representative coverage of different feedstock categories in both sets, and model reliability was further assessed using stratified 5-fold cross-validation. Physics-informed constraints were applied post-training to enforce mass balance (total yield $\approx 100\%$) and thermochemical consistency, ensuring adherence to fundamental physical laws.

Results:

The framework achieved strong predictive performance, with R^2 values of 0.78 for syngas, 0.76 for bio-oil, and 0.59 for biochar. Reactor type emerged as a significant predictor: fluidized-bed reactors showed higher bio-oil yields due to enhanced heat and mass transfer compared to fixed-bed systems, while auger reactors favored biochar formation under lower heating rates. Temperature remained the dominant operational variable, with an optimal bio-oil production region identified near 526 °C and a heating rate of approximately 100 °C/min.

Conclusions:

This study introduces a novel, physics-informed machine-learning framework that combines algorithm benchmarking, feedstock-diverse validation, and thermodynamic constraints for pyrolysis modeling, addressing key limitations in existing AI-based pyrolysis research. Rather than providing fixed emission reduction values, the model offers a pathway toward improved process efficiency and informed operational optimization. By enabling data-driven reactor and condition selection, this work supports the development of smarter and more sustainable waste-to-energy systems within a circular economy framework.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166371: An Optimized Hybrid Artificial Intelligence-based Control Strategy for Standalone Photovoltaic Systems under Complex Partial Shading Conditions

Oumaima Echab *, Nouredine Ech-cherki, Abdellatif Obbadi, Youssef Errami and Smail Sahnoun

Laboratory: Electronics, Instrumentation and Energy (LEIE), Faculty of Science, Chouaib Doukkali University, El Jadida, Morocco

Artificial intelligence (AI) techniques play a crucial role in providing smart and adaptive solutions to complex problems. By combining optimization, learning, and predictive capacities, the use of these methods remains relevant for enhancing the operational behavior of engineering systems. Therefore, the integration of AI techniques into energy-conversion systems has attracted significant attention recently due to their high performance, especially in photovoltaic (PV) systems, such as Standalone mode. Classical Maximum Power Point Tracking (MPPT) methods often suffer from slow convergence and reduced tracking efficiency under severe operating conditions such as Partial Shading Conditions (PSCs). However, most existing hybrid AI-based MPPT techniques rely on continuous metaheuristic optimization processes that increase computational complexity in standalone PV systems under rapidly varying PSCs. The current paper proposes an AI-combined MPPT control technique based on an Improved Perturb and Observe (IP&O) algorithm with a Grey Wolf Optimizer (GWO) for maximizing PV power extraction under these highly complex, non-uniform irradiance conditions, which emulate realistic operating conditions. Unlike traditional P&O, the suggested MPPT employs the GWO algorithm as an adaptive layer to dynamically tune the IP&O step size, enabling faster convergence while reducing the computational burden. At the same time, this improved AI-based method rapidly regulates the duty cycle of the Boost converter. The configuration of the standalone PV system comprises a PV array, a DC–DC boost converter, and a resistive DC load, regulated by the suggested GWO-IP&O approach, which is simulated in MATLAB/Simulink environment, version 2020b. The findings indicate that the proposed control technique achieves a tracking efficiency above 97%, reducing convergence time by approximately 30% and decreasing steady-state oscillations by nearly 50% compared to traditional P&O. Furthermore, it maintains the overall stability around the operating points, which significantly minimizes the PV power losses. The novelty of this work lies in its integration of the bio-inspired GWO optimization algorithm for adaptively tuning the parameters of the IP&O, enabling an improved performance. The obtained results demonstrate the superior potential of bio-inspired artificial intelligence applications, which provide a powerful solution for improving advanced MPPTs, and can be applied to achieve intelligent energy conversion in standalone PV mode in terms of robustness and reliability when exposed to complex PSCs.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165627: Applications of RNN, LSTM, and GRU in Solar Irradiance Prediction for Photovoltaic Systems

Casimiro Agostinho * and Fabio Meneghetti Ugolino de Araujo de Araujo

Department of Control and Automation, Federal University of Rio Grande do Norte (UFRN), Natal, 59078-970, Brazil

Introduction

The rigorous analysis of solar radiation data is fundamental to the advancement of renewable technologies and climate studies, particularly in Natal, Brazil, a strategic location characterized by an annual insolation of approximately 2,968.4 hours and an average daily irradiance of 5.0 kWh/m². This research aims to address a critical gap in the literature often limited by a scarcity of validated models for the high volatility of tropical regions and an overreliance on univariate approaches that neglect external environmental variables by investigating the application of Deep Learning architectures, such as Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM), and Gated Recurrent Units (GRU). By modeling complex temporal dependencies and dynamic patterns in multivariate series, this study seeks to validate the efficacy of these configurations in optimizing energy resource forecasting and enhancing grid reliability.

Methodology

The methodological framework commenced with comprehensive data pre-processing, employing spline interpolation techniques to handle missing values and z-score standardization for data normalization. To capture the temporal dynamics of the series, the data were segmented into sliding windows of 10 samples each, serving as input for the neural networks. The dataset was partitioned into training (90%) and testing (10%) sets, ensuring the preservation of sequential integrity for robust validation. The implementation was executed in Python using the TensorFlow and Keras frameworks. The evaluated architecture consisted of a four-layer deep structure (256, 128, 64, and 1 neuron in the output layer), utilizing ReLU activation for hidden layers and linear activation for the output. Hyperparameter optimization was conducted by systematically varying batch sizes (16, 32, and 64) and training durations (50 and 100 epochs) to identify the most efficient model configurations.

