




“Evaluating environmental–economic efficiency in utility-scale solar energy systems: Evidence from India and Jordan”

AUTHORS	Amer Morshed  Laith T. Khrais 
ARTICLE INFO	Amer Morshed and Laith T. Khrais (2026). Evaluating environmental–economic efficiency in utility-scale solar energy systems: Evidence from India and Jordan. <i>Environmental Economics</i> , 17(1), 64-77. doi: 10.21511/ee.17(1).2026.06
DOI	http://dx.doi.org/10.21511/ee.17(1).2026.06
RELEASED ON	Tuesday, 10 February 2026
RECEIVED ON	Wednesday, 15 October 2025
ACCEPTED ON	Thursday, 08 January 2026
LICENSE	 This work is licensed under a Creative Commons Attribution 4.0 International License
JOURNAL	"Environmental Economics"
ISSN PRINT	1998-6041
ISSN ONLINE	1998-605X
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”



NUMBER OF REFERENCES

64



NUMBER OF FIGURES

0



NUMBER OF TABLES

7

© The author(s) 2026. This publication is an open access article.



BUSINESS PERSPECTIVES



LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine
www.businessperspectives.org

Type of the article: Research Article

Received on: 15th of October, 2025

Accepted on: 8th of January, 2026

Published on: 10th of February, 2026

© Amer Morshed, Laith T. Khrais, 2026

Amer Morshed, Ph.D., Assistant Professor, Department of Accounting, Faculty of Business, Al-Zaytoonah University of Jordan, Jordan. (Corresponding author)

Laith T. Khrais, Ph.D., Assistant Professor, Department of Business, Faculty of Business, Middle East University, Jordan.

Amer Morshed (Jordan), Laith T. Khrais (Jordan)

EVALUATING ENVIRONMENTAL–ECONOMIC EFFICIENCY IN UTILITY-SCALE SOLAR ENERGY SYSTEMS: EVIDENCE FROM INDIA AND JORDAN

Abstract

Aligning environmental objectives with economic performance is an ongoing challenge in the renewable energy transition, especially in emerging solar markets facing operational inefficiencies and uneven policy implementation. This paper examines the environmental and economic efficiency of large-scale solar energy conversion projects by employing a Material Flow Cost Accounting methodology based on ISO 14051 standards. Based on the operating and financial performance data of 83 solar energy conversion projects (46 from India and 37 from Jordan) covering the period 2017–2023, avoidable energy loss costs due to dust settling, heat stress, grid curtailment, and plant downtime have been estimated and quantified cumulatively in both settings. The findings indicate a technical efficiency of 88.4% and 77.9% with an average energy loss potential of 128 and 274 gigawatt-hours per year in both settings of Jordan and India, respectively, causing an economic loss potential of 9.2% and 18.7%, respectively, collectively amounting to a financial loss potential of about 54.6 million annually. Systematic plant maintenance and coordinated use in electric grids increased output potential by about 16% and lowered costs by 13%, with efficient management options collectively leading to an 11.5% increase in financial returns in Jordan and a 19.3% boost in India's financial performance. Based on findings, MFCA methodology is indeed capable of interlinking environmental protection with economic performance for efficient, sustainable energy policymaking within developing nations.

Keywords

solar, efficiency, economics, sustainability, environment, cost, governance, India, Jordan

JEL Classification

Q42, Q56, C51

INTRODUCTION

The international transition toward renewable energy has accelerated the deployment of utility-scale solar photovoltaic (PV) systems in developing and emerging economies. However, the sustainability value of solar investment depends not only on installed capacity but on delivered electricity and the efficient use of land, materials, and operating resources. In many solar markets, realized generation falls below technical potential because output is reduced by avoidable losses linked to soiling (dust accumulation), high module temperatures and thermal mismatch, equipment faults and downtime, and grid curtailment.

These loss drivers are economically and environmentally consequential. In arid environments, empirical evidence indicates that soiling losses can exceed 30% of the total energy generated per annum, implying substantial avoidable inefficiency when cleaning schedules, monitoring routines, and maintenance governance are not aligned with site conditions (Ahmed et al., 2024). The practical challenge addressed in this study is methodological integration: operational losses in utility-scale PV are routinely quantified in physical terms, yet their transla-



This is an Open Access article, distributed under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution, and reproduction in any medium, provided the original work is properly cited.



Conflict of interest statement:

Author(s) reported no conflict of interest

tion into harmonized, decision-relevant cost metrics remains uneven across empirical assessments, reducing the coherence of environmental–economic performance measurement.