Results

In terms of practical application, the selection among these Deep Learning architectures depends on the specific energy system requirements: RNNs are ideal for rapid processing within short time windows; LSTMs are essential for systems requiring high reliability in long-term and seasonal forecasting, as their 'memory gates' prevent the loss of historical information; meanwhile, GRUs represent the most balanced solution for implementation in microcontrollers and low-cost embedded systems, offering the robustness of LSTMs with significantly lower memory and processing demands. Although all architectures converged toward a coefficient of determination (R²) of 0.94, the practical distinction between the models lies in the trade-off between statistical precision and structural complexity. The RNN 3 model achieved the lowest absolute errors, establishing itself as the most accurate configuration for this specific dataset. In contrast, the LSTM and GRU architectures demonstrated greater robustness in handling long-term temporal dependencies, effectively mitigating the vanishing gradient problem. Notably, GRU 3 offered performance equivalent to LSTM 3, but with a more simplified and efficient computational structure.

The error metrics for the top-performing configurations are summarized as follows:

RNN 3: RMSE of 291.92; MAE of 208.47; R² of 0.94. GRU 3: RMSE of 295.69; MAE of 211.90; R² of 0.94. LTM 3: RMSE of 296.14; MAE of 213.44; R² of 0.94.

Conclusions

This study concludes that the LSTM model demonstrated the greatest robustness in solar radiation forecasting, exhibiting a high correlation with empirical data and superior stability in predicting peak events and seasonal patterns. The primary contribution of this work lies in the use

of an unprecedented regional dataset, allowing for a rigorous performance evaluation of these architectures under the specific geoclimatic conditions of tropical regions. Notably, the LSTM architecture outperformed the conventional RNN by maintaining lower sensitivity to stochastic noise and modeling complex nonlinear relationships with higher precision, even in the presence of high local thermal and irradiance volatility. These findings validate the implementation of advanced recurrent architectures as a robust and contextualized tool for the sustainable management of solar energy systems in tropical environments.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170412: Comparative Evaluation of YOLOv8n and YOLOv26n for Edge-Optimized Defect Detection in PV Electroluminescence Imaging

Yacine Boutana^{1,*}, Sofiane Haddad¹, Ammar Soukkou¹, Nassir Rouibah², Abdelhamid Rabhi³ and Mohamed Benghanem⁴

¹ Renewable Energy Laboratory, Faculty of Sciences and Technology, Jijel University, Algeria.

² Building Physics And Environment Division , National Center of Studies and Integrated Research of Building, Soudania, 16097, Algeria.

³ Modeling, Information and Systems Laboratory, University of Picardie Jules Verne, Amiens, France.

⁴ Physics Department, Faculty of Science, Islamic University of Madinah, Madinah, KSA.

Photovoltaic systems play a central role in the worldwide transition to renewable energy sources, yet their efficiency and safety are frequently compromised by defects introduced during manufacturing or arising during their operation. Irregularities ranging from structural discontinuities to electrical anomalies can lead to considerable power losses and the development of localized hotspots. Electroluminescence (EL) imaging offers high-resolution, non-invasive visualization of cell-level defects, but manual inspection remains labor-intensive, subjective, and unscalable for large solar farms or remote installations. Recent advances in lightweight deep learning models, particularly the You Only Look Once (YOLO) family, enable automated, real-time detection. Nevertheless, achieving both strong detection performance and minimal computational demand on resource-constrained edge devices remains difficult, particularly when working with imbalanced, long-tailed distributions such as those found in the PVEL-AD dataset.

This feasibility study assesses two compact variants from the YOLO series, YOLOv8n, which serves as the established reference, and YOLOv26n, the most recent edge-focused model featuring a native end-to-end design without non-maximum suppression (NMS). Both models are trained and evaluated using a representative subset of the PVEL-AD dataset, which comprise 4500 electroluminescence (EL) images (3600 for training and 900 for validation) containing 7799 annotated defect instances distributed across eight key defect types: black_core, crack, finger, thick_line, star_crack, horizontal_dislocation, vertical_dislocation, and short_circuit. The dataset displays a pronounced long-tail distribution, where finger and crack defects constitute more than half of all instances. Training was performed with conservative settings to simulate resource-constrained experimentation: 512×512 input resolution, 50 epochs, early stopping (patience=10), minimal augmentation. And the models were trained and inferenced on a Tesla P100 GPU using the Ultralytics framework.

The evaluation adopts standard object detection metrics: mean Average Precision at IoU thresholds of 0.5 (mAP@0.5) and across 0.5 to 0.95 (mAP@0.5:0.95), along with precision, recall, and inference latency (encompassing preprocessing, inference, and postprocessing time in milliseconds per image, as well as frames per second). All measurements are derived from the 900-image validation subset, which includes 1586 defect instances.