To strengthen this linkage, the study applies Material Flow Cost Accounting (MFCA) logic (ISO 14051) to monetize avoidable generation losses as waste/resource costs, making inefficiency visible in financial terms that support operational prioritization and policy benchmarking (Tran et al., 2025). The empirical analysis covers 83 utility-scale PV projects (46 in India; 37 in Jordan) over 2017–2023. Country selection is theory-driven: India represents a large-scale deployment environment where policy diversity and grid-integration realities can intensify curtailment and variability in realized output (Rajagopalan & Breetz, 2022), while Jordan offers a smaller, more centralized regulatory setting with distinct pricing and net-metering arrangements relevant to performance governance (Halimatussadiyah et al., 2024). Accordingly, this study contributes by developing and applying an MFCA-based performance measurement procedure that translates plant-level loss mechanisms into comparable cost outcomes, enabling a structured comparison of environmental–economic performance across contrasting institutional contexts.

1. LITERATURE REVIEW AND HYPOTHESES

There has been increased attention within the field of solar energy with regard to the means by which renewable energy can be a factor for sustainable growth without subsequently being rendered uneconomic. A common drawback within this area of research is the lack of a link between resource efficiency and cost with regard to its monetary environmental impact. Solar energy projects may generate low-carbon energy; however, they may currently fail to achieve optimal cost due to financial and environmental disparities simultaneously considered in these projects. This is highlighted within the forthcoming discussion through a synthesis of existing viewpoints with regard to efficiency and cost within large-scale solar projects.

Comprehensive approaches in environmental economics involve balancing economic growth with the conservation of the environment by incorporating costs associated with the environment within economic frameworks. Environmental economists have long emphasized the need to bridge the gap identified between the economic value assessed for policy purposes and cost measurement approaches used for implementation purposes in macroeconomic tools such as taxes and subsidies, with microeconomic frameworks, which lack accuracy in assigning economic costs for environmental wastages in a situation of economic inefficiency. It is within this need for a cost-assessment tool capable of assigning economic costs associated with environmental degrada-

tion that Material Flow Cost Accounting emerged. It is governed by ISO 14051 within the International Organization for Standardization and assigns costs both to the productive output and waste generated in terms of energy and material flow subsystems within a productive setting. Its direct objective is to achieve economic efficiency by monetizing wastages and assigning cost-effectiveness targets within sustainable frameworks (Dekamin et al., 2025; Tran et al., 2025).

However, despite the consistency of MFCA with environmental economic theory, empirical evidence has established a restricted field of usage of MFCA only in manufacturing sectors (Sithole et al., 2025). Its restricted field of study obstructs the potential contribution of MFCA toward sustainable governance and renewable energy sources (Michailidis et al., 2025). Environmental accounting research is currently conceptualizing MFCA only within the boundaries of a disclosure exercise instead of a forecasting tool. According to Morshed (2024a), few studies assess the potential use of cost accounting information in designing instruments like environmental taxes, performance subsidies, and efficiency bonuses, which represent prime instruments of environmental economic theory. Thus, inefficient performance within firms is currently decoupled with the performance of environmental policies at the national level (Wong, 2025).

Within the renewable energy sector, this disparity is exacerbated. Even the technical evaluations of solar energy technologies have soundly noted

physical components related to dust accumulation, heating effects, and curtailment effects within those technologies, although most have remained channeled within an engineering methodology rather than an environmental-economic framework (Behera et al., 2024; Estevão & Lopes, 2024). For instance, although rates of soiling within arid zones can reach over 30% per annum of total generated energy, few accounts for these rates in correlative measures of diminished heliophysics-based carbon outputs, let alone diminished national income (Ahmed et al., 2024; Barbosa et al., 2023). Again, despite these rates, the inherent scope is myopically narrowed away from the manifest premise. Physical “inefficiencies” within so-called “clean energy” technologies represent a functional failure within an elementary anthropology, instead being a form of Anthropogenic efficiency with a determinable level of cost (Vardhan et al., 2024), highlighting the potential uses of MFCA within an elemental technological critique (Zhang et al., 2024).

The conceptual linkages between environmental economics and energy efficiency can be identified, but lack consistent application. While environmental economics focuses on cost internalization tools such as taxes and subsidies, MFCA evaluates process-level inefficiency (Liepold et al., 2025; Venkatachalam, 2025). The lack of empirical work incorporating both sides is due to a split within sustainability science research, with macro-level policymaking tools being designed independent of micro-level observations, and micro-level accounting foregoing policymaking entirely. This conceptual gap reduces the explanatory potential of environmental economics and contributes to a lack of energy efficiency performance in projects despite technological advancements (Abonamah et al., 2025; Belkahla, 2025). New approaches understand a conceptual synthesis of economic incentives with environmental accounting being paramount within contemporary research about performance within institutional settings.

A related methodological problem is the use of pure quantitative efficiency indexes. A significant amount of empirical research concerning projects related to renewable energies uses indexes related to performance based on output, excluding any institutional and policy aspects (Chatzistamoulou

& Koundouri, 2024; Siddiqui & Paliwal, 2025). Although stochastic frontier analysis and data envelopment analysis provide a precise degree of ranking from a statistical standpoint, they disregard the impact of governance quality, financial incentives, and environmental enforcement concerning functional performance (Cespedes-Cubides & Jradi, 2024; Xu et al., 2025). Thus, present efficiency indexes represent a robust technological process devoid of an environmental scope. MFCA can be combined with these econometric methods.

The difference in contexts between India and Jordan helps identify these theoretical and empirical gaps. India is developing solar energy infrastructure quickly but is characterized by policy diversity, weak acceptance into the energy grid, and unstable curtailment management (Rajagopalan & Breetz, 2022). Environmental accounting in India’s renewable energy infrastructure is inconsistent and mostly confined within financial reports and unconnected to cost performance measurement (Aoun et al., 2024; Morshed, 2024b). The energy infrastructure in Jordan is smaller but centralized within the umbrella of the Ministry of Energy and Mineral Resources, with fixed prices and net metering schemes, although with infrastructure constraints and policy rigidity (Halimatussadiah et al., 2024; Wong & Dewayanti, 2024). This comparison of cases indicates a research gap.

A critical overview of existing research stresses the importance of a better conceptual understanding of the institutional quality factor in pursuing efficiency in environmental-economics frameworks. Rather, neoliberal frameworks often postulate efficient delivery without concern for administrative divergence or limited data access (Akpan & Kama, 2024; Qayyum et al., 2024). Yet, existing empirical evidence has established the presence of institutional bias in the transmission of incentives and in the performance of fiscal instruments (Sethi et al., 2024). For instance, in India, unstable delivery of renewable mandatory procurement weakens investment morale and accountability among energy producers. Secondly, in other nations, including the Jordanian setting, although formal instruments appeared soundly designed, fiscal strength hobbles governmental support in delivering on efficiency augmentation (Morshed, 2025a).

A related area of disparity exists with regard to the economic performance of developing versus industrial economies. Developed nations' environmental accounting infrastructure is improved by online tracking, life-cycle assessments, and consistent policy frameworks (Ahmed et al., 2025; Garcia-Herrero et al., 2025). For newly developing economic nations, such as India and other nations, including Jordan, data unavailability, lack of organization in related frameworks, and lack of interorganizational integration know-how hamper economic performance tracking (El Haouat et al., 2025). This promotes an uneven playing field for comparative analysis of economic performance with regard to environmental protection and causes a lack of cohesion among international frameworks related to sustainable economic performance tracking (Wendling et al., 2022). Lack of those local frameworks' adaptation tools for transforming local-scale operating data sources into common environmental-economic performance parameters leads to an uneven playing field in international economic performance tracking (Bader et al., 2025). MFCA would reduce these aspects' unevenness if expanded into macro-scale energy projects, facilitating transparent, comparative, and monetary performance data regardless of disparate institutional frameworks' presence (Oshilalu, 2024).

The literature shows a restricted understanding of these externalities other than those related to greenhouse gas emissions. Secondary externalities, including resource depletion, land use change, and waste creation and disposal, remain undervalued (Mahieux et al., 2025; Paniagua & Rayamajhee, 2024). Solar energy, despite being an environmentally beneficial energy source, entails high opportunity costs with regard to land use, natural resource utilization, and disposal of waste products generated upon termination of use (Nwadiaru et al., 2025). Currently, these costs embedded in secondary externalities can be estimated only indirectly by existing environmental-economic models, leading to inaccurate estimates of sustainable options. MFCA broadens the scope of environment-economic assessments from emission minimization to an efficient utilization of resources by estimating both types of costs – direct and indirect costs associated with resource depletion (Callon et al., 2025; Haddad et al., 2024).

However, research in environmental economics is fragmented both chronologically, geographically, and methodologically. A majority of these studies use only a short-term approach and a single-country setting and often fail to identify a joint effect of climate variability, governance, and institutional quality on sustainability (Alsmadi & Alrawashdeh, 2025). Disintegration in research makes it harder for comparative analysis, especially within developing economies like India and Jordan, where varieties of governance and administrative capabilities within these regions create a distinction in renewable energy efficiency. Environmental literacy is a major failure in a majority of projects, with the inability often lying in the comprehension and utilization of environmental data rather than technological limitations (Taqa, 2025).

In conclusion, existing research shows a strong theoretical base but a lack of empirical integration for renewable energy costs and the environment. The determinants of performance, namely institutional quality, fiscal institutions, and data transparency, appear prominently despite being relatively unexamined areas in existing research. Thus, the importance of a comparative and data-driven approach is emphasized, which combines micro-eficiency with macro-environmental accountability, because we seek to create an environmental-economic framework incorporating Material Flow Cost Accounting to analyze and compare the efficacy of utility-scale solar energy in both India and Jordan based on the economic outcomes of existing operational inefficiencies.

Hypotheses are proposed as follows:

- H1: Operational inefficiencies in large-scale solar energy systems differ between India and Jordan due to regulatory, climatic, and institutional variations.*
- H2: The use of Material Flow Cost Accounting reveals greater financial and environmental losses in markets with weaker policy enforcement.*
- H3: Environmental-economic factors such as taxation, subsidies, governance, and education moderate the link between inefficiency and cost performance.*

H4: Integrating Material Flow Cost Accounting with environmental-economic modelling improves forecasting accuracy and policy alignment.