On this validation set, YOLOv26n attains an overall mAP@0.5 of 0.897 and mAP@0.5:0.95 of 0.654, accompanied by a precision of 0.832 and recall of 0.891. In comparison, YOLOv8n yields modestly higher accuracy, with mAP@0.5 reaching 0.926, mAP@0.5:0.95 at 0.671, precision at 0.915, and recall at 0.889. Both architectures demonstrate excellent performance on larger or more structurally distinct defect categories (AP@0.5 exceeding 0.96 for black_core, short_circuit, and both dislocation types). Detection remains more moderate, however, on particularly difficult classes such as crack (0.687–0.737) and star_crack (0.768–0.771).

Inference speed markedly favors YOLOv26n, which records an average total latency of approximately 2.5 ms per image (corresponding to roughly 397 FPS), in contrast to approximately 3.3 ms (~302 FPS) for YOLOv8n. This advantage stems largely from the model's NMS-free

architecture, which eliminates the computational overhead associated with traditional post-processing steps.

This preliminary evaluation demonstrates that lightweight YOLO models, particularly YOLOv26n, offer a compelling trade-off between detection performance and inference speed for PV defect monitoring using EL imagery. Despite training on a subset with minimal augmentation, the models achieve competitive mAP@0.5 values (0.897–0.926) and sub-10 ms latency, making them suitable for real-time deployment on edge devices in industrial or remote solar environments. The strong performance on dominant defect types and reasonable results on rarer classes highlight their practical potential. Future work will extend this study to the full PVEL-AD dataset, incorporate additional architectures, stronger augmentation, and quantization for ultra-low-power settings.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-166328: Data Driven Prediction of DC Current in an Inverter Free Photovoltaic Battery System for Telecommunication Antenna Applications

Gabriel Jaime Osorio-Hernandez *, Daniel Sanin-Villa and David Velásquez

Industry, Materials, and Energy Area, School of Applied Sciences and Engineering, EAFIT University, Medellín, 050022, Colombia

Introduction

Remote telecommunication antennas increasingly rely on hybrid renewable systems to reduce operating costs and emissions while maintaining high service availability. Many of these facilities operate natively with direct current loads, which enables inverter-free architectures and introduces different operational constraints compared with conventional AC microgrids. Despite this practical relevance, the literature still shows limited evidence on data-driven prediction of DC electrical variables in real photovoltaic battery systems supplying telecom infrastructure. This study addresses this gap by proposing a machine learning-based framework to predict DC current demand and generation for a grid-assisted solar-powered telecommunication antenna. The installation is designed to operate without an AC inverter, since the load is entirely DC, which makes current prediction a key variable for energy management and battery utilization.

Methods

The case study considers a real installation located at Sucre, Colombia, equipped with approximately 20 kWp of installed photovoltaic capacity, two battery units rated at 10 kWh each, and a rectifier that enables energy intake from the utility grid when required. High-resolution operational data were collected, including solar generation, battery behavior, DC load current, and relevant meteorological variables. An exploratory data analysis stage was first conducted using statistical distributions and median-based smoothing to identify patterns, outliers, and temporal dependencies. Feature relevance was then assessed through correlation analysis between climatic variables, solar irradiance, and DC electrical measurements, allowing dimensionality reduction to the most influential predictors. Model development was carried out using the EvalML framework for automated machine learning, with additional benchmarking performed using PyCaret to ensure consistency and robustness. Multiple regression-based and tree-based models were trained and validated under identical data partitions to identify the most suitable structure for DC current prediction in this inverter-free configuration.

Results

The results indicate that the proposed framework achieves high predictive accuracy for DC load current. The best-performing model, a CatBoost Regressor, achieved a mean absolute error of 0.4204 A, a mean squared error of 0.3166 A², and a root mean squared error of 0.5615 A on the validation dataset. The coefficient of determination reached 0.9761, indicating strong explanatory power, while the mean absolute percentage error was limited to 1.62 percent. Additional validation yielded an R² of 0.9999 under controlled conditions, confirming the stability of the learned relationships. These results demonstrate that accurate DC current prediction is feasible without relying on inverter-related variables, and that parsimonious models can achieve reliable performance suitable for edge deployment in telecommunication sites.

Conclusions

This work demonstrates a practical and original data-driven approach for predicting DC current in photovoltaic battery systems supplying telecommunication antennas. By explicitly considering a DC load architecture without an inverter, the study contributes new evidence to an underexplored area of renewable-powered telecom systems. The proposed framework supports improved energy management, battery scheduling, and grid interaction decisions, while remaining computationally efficient. These results are relevant to sustainable transition strategies

for critical infrastructure in our Country and align with emerging applications of artificial intelligence in energy conversion systems, particularly in DC-dominant installations.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171377: Deep Learning-Driven Real-Time Optimization for Improved Exergy Efficiency in Hybrid Renewable Energy Conversion Systems

Desmond Chinecherem Nwana

Department of Accountancy, Faculty of Management Sciences, University of Nigeria, Nsukka, 410001, Nigeria

Hybrid renewable energy systems that integrate solar, wind, and energy storage provide a promising solution for sustainable electricity generation. However, the intermittent nature of these resources often leads to inefficient energy conversion and increased thermodynamic losses, reducing exergy efficiency. Traditional rule-based control strategies struggle to adapt to rapidly changing environmental conditions. This study proposes an artificial intelligence-based framework that combines deep learning forecasting with reinforcement learning control to enhance system performance.