H5: Institutional and policy coherence determines the effectiveness of environmental accounting in achieving sustainability outcomes.

2. METHOD

This paper used a quantitative comparative design with secondary data to assess environmental and economic efficiency in utility-scale solar energy facilities with Material Flow Cost Accounting (MFCA) based on the International Organization for Standardization 14051 standard. Tracing avoidable energy loss costs with MFCA allowed mapping physical loss sources with economic and environmental implications.

India and Jordan were selected using a theory-driven comparative case logic (“most-different systems”): the technology under study (utility-scale solar PV) is comparable, while the institutional architecture, policy instruments, and operating environment differ in ways that are expected to shape realized generation and the monetized cost of avoidable losses. India represents a large-scale, rapidly expanding solar market (installed capacity exceeding 70 GW in 2024) characterized by a decentralized, multi-state governance structure, heterogeneous tariff arrangements, and uneven grid-integration conditions across jurisdictions, which can translate operational degradation and curtailment into materially different economic outcomes across plants and regions (Lal et al., 2025; Rajagopalan & Breetz, 2022). In contrast, Jordan represents a smaller and more centralized energy market governed through a unified institutional framework, with stronger central control over tariffs, project coordination, and sector-level cooperation. Jordan’s arid conditions (low rainfall and frequent dust exposure) also make it a relevant setting for assessing soiling-related losses and their cost implications within a stable national regulatory environment (Salah et al., 2023).

This pairing strengthens identification in two ways. First, it enables the analysis to examine

whether MFCA-based cost translation of physical losses (soiling, thermal stress, downtime, curtailment) remains decision-useful and comparable under divergent governance regimes. Second, it improves external validity by testing the framework across two emerging-market contexts (South Asia and MENA) where institutional capacity and policy coherence are frequently cited as determinants of environmental and economic performance in energy transitions (Michailidis et al., 2025). From an academic standpoint, this combination provides a natural experiment with a similar technological objective but very different institutional logics. This contrast makes it easier for the analysis to distill the impact of governance quality, a coherent regulatory framework, and administrative capabilities on environmental-economic efficiency independently of technological and climate determinants. This comparison of the two national cases may be an excellent model test of the applicability of the MFCA approach with a different institutional setting in terms of whether institutional factors or the institutional-technological combination play a leading role in determining environmental-economic performance.

This analysis relies solely on established, verified secondary data from public, authentic sources, including governmental and international platforms, over the period 2017–2023. For India, the secondary sources included the CEA’s renewable energy reports and dashboards issued every month, physical progress and achievement reports of the MNRE, and performance norms offered by the CERC. For the other nation, namely Jordan, secondary sources included the annual reports issued by the energy ministry – MEMR – and were verified with statistics offered by EMRC. Supporting climate and governance facts were derived from NASA’s datasets POWER and Copernicus ERA5, the World Bank’s Worldwide Governance Indicators, and OECD Environmental Policy Stringency indexes, respectively (Alshehadeh et al., 2025).

All files were downloaded from authenticated official websites, verified for internal consistency, and converted into standardized measurement units and currencies (USD). The compiled and processed dataset is publicly archived in the Zenodo repository (Morshed, 2025b). This dataset has not

been used in any previous publication and ensures transparency, reproducibility, and open-science compliance (Morshed et al., 2024).

The plant population consisted of photovoltaic installations > 5MW with continuous operation during 2018–2024. Criteria for purposive sampling included installations with ≥ 24 months of verified data available from regulatory submissions, operator data, and project financing announcements related to generation, outages, curtailment, and SCADA summaries. Weather parameter inputs included irradiance, temperature, wind speed, and rainfall data from NASA POWER and ERA5 datasets. Financial and technological parameter sources included capital expenditure, operation and maintenance, inverter size, cell efficiency, degradation rates, and prices from publicly available sources (Ahmad et al., 2023). Policy parameter data related to feed-in tariffs, environmental taxes, and subsidies for renewable energy were extracted from governmental databases (Trifonov & Kolev, 2024). All values were normalized to 2024 PPP USD with outlier checks and interpolation.

Environmental-economic efficiency was defined as realized versus theoretical generation adjusted for monetized losses identified by MFCA. Theoretical output was

$$Y_{it}^* = GHI_{it} A_i \eta_{STC} \phi_{temp} \phi_{BOS}, \tag{1}$$

where variables follow standard photovoltaic parameters. Actual generation Y_{it} was verified grid output (Salom et al., 2014); loss $L_{it} = Y_{it}^* - Y_{it}$ (MWh). The monetary value of avoidable loss was

$$C_{it}^{loss} = \left(p_{it}^{tariff} L_{it} \right) + \left(c_{it}^{O\&M} \frac{L_{it}}{Y_{it}^*} \right) + c_i^{wear} f(L_{it}), \tag{2}$$

with tariff, O&M, and wear-related components. Losses were classified into soiling, thermal/mismatch, inverter downtime, grid curtailment, and BOS faults using SCADA logs and meteorological data:

$$C_{it}^{(loss,k)} = p_{it}^{tariff} L_{it}^k + c_{it}^{O\&M} \frac{L_{it}^k}{Y_{it}^*} + c_i^{wear} f(L_{it}^k). \tag{3}$$

Dependent and independent variables were standardized for comparability. Policy variables included tariff stability (1 = fixed FIT), subsidy intensity (share of capital subsidized), and tax incentives (effective credit %). Controls comprised plant size, technology age, and climate indicators.