The proposed approach utilizes a Long Short-Term Memory (LSTM) neural network to predict short-term solar irradiance and wind speed using meteorological data from NASA POWER and historical records. These forecasts are integrated into a reinforcement learning agent based on the Proximal Policy Optimization (PPO) algorithm, which dynamically adjusts system parameters such as inverter operation, battery scheduling, and wind turbine pitch angle. The objective is to minimize exergy destruction while maintaining stable energy output.

The framework was evaluated using a simulation model of a hybrid solar-wind-battery system developed with Python-based tools, including TensorFlow. Exergy analysis was applied to quantify losses across system components. Validation was further conducted using a small-scale laboratory prototype comprising photovoltaic panels, a micro wind turbine, battery storage, and programmable converters.

Results indicate that the proposed approach achieves a noticeable improvement in exergy efficiency compared to conventional control strategies, primarily due to reduced losses in storage and conversion stages. These findings highlight the potential of AI-driven optimization for improving the efficiency and reliability of hybrid renewable energy systems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171173: Energy-Aware Machine Learning Framework for Multi-Class Weather Classification in Edge-Enabled Renewable Energy Systems

Veena Madavanathara Narayanan^{1,*}, **Chris Ogwumike**², **Maria Jenisha Packiaraj**³ and **Michael Short**⁴

¹ School of Computing, Engineering & Digital Technologies, Teesside University, Middlesbrough, UK

² Electrical & Electronic Engineering, SCEDT Engineering, Centre for Sustainable Engineering, Teesside University, Middlesbrough, UK

³ Engineering (Electrical/Mechanical), SCEDT Engineering, Teesside University, Middlesbrough, UK

⁴ SCEDT Engineering, Teesside University, Middlesbrough, UK

Accurate, low-latency weather intelligence plays a critical role in renewable energy integration, smart grid stability, and climate-resilient infrastructure planning. Conventional numerical weather prediction approaches, while physically robust, are computationally intensive and often unsuitable for localized and real-time decision-making in distributed energy environments. This work proposes an energy-aware machine learning framework for multi-class weather classification designed to support edge-enabled renewable energy systems and data-driven urban energy management. A decade-long historical meteorological dataset (2014–2023) containing hourly weather observations is utilized to train and evaluate multiple supervised learning models under a unified experimental protocol.

Four widely adopted classifiers—Decision Trees, Gaussian kernel Support Vector Machines, Feedforward Neural Networks, and Ensemble (Bagging) methods—are systematically compared using consistent preprocessing, temporal feature extraction, five-fold cross-validation, and Bayesian hyperparameter optimization. Model performance is assessed using both predictive and computational metrics, including classification accuracy, macro-averaged F1-score, ROC-AUC, training time, and inference throughput. This dual-metric evaluation enables explicit quantification of the trade-off between predictive quality and computational energy demand, which is a critical factor in edge and embedded deployment scenarios.

Experimental results indicate that Ensemble (Bagging) achieves the highest predictive performance with an accuracy of 85.44% and ROC-AUC of 0.91, demonstrating strong generalization across diverse weather categories. Gaussian SVM provides near-comparable accuracy with reduced training overhead, offering a balanced compromise between precision and computational burden. Decision Trees exhibit exceptional inference speed exceeding 590,000 observations per second, highlighting their suitability for real-time and low-power edge applications despite comparatively lower accuracy. Neural Networks deliver moderate but stable performance across all metrics, emphasizing the influence of architecture depth and optimization strategies on tabular meteorological data.

The findings reveal a clear accuracy–efficiency frontier that supports application-specific model selection for renewable energy forecasting, solar and wind resource assessment, smart city weather sensing, and distributed energy management systems. Conceptual edge-AI deployment analysis further suggests that lightweight classifiers can significantly reduce computational energy consumption while maintaining acceptable predictive reliability. This research contributes an energy-conscious, scalable machine learning approach that bridges artificial intelligence and sustainable energy infrastructures, enabling more resilient, adaptive, and environmentally responsible smart energy ecosystems.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170645: Enhancing Renewable Energy Efficiency with Artificial Intelligence

Karim Aouragh

Independent Researcher

Introduction

Traditional power assets face tremendous demanding situations inclusive of pollution, greenhouse gas emissions, and the fast depletion of herbal assets, which will increase the need for sustainable answers.

Renewable energy, which includes solar, wind, and hydropower, is taken into consideration as one of the most crucial environmentally friendly options. However, it faces challenges in predicting output and efficiently dealing with grids due to climate fluctuations and manufacturing instability. Artificial intelligence offers powerful equipment to cope with these challenges by way of analyzing big information, forecasting manufacturing, optimizing storage, and handling clever grids efficiently.

Integrating AI with renewable energy can accelerate the transition towards a low-emission financial system and enhance environmental and social sustainability.

Methodology

Data Collection: Gather manufacturing measurements from renewable power vegetation, weather records, and reading power consumption.

Data Analysis: Use machine learning techniques to forecast power manufacturing and consumption.

Modeling: Develop predictive fashions to optimize energy distribution and decrease losses.
Implementation: Integrate models into smart grids to manage assets extra efficiently.

Results

Significant improvement was achieved in the accuracy of forecasting solar and wind electricity generation, increasing by up to 20–30%, enabling better planning and optimization of renewable energy resources. Losses were reduced in intelligent electrical grids, resulting in enhanced overall grid stability, reliability, and operational efficiency. The economic feasibility of renewable energy solutions increased, encouraging wider adoption of smart grids, and promoting integration of clean energy technologies, and ultimately supporting a more sustainable and resilient energy infrastructure for the future.

Conclusion

Traditional energy sources face major challenges such as pollution, greenhouse gas emissions, and the depletion of natural resources. Renewable energy, including solar, wind, and hydropower, offers an environmentally friendly solution, but it faces difficulties in production forecasting and smart grid management. Artificial intelligence contributes by analyzing data, predicting output, and optimizing storage and grid management, thereby increasing renewable energy efficiency, reducing losses, and enhancing economic, environmental, and social sustainability.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165700: Integrating Electro-Thermal Dynamics into SOC Estimation through Internal Resistance and Thermal Loss Regularization

Hafsa Khayrane *, Asma R'guibi, Fatima Wardi, Oussama Oussama Khouili and Mohamed Louzazni

Science Engineer Laboratory for Energy, National School of Applied Sciences, Chouaib Doukkali University of El Jadida, El Jadida, Morocco

The accurate estimation of the State of Charge in lithium-ion batteries represents a fundamental task for modern energy management systems, yet it remains a complex challenge due to latent electro-thermal dynamics that cannot be directly observed through simple terminal measurements. In this study, we present a robust and physically consistent framework that utilizes internal resistance as an intermediate variable to stabilize the prediction of the State of Charge. The work begins with an in-depth predictive power analysis conducted on an experimental dataset. The primary objective was to evaluate the observability of the effective internal resistance based on current, voltage, and temperature statistics. The results of this preliminary analysis revealed a significant disparity in the information provided: while the mean values of current and temperature show limited correlation when considered individually, the statistical features derived from voltage, including variance and quartile distributions, carry the dominant predictive information. Furthermore, we demonstrated that the calculation of the instantaneous ratio between voltage and current variations acts as an essential physical descriptor capable of linking raw data to the electrochemical state of the cell. Based on these findings, an extremely lightweight resistance estimator was trained, achieving a very low relative error. This component is then coupled with a lumped thermal model. The true innovation of this approach lies in the way the thermal model is utilized: instead of incorporating it as additional input data, which would increase computational complexity during real-time use, it is introduced as a regularization term within the loss function during the training phase. This method imposes electro-thermal consistency by penalizing State of Charge trajectories that deviate from the heat generation profiles predicted by the physics of Joule heating. Experimental results demonstrate that this strategy significantly improves the robustness and stability of the system under various operating conditions, while ensuring zero additional computational load for the on-board hardware during final execution.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170548: IuditAR: A Pilot Study on Overcoming Indonesia's Household Energy Waste via AI-driven Game-As-Reality (GAR) Audits

Tegar Septyan Hidayat

Sustainability Research Group, TEG Institute (Technology & Education Global), Jakarta 13230, Indonesia

Introduction

Indonesia faces a severe residential energy crisis, with household usage accounting for around 42% of national electricity use, and energy literacy levels remain low. It costs Indonesia an estimated 15-20 trillion rupiah annually in lost economic activity due to electrical waste, such as vampire power problems, commonly considered standby and energy waste. Current traditional energy audits, which are very costly, require trained auditors and cannot be scaled to a million homes in Indonesia, making it harder for citizens to be aware of energy-saving issues. As a result, there exists a significant intention-action gap for the average citizen to understand abstract concepts such as saving energy because they cannot easily get energy-saving education and apply their understanding to sustainable action. In this paper, we present IuditAR as a solution to the residential energy crisis in Indonesia, part of the Game-As-Reality (GAR) verse in sustainability, which employs a novel GAMERS protocol (Geste, Ambience, Mechanics, Engine, Reality, Sustainability). In contrast to passive education methods or pure gamification/game-based learning, the GAR-verse paradigm turns the home itself into a playable audit environment where the user can interact with real appliances as virtual game objects using AI-powered markerless augmented reality and obtain progress within the game upon completing verified actions. It can be a game-changer for energy-saving actions to make them more engaging and effective.

Methods

We conduct a quasi-experiment as a pilot study to evaluate the feasibility and initial user engagement of the IuditAR system using 32 participants over a one-week period. Our IuditAR utilizes AI for device detection with around 95% accuracy, markerless augmented reality for generating context-aware energy-saving missions, and giving personalized advice. It is operationalized in GAMERS protocols as follows: G (Geste), a narrative story to frame users as "Energy Guardians" on a hero's journey; A (Ambience), a hybrid physical and digital environment to support AR panels attached to detected appliances; M (Mechanics), a mechanism to award users XP/badges only upon successful completion of actions that were verified; E (Engine), supporting technology and tools to educate; R (Reality), a connection from the program to real impact conducted by users in real life; and S (Sustainability), features to support streak mechanisms and cumulative savings dashboards for users to sustain behavior change and retention. We measure the outcomes via several indicators using KAB (knowledge, attitudes, behavior) toward energy-saving and the GAMERS framework experience scale.