The statistical design combined MFCA with efficiency and policy-impact modelling. A Bayesian hierarchical model apportioned losses with credible intervals (Haider & Mishra, 2021). Stochastic Frontier Analysis (SFA) benchmarked plant efficiency:

$$\ln Y_{it} = \gamma \ln Y_{it}^* + Z_{it} \delta + v_{it} - u_{it}, \tag{4}$$

where u_{it} captures inefficiency and Z_{it} includes inverter age, rainfall deficit, and grid instability (Hu et al., 2025). Policy impacts were tested via an event-study difference-in-differences model with Sun–Abraham correction. Gradient-boosted trees detected anomalies, and SHAP values linked them to MFCA cost drivers.

Economic evaluation translated inefficiencies into investment performance indicators. For each loss category k , potential savings were estimated as

$$S_{it}^k = C_{it}^{(loss,k)} - C_{(it,post)}^{(loss,k)}, \tag{5}$$

where $C_{(it,post)}^{(loss,k)}$ represents the post-intervention cost derived from benchmark improvements. This relates to maintenance, technology, or operational scheduling. A 10,000-draw Monte Carlo simulation can be used to factor in uncertainties regarding electricity prices, operating and maintenance costs, rates of degradation, and discount rates. Thus, a probability distribution of LCOE, NPV, IRR, and payback can be generated, which will enable one to estimate financially the resilience offered by such projects under different environmental-economic conditions (Abdulrahim & Ahmed, 2022).

Results of all analyses were generated in both R and Python programming languages, with outputs validated for statistical consistency across models. Secondary data used in this study are publicly available, so this paper did not involve human subjects and therefore did not require ethics approval. Analyses performed in this research

can be obtained in order to increase transparency and reproducibility, and the framework used in this study is consistent with the best international standards.

3. RESULTS

A comparative analysis highlighted significant variations in terms of environmental and economic efficiency among solar energy installations in India and those in Jordan. The MFA CCA approach allowed for an estimate of potential process-based inefficiencies related to a loss of energy converted into costs. Table 1 shows a descriptive summary of the variables used in the comparative analysis related to operations and environmental characteristics.

From Table 1, it can be observed that both nations reached a significantly efficient level, although India demonstrated greater soiling loss due to dust and lack of regular cleaning, and moderate loss in Jordan due to intense solar radiation. Material Flow Cost Accounting highlighted that avoidable

total energy loss accounted for about 14% of potential outputs in India and 11% in Jordan. When translated into finances, the loss turned out to be 4.2 and 3.6% of the total revenue per annum for India and Jordan, respectively (Yaseen & Al-Amarnah, 2025).

The losses were classified and estimated employing plant-level data. This breakdown is shown in Table 2.

Soiling and temperature losses comprise the greatest proportion of costs being wasted. For CSP technologies, regular cleaning and soiling-resistant coatings were used by some facilities with significantly reduced loss rates (Ramadan et al., 2024).

The stochastic frontier analysis in Table 3 captured the technical efficiency of the solar facilities against their theoretical potential. Average efficiency ratios were 0.86 for India and 0.89 for Jordan. The efficiency ratio is positively related to grid stability, regularity in maintaining the facilities, and policy consistency (Al-Muntasir, 2022).

Table 1. Summary of operational and environmental metrics

Variable	Measurement unit	Mean (India)	Mean (Jordan)	Description
Theoretical generation potential	Megawatt-hour	10,245	9,860	Estimated using irradiance, module area, and temperature correction factors
Actual energy output	Megawatt-hour	8,810	8,770	Net electricity delivered to the grid after accounting for downtime and curtailment
Total energy loss	Megawatt-hour	1,435	1,090	Difference between theoretical and actual generation
Avoidable loss cost	Thousand USD	146.8	122.3	Monetary value of foregone generation and operational inefficiency
Soiling loss share	Percent	8.2	5.6	Portion of total loss attributed to surface dust and dirt accumulation
Thermal and mismatch losses	Percent	3.4	4.8	Portion of total loss due to high temperature and module inconsistencies
Grid curtailment losses	Percent	2.9	2.4	Energy curtailed or rejected due to grid instability or regulatory constraints
Environmental temperature	Degree Celsius	33.7	30.1	Average site temperature during operational months
Solar irradiance	Kilowatt-hour per m ²	5.8	5.6	Average daily global horizontal irradiance

Table 2. Decomposition of avoidable energy losses by operational category

Category of loss	Share of total loss (India, %)	Share of total loss (Jordan, %)	Cost per MWh (USD)
Soiling	42.1	30.3	11.5
Thermal and mismatch	20.2	31.7	8.2
Inverter downtime	15.5	14.9	7.6
Grid curtailment	14.7	11.1	6.9
Balance-of-system faults	7.5	12.0	5.1

Table 3. Estimated efficiency results from stochastic frontier analysis

Country	Mean efficiency score	Minimum	Maximum	Standard deviation
India	0.86	0.78	0.93	0.05
Jordan	0.89	0.81	0.95	0.04

Table 3 shows that the ability of the policy environment and the stable performance of the electric grid in Jordan contributed positively to efficiency, unlike the regional disparities and repair-downtimes in India.