Results and Conclusion

Based on our study, we found significant results in several parameters. Participants engaged with a mean of 36.5 AI scans/user across >50 household objects to identify potential savings. In the KAB (knowledge, attitude, and behavior) parameter, participants' knowledge scores and attitudes towards energy behaviors changed significantly ($p < 0.0001$) from the baseline, indicating that they would take action to save energy. They also demonstrated high compliance with the behavioral checklist, with more than 90% of users reporting sustaining energy-saving actions such as unplugging gadgets after charging and turning them off. Our system validates their energy-saving actions by verifying their uploaded photos. In the GAMERS experience scale, the Reality and Geste components received the highest ratings and predict participants' behavior significantly. It indicates that digital progression in a game to physical actions that have been verified by AI can be a powerful mechanism for locking in behavior changes that are not available in conventional apps or usual games/simulations.

This pilot study demonstrates the feasibility and user acceptance of the GAMERS protocol as a scalable framework for energy education. While the current results rely on self-reported data with verification in the app to verify their results and limited participants, they provide a strong foundation for future research. The next phase of development will focus on validating these behavioral changes through integration with PLN (state utility) smart meter data and conducting longitudinal Randomized Controlled Trials (RCTs) to objectively measure kilowatt-hour reduction. IuditAR represents a promising step toward scalable, AI-driven sustainability tools for the Global South, aligning with SDG 7 and Indonesia's 2060 net-zero goals.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170894: Machine Learning-Based Forecasting and Adaptive Control of Energy Flow in Intelligent Electrical Networks

Noilakhon Yakubova

Department of Control Systems and Information Processing, Tashkent State Technical University, Tashkent 100095, Uzbekistan

Modern intelligent electrical networks, commonly referred to as smart grids, operate under conditions of increasing uncertainty caused by rapidly fluctuating load demands, high penetration of renewable energy sources, and complex nonlinear interactions among system components. The integration of distributed generation units, such as photovoltaic and wind energy systems, introduces significant variability and intermittency into power supply regimes. Under such conditions, conventional forecasting and control strategies, which are typically based on static models and predefined operating rules, often fail to provide sufficient adaptability, robustness, and efficiency. As a result, power system operators face challenges related to energy losses, voltage instability, and reduced reliability of grid operation. In this context, the development of intelligent forecasting and adaptive control approaches capable of responding to real-time operating conditions has become a critical research direction for sustainable and resilient energy systems. This study develops a machine learning-based forecasting and adaptive control framework to optimize energy flow in intelligent electrical networks under uncertain load and renewable generation conditions. The methodology consists of four main stages: data preparation, forecasting model construction, adaptive control and constrained optimization, and simulation-based validation. Historical and real-time operational data are organized into an input-output dataset including load demand, renewable generation output, voltage and frequency deviations, and operational constraints. A neural network-based time-series forecasting model is employed to predict short-term load dynamics and system operating states, capturing nonlinear temporal dependencies. Based on the predicted states, an adaptive control layer computes real-time control actions using a constrained optimization strategy to minimize energy losses while maintaining system stability and satisfying technological and safety constraints. The framework supports bidirectional energy exchange between the main grid and distributed renewable energy sources and is designed for real-time operation within a smart grid architecture. Simulation studies are conducted using a representative intelligent electrical network model operating under variable load conditions and renewable energy penetration. The proposed framework is evaluated in terms of forecasting accuracy, energy efficiency, and dynamic stability and compared with conventional forecasting and control strategies. The results demonstrate that the machine learning-based forecasting model improves short-term load prediction accuracy by approximately 15–20%. In addition, the adaptive control mechanism enables more efficient energy flow regulation, resulting in a reduction in total energy losses by about 10–12%. The system also exhibits improved dynamic stability, characterized by faster convergence to steady-state operating conditions and reduced sensitivity to load fluctuations. The obtained results confirm that the integration of machine learning-based forecasting with adaptive control mechanisms significantly enhances the performance of intelligent electrical networks under uncertain operating conditions. The proposed framework improves operational stability, efficiency, and resilience and can be effectively integrated into smart grid decision-support systems and digital twin platforms. Overall, this study demonstrates the potential of machine learning-based forecasting and adaptive control for sustainable, reliable, and efficient smart grid operation.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171147: Machine Learning-Based Optimization of Energy Consumption in Ion-Exchange Wastewater Treatment Systems

Jaloliddin Eshbobaev^{1,*}, Adham Norkobilov² and Zafar Turakulov³

¹ Tashkent Institute of Chemical Technology, Tashkent 100011, Uzbekistan

² Faculty of Food Engineering in Shahrisabz, Karshi State Technical University, Shahrisabz 181306, Uzbekistan

³ Department of Automation and digital control, Tashkent Institute of Chemical Technology, Tashkent 100011, Uzbekistan

Improving the energy efficiency of industrial wastewater treatment processes is a critical challenge driven by increasing operational costs and sustainability requirements. In ion-exchange-based wastewater treatment systems, the specific final energy use is primarily associated with pumping operations and hydraulic losses, which are strongly influenced by flow regulation strategies. Conventional control approaches typically operate under fixed or conservatively selected flow conditions to ensure treatment quality, often leading to excessive final energy use, especially under varying influent water quality. This study investigates the application of machine learning (ML) methods to support energy-efficient operation of an ion-exchange wastewater treatment system by identifying adaptive flow control strategies that balance treatment performance and energy use. A laboratory-scale experimental setup was developed, and a dataset of 300 operating samples was collected under varying conditions of water hardness, total dissolved solids (TDSs), and valve opening degree. The specific final energy use (kWh/m³), estimated from hydraulic operating parameters, was used as a key performance indicator. The dataset was divided into training (80%) and testing (20%) subsets, and model performance was evaluated using R², RMSE, and MAE metrics. Extreme Gradient Boosting (XGBoost) was employed as the primary predictive model due to its robustness in handling nonlinear relationships and small-to-medium datasets, while Random Forest (RF) was used as a baseline for comparison. Hyperparameters of both models were tuned using cross-validation to improve generalization performance. The results demonstrate that ML models can accurately approximate the nonlinear relationship between water quality parameters, control actions, and energy use. XGBoost achieved higher predictive accuracy and stability compared to RF. Model-based analysis identified operating regions where treatment requirements are satisfied with reduced final energy use. Under representative operating scenarios, the proposed ML-assisted control strategy indicates a potential reduction of specific final energy use by approximately 10–15% without compromising treatment performance. These findings confirm the feasibility of integrating machine learning as a decision-support tool for energy-aware control in ion-exchange wastewater treatment systems and provide a basis for future implementation of real-time intelligent control frameworks.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-170959: Optimizing Remaining Useful Life Prediction in Photovoltaic Systems Using AI-Enhanced LSTM Models

Blessed Olalekan Oyebola^{1,2,*} and Emmanuel S. Babatunde³

¹ Department of Electrical/Electronic Engineering, Lead City University, Ibadan, Nigeria

² Department of Computer Engineering Technology, Gateway (ICT) Polytechnic Saapade, Ogun State, Nigeria

³ Department of Electrical and Information Engineering, Achievers University, Owo, Nigeria

Introduction

Accurate prediction of the Remaining Useful Life (RUL) of photovoltaic (PV) systems is essential for proactive maintenance, cost reduction, and sustainable energy planning. Unlike structural health monitoring, RUL forecasting relies on modeling long-term temporal degradation patterns derived from electrical output, environmental exposure, and operational stressors. In Nigerian PV installations, high temperature variability, dust loading, and irradiance fluctuations intensify nonlinear degradation, rendering traditional statistical models insufficient. This work presents an AI-driven RUL prediction framework that systematically evaluates time-series learning models, with emphasis on Long Short-Term Memory (LSTM) networks integrated with Internet of Things (IoT) sensor data. The study is based on a systematic literature analysis and multi-criteria analytical evaluation of published photovoltaic diagnostic studies, rather than new experimental or field-generated data.

Methods

A multi-criteria analytical framework was applied to rank AI-hardware alternatives for RUL prediction using literature-derived, traceable performance metrics. Evaluated alternatives included RNN/LSTM + IoT sensors, ARIMA + sensors, ANN/DNN + I-V tracers, hybrid CNN + IoT + I-V ensembles, autoencoder-IoT models, and SVM-based approaches. Performance criteria comprised RMSE, MAE, MAPE, R^2 , Accuracy, and Scalability. Metrics were normalized and weighted using the CRITIC method, which assigned dominant importance to R^2 (0.2632), RMSE (0.2584), MAE (0.2381), and MAPE (0.2367), while Accuracy received minimal weight (0.0036) due to limited discriminatory power. TOPSIS ranking was then applied to identify the most reliable RUL forecasting pipelines under real-world conditions.

Results

The TOPSIS evaluation ranked RNN/LSTM + IoT sensors as the strongest RUL prediction approach with a closeness coefficient of 0.663, significantly outperforming all alternatives. LSTM-IoT models achieved RMSE values as low as 0.0019–0.0020, MAE $\approx$ 1.24 kWh, and near-perfect explanatory power ($R^2 \approx$ 0.9999) across multiple studies. Hybrid CNN + IoT + I-V ensembles ranked second ($C_i = 0.522$), demonstrating robustness through multi-modal fusion. ARIMA-sensor models ranked third ($C_i = 0.504$), showing strong statistical fit but reduced adaptability to nonlinear degradation. Autoencoder-IoT methods reported extremely high accuracies ($\approx$ 99–100%) but ranked lower due to weak error-based performance and limited field validation. ANN/DNN and SVM-based models consistently ranked lowest due to sparse reporting of RUL-specific error metrics and constrained scalability.

Conclusion

The findings confirm that LSTM-based IoT frameworks are the most effective and field-ready solution for RUL prediction in photovoltaic systems, particularly under Nigerian environmental conditions. By minimizing prediction error while maintaining high explanatory power, LSTM-IoT models enable reliable forecasting of PV degradation trajectories and support predictive maintenance scheduling. When integrated with UAV-thermal SHM pipelines, the approach forms a unified, end-to-end diagnostic framework that addresses both immediate structural faults and long-term lifespan degradation, advancing scalable PV asset management in sub-Saharan Africa.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-165652: Physics-Informed Neural Network Hysteresis Compensation for Precision Piezoelectric Energy Conversion Systems

Prince Alex Ogbodum

Department of Robotics and AI, Faculty of Control systems and robotics, National Research University ITMO, 197101, Kronverkskiy Prospekt, 49, St Petersburg, Russia

Introduction

Piezoelectric actuators are critical components in precision energy systems, enabling applications ranging from renewable energy inspection robotics to vibration energy harvesting. However, inherent hysteresis nonlinearity degrades positioning accuracy by 10–15% of the full stroke, limiting energy conversion efficiency and operational precision. Standard proportional-integral-derivative (PID) control fails to adequately compensate for this history-dependent behavior. This work presents a hybrid physics-informed neural network (PINN) control strategy that combines analytical inverse hysteresis modeling with data-driven residual learning to achieve superior accuracy and robustness compared to purely analytical or data-driven approaches.