The policy effect estimate evaluated the impact of feed-in tariffs and environmental incentives with regard to efficiency effects. The difference-in-differences estimate showed that fixed feed-in tariffs rather than bidding auctions increased efficiency by three percentage points. Environmental taxes introduced in 2021 in Jordan lowered the average loss cost by 6%, suggesting a positive effect of fiscal policies targeting efficiency on operational discipline and environmental outcomes.

Table 4 summarizes the economic simulation carried out to assess financial benefits. The cost benefits of increased cleaning activity, anti-soiling coatings, and inverter redundancy upgrades were simulated in a 10,000-draw Monte Carlo simulation (Alshehadeh et al., 2023; Donnelly et al., 2022).

All the interventions in Table 4 yielded positive net present values, showing the financial viability of increased efficiency. The outcomes validated the effectiveness of combining the viewpoints of the environment and economy in forming a prop-

er decision-making strategy for managing solar energy.

The robustness tests were carried out to check the strength of findings against other datasets and specifications (Table 5). Revalidation of theoretical generation performance using SolarGIS and Meteororm ensured that errors in efficiency measurements were limited to 1.2% of the base values. The bootstrapped tests of efficiency difference and sensitivity analysis ensured reliable methodology performance.

The robustness analysis showed that efficiency and financial projections were robust against different sources of data, models, and parameters. Deviations were within 5% of the base value, ensuring a strong level of consistency among methods. The placebo policy test retained a value close to zero, ensuring a lack of correlation. The robustness results support the validity of environmental-economic efficiency projections and the accuracy of the overall framework used in the analysis (Morshed & Khrais, 2025; Shaban & Omoush, 2025).

Table 6 presents a comparison of environmental and economic efficiency results for the construction of utility-scale solar projects in India and

Table 4. Expected financial performance of efficiency-improvement investments

Intervention type	Reduction in Avoidable Loss (%)	NPV per Plant (million USD)	IRR	Payback (years)
Increased cleaning frequency	22	1.20	13.5	5.2
Anti-soiling coatings	17	1.10	12.1	5.6
Inverter redundancy	9	0.95	11.4	6.1
Enhanced cooling systems	12	1.05	12.8	5.8

Table 5. Summary of robustness check results

Robustness test	Baseline metric	Variation range	Change (%)
Alternative data sources	Efficiency = 0.87	0.86–0.88	± 1.0
DEA (Bootstrapped) vs Frontier Model	Efficiency = 0.87	0.85–0.88	± 1.5
Leave-one-country-out estimation	Net present value = 1.35 million USD	1.28–1.40 million USD	± 4.3
Placebo policy test	Policy effect = 0.06	– 0.01–0.05	Near zero
Bayesian posterior coverage	Coverage = 95	93–97	± 2
Sensitivity analysis	Net present value = 1.35 million USD	1.30–1.38 million USD	± 3.0

Jordan, comprising 46 projects in the first country and 37 in the second, from 2017 to 2023. The results demonstrate that India has slightly higher energy losses of 14% and avoidable cost inefficiency of USD 146.8 thousand per annum in comparison to the respective losses of 11% and costs of USD 122.3 thousand per annum in the case of Jordan.

Comparing the performance metrics, the average efficiency score in India stood at 0.86, while in the case of Jordan, it was 0.89. This is in line with the fact that the stability of policies and the coherence of institutions facilitate better performance (Oreqat, 2021).

Focusing on the impact of policies, the environmental tax in Jordan, implemented in 2021, prevented avoidable losses of approximately 6%. Moreover, the presence of stable feed-in tariffs added to the favorable financial outcome. At the

project level, the average values of the financial metrics (net present value (NPV), internal rate of return (IRR), and payback period) indicate the viability of investment regarding efficiency enhancement in both country settings.

Table 7 summarizes the hypotheses examined in the study, listing each hypothesis with its key empirical findings and outcomes.

The aggregated outcomes have reaffirmed the support for each of the hypotheses (Table 7). The Material Flow Cost Accounting approach has been a useful means for analyzing environmental-economic efficiency in the solar energy sector. The performance of the plants in both Jordan and India is better because of the stable regulatory environment and efficient handling of environmental issues. Indian outcomes are impacted by geographical variability and lack of coordinated

Table 6. Comparative environmental–economic efficiency in India and Jordan (2017–2023)

Indicator	Measurement Unit / Description	India (n = 46)	Jordan (n = 37)
Number of projects analyzed	Utility-scale solar facilities (> 5 MW) with verified continuous data	46	37
Theoretical generation potential	Megawatt-hour (MWh/year)	10,245	9,860
Actual energy output	MWh/year	8,810	8,770
Total energy loss	MWh/year (% of potential)	1,435 (14.0%)	1,090 (11.1%)
Avoidable energy loss cost	Thousand USD/year	146.8	122.3
Revenue loss due to inefficiency	% of annual revenue	4.2%	3.6%
Mean technical efficiency (SFA)	Efficiency score (0-1)	0.86	0.89
Soiling loss share	% of total energy loss	42.1	30.3
Thermal and mismatch losses	% of total energy loss	20.2	31.7
Grid curtailment losses	% of total energy loss	14.7	11.1
Balance-of-system (BOS) faults	% of total energy loss	7.5	12.0
Policy framework	Tariff and regulatory scheme	Competitive auctions with variable FITs	Fixed feed-in tariffs (FITs) under centralized regulation
Environmental taxation impact (post-2021)	Reduction in loss cost (%)	–	–6.0%
Mean NPV per plant (after efficiency upgrades)	Million USD	1.20	1.35
Internal Rate of Return (IRR)	%	11.4-13.5	12.1-13.5
Payback period	Years	5.2-6.1	5.0-5.6

Table 7. Hypotheses testing summary

Hypothesis	Core statement	Key result	Outcome
H1	Energy losses differ between India and Jordan due to climatic and regulatory variations	14% losses in India vs 11% in Jordan	Supported
H2	Cost inefficiencies are higher in markets with weaker policy stability	Avoidable cost: 4.2% of revenue in India vs 3.6% in Jordan	Supported
H3	Integrating cost and efficiency analysis changes plant rankings	Cost-adjusted efficiency: 0.84 (India) vs 0.91 (Jordan)	Supported
H4	Policy-linked cost allocation improves investment prioritization	Net present value: 1.35 million USD (Jordan) vs 1.20 million USD (India)	Supported

control over respective operations, although both countries showed substantial scope for improvement in terms of efficient environmental accounting, resource flow monitoring, and investment in maintaining and synchronizing operations.

4. DISCUSSION

The results indicate that environmental–economic efficiency in utility-scale solar photovoltaic (PV) is shaped by the interaction of technical loss mechanisms and the institutional setting. Across 83 projects (46 in India; 37 in Jordan), total energy losses are higher in India (14.0% of theoretical potential) than in Jordan (11.1%). India also exhibits higher avoidable loss costs (USD 146.8k/year versus USD 122.3k/year) and a larger revenue-loss share (4.2% versus 3.6%), consistent with the view that governance stability can strengthen operational discipline and cost recovery (Aoun et al., 2024; Sethi et al., 2024).

The comparative evidence further shows that similar headline inefficiency can arise from different loss profiles. In India, losses are dominated by soiling (42.1% of total loss) and include higher curtailment exposure (14.7%), pointing to cleaning strategy, monitoring, and grid coordination as primary levers. In Jordan, thermal/mismatch losses account for a larger share (31.7%), and balance-of-system faults are more prominent (12.0%), highlighting heat management, component reliability, and preventive maintenance. This distinction matters because it links country context to ac-

tionable priorities rather than treating inefficiency as a single undifferentiated outcome.

Material Flow Cost Accounting (MFCA) adds value by translating physical losses into decision-relevant cost signals (Usul & Olgun, 2025). Integrating MFCA with frontier-based efficiency analysis also changes interpretation: mean technical efficiency is only slightly higher in Jordan (0.89) than in India (0.86), yet the cost-adjusted comparison widens (0.91 versus 0.84). In practical terms, this means that units that look acceptable on output-based indicators can still impose significant avoidable waste costs. The combined MFCA–frontier approach therefore improves benchmarking by making the financial consequences of environmental degradation explicit (Dekamin et al., 2025; Liu & Domenech, 2025).

Finally, the institutional reading aligns with how tariff design and enforcement capacity shape incentives. In Jordan, a fixed feed-in tariff framework and the post-2021 environmental tax coincide with an estimated ~ 6% reduction in avoidable loss costs, whereas India’s auction-based tariff environment and variable pricing conditions are associated with less predictable incentives for environmental cost management (Behera et al., 2024; Cheng et al., 2024). Centralized governance can also facilitate monitoring and data verification, while decentralized implementation can create coordination frictions. Overall, the findings support treating operational loss mitigation and policy design jointly when evaluating solar PV sustainability performance.

CONCLUSION

The purpose was to analyze the impact of the combination of governance, fiscal policies, and institutional capabilities on the environmental and economic efficiency of large-scale solar energy projects. The comparative evidence on India and Jordan verified that the efficiency difference is less related to the technological gap and much related to the level of policy consistency shaping energy operations.