Methods

The system models a PI P-088.741 piezoelectric stack integrated into a flexure-guided stage, characterized by a second-order transfer function (natural frequency 3.45 kHz) and Bouc–Wen hysteresis. The control architecture comprises three cascaded components: (1) an analytical Bouc–Wen inverse model computing the baseline voltage; (2) a physics-informed residual neural network (RRN) predicting a voltage correction term; and (3) a PID feedback controller with anti-windup. The RRN implementation utilizes a compact feedforward architecture (two hidden layers, 64 neurons each, ReLU activation) trained to minimize mean-squared error on the residual voltage. Crucially, the network is physics-informed through its input features, which include reference displacement, tracking error, and physics-derived inverse voltage terms, ensuring the network learns context-aware corrections grounded in physical system states rather than black-box mapping.

Results

Validation was conducted via high-fidelity simulation under both nominal and parameter mismatch conditions. Performance metrics included RMS tracking error, transient response specifications, and frequency robustness. Against a baseline PID controller, the hybrid (inverse and PID) configuration achieved an 88–91% reduction in RMS tracking error across 1–10 Hz sinusoidal tests. The hybrid PINN variant maintained robustness under parameter mismatch, with performance degradation remaining below 10% for unseen frequencies (2–6 Hz), though slight degradation occurred at higher unseen frequencies (7–9 Hz). Transient validation using a 10 μm step command demonstrated settling times of approximately 6 ms (well within the 0.5 s specification) and negligible overshoot (0.02%). The results confirm that the residual learning approach effectively compensates for model uncertainties without sacrificing stability.

Conclusions

This research demonstrates the feasibility of hybrid physics-informed residual learning for precision piezoelectric positioning in energy systems. By leveraging an analytical physics-based inverse as the primary compensator and a neural network for residual correction, the proposed method balances interpretability with adaptive accuracy. The validated controller enables high-precision operation under hysteresis-limited conditions, suitable for smart energy inspection and harvesting applications. Future work will focus on hardware implementation and expanding robustness validation to broader frequency ranges and amplitude variations.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

sciforum-171477: Securing Critical Energy Infrastructure: Cyber Risks, Challenges, and Defense Strategies in the Digital Era

Hirak Modi ^{1,2*} and **Veera Gnaneswar Gude** ^{1,3,4}

¹ Purdue University Northwest Water Institute, Purdue University Northwest, Hammond, IN 46323, USA

² Department of Computer Science, Purdue University Northwest, Hammond, IN 46323, USA

³ Department of Mechanical and Civil Engineering, Purdue University Northwest, Hammond, IN 46323, USA

⁴ School of Sustainability Engineering and Environmental Engineering, Purdue University, West Lafayette, IN 47907, USA

Securing Critical Energy Infrastructure: Cyber Risks, Challenges, and Defense Strategies in the Digital Era

The rapid digitalization of the energy sector has improved operational efficiency but significantly increased exposure to cyber threats against critical infrastructure. Recent analyses indicate that reported cyberattacks on energy assets more than doubled between 2019 and 2023, with ransomware accounting for nearly 40% of incidents. Individual attacks, such as the Colonial Pipeline breach, caused multi-day fuel disruptions and ransom payments totaling more than USD 4 million. Automation is rapidly expanding in energy sectors, including bioenergy and renewable energy power plants, where digital control systems improve efficiency and reliability. However, cybersecurity risks in these critical infrastructures remain less understood, with limited awareness among operators and engineers. To address this knowledge gap, this research examines potential cyber threats targeting power control systems and evaluates their impacts on process safety and energy security. Understanding these challenges is essential to ensure resilient and secure operations as facilities become more interconnected. This study provides valuable insights into emerging vulnerabilities, helping guide future risk mitigation strategies and strengthen the overall security of energy systems.

This study synthesizes cybersecurity risks, challenges, and mitigation strategies across oil and gas, electricity, nuclear, and renewable energy systems. Key challenges include securing legacy industrial control systems and virtual power plants, managing complex cloud-based and highly interconnected architectures, and addressing systemic gaps in workforce skills, governance, and security culture. The analysis highlights advanced detection and response strategies leveraging artificial intelligence and machine learning, multi-criteria decision-making methods for cyber-risk prioritization, and edge-based security architectures for distributed generation as promising technical approaches. In parallel, the study underscores the need for harmonized international standards, sector-specific regulation, continuous cyber exercises, and robust public-private partnerships to enhance resilience. Overall, the findings argue for a proactive, adaptive cybersecurity posture that integrates technical, organizational, and policy measures to safeguard critical energy assets and ensure a reliable, sustainable energy supply.



© 2026 by the author(s). Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

MDPI AG
Grosspeteranlage 5
4052 Basel
Switzerland
Tel.: +41 61 683 77 34

Energies Editorial Office
E-mail: energies@mdpi.com
www.mdpi.com/journal/energies



Disclaimer/Publishers' Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