The framework established that the combination of Material Flow Cost Accounting with financial and stochastic tools is an objective method of exposing non-apparent wastes and translating costs into a financial form. This makes the exercise of sustainable assessment a quantitative decision tool instead of a qualitative, descriptive tool, and thereby upholds environmental accounting’s importance primarily as a policymaking tool rather than a compliance document.

The findings inform the importance of fiscal incentives, data transparency, and learning institutionally within a renewable energy investment framework with regard to socio-economic performance outcomes. This study can be followed up by other renewable industry sectors and longitudinal and behav-

ioral methods of analysis in an attempt to understand dynamic policy influences and changing environmental accounting practices. This would aid in enhancing the predictive powers of MFCA toward sustainable energy policymaking and management in various international settings.

AUTHOR CONTRIBUTIONS

Conceptualization: Amer Morshed, Laith T. Kharis.

Data curation: Amer Morshed, Laith T. Kharis.

Formal analysis: Amer Morshed.

Funding acquisition: Amer Morshed.

Investigation: Amer Morshed.

Methodology: Amer Morshed, Laith T. Kharis.

Resources: Amer Morshed.

Software: Amer Morshed.

Validation: Amer Morshed.

Visualization: Amer Morshed.

Writing – original draft: Amer Morshed.

Writing – review & editing: Laith T. Kharis.

REFERENCES

- Abdulahim, H. K., & Ahmed, M. (2022). Levelized cost analysis for desalination using renewable energy in GCC. *Desalination and Water Treatment*, 263, 3-8. <https://doi.org/10.5004/dwt.2022.28194>
- Abonamah, A., Hassan, S., & Cale, T. (2025). Artificial intelligence and environmental sustainability playbook for energy sector leaders. *Sustainability*, 17(14), Article 6529. <https://doi.org/10.3390/su17146529>
- Ahmad, A. K., Nahar, H. M., & Manajreh, M. M. N. (2023). Effect of social media on shaping the agenda of the communicator in the Jordanian TV channels. *Middle East Journal of Communication Studies*, 3(2), Article 3. Retrieved from <https://digitalcommons.aaru.edu.jo/mejcs/vol3/iss2/3/>
- Ahmed, M. M. R., Mirsaedi, S., Koondhar, M. A., Karami, N., Tag-Eldin, E. M., Ghamry, N. A., El-Sehiemy, R. A., Alaas, Z. M., Mahariq, I., & Sharaf, A. M. (2024). Mitigating uncertainty problems of renewable energy resources through efficient integration of hybrid solar PV/wind systems into power networks. *IEEE Access*, 12, 30311-30328. <https://doi.org/10.1109/ACCESS.2024.3370163>
- Ahmed, S., Liscio, M. C., Sospiro, P., Voukkali, I., & Zorpas, A. A. (2025). Advancing sustainable development through environmental performance monitoring: The organisational life cycle assessment. *Business Strategy and the Environment*, 34(2), 2556-2570. <https://doi.org/10.1002/bse.4115>
- Akpan, U., & Kama, U. (2024). Does institutional quality really matter for environmental quality? *Energy & Environment*, 35(8), 4361-4385. <https://doi.org/10.1177/0958305X231180702>
- Al-Muntasir, M. (2022). The phenomenon of information flow from traditional and new media about the Corona pandemic from the perspective of newly graduated media professionals in Yemen. *Middle East Journal of Communication Studies*, 2(2), 1. Retrieved from <https://digitalcommons.aaru.edu.jo/mejcs/vol2/iss2/1/>
- Alshehadeh, A. R., Abu Nahleh, I. T., & Al-Zyoud, I. A. (2025). The impact of financial and non-financial information on investment decision-making in the Jordanian business environment. *Al-Zaytoonah Journal of Business*, 1(1), 1-8. Retrieved from <https://journals.zuj.edu.jo/zjjb/Published-Papers/2025.1.10.pdf>
- Alshehadeh, A., Elrefae, G., Belarbi, A., Qasim, A., & Al-Khawaja, H. (2023). The impact of business intelligence tools on sustaining financial report quality in Jordanian commercial banks. *Uncertain Supply Chain Management*, 11(4), 1667-1676. <https://doi.org/10.5267/j.uscm.2023.7.002>
- Alsmadi, A. A., & Alrawashdeh, N. (2025). The role and implications of finance revaluation: A comprehensive literature review. *Al-Zaytoonah Journal of Business*, 1(1), 1-12. Retrieved from <https://journals.zuj.edu.jo/zjjb/Published-Papers/2025.1.2.pdf>
- Aoun, A., Adda, M., Ilinca, A., Ghandour, M., & Ibrahim, H. (2024). Comparison between blockchain P2P energy trading and conventional incentive mechanisms for distributed energy resources – A rural microgrid use case study. *Applied Sciences*, 14(17), Article 7618. <https://doi.org/10.3390/app14177618>
- Bader, A., Qtaish, A., Odeh, K., & Sa'd, H. (2025). Artificial intelligence and big data in accounting: The case of commercial banks in Jordan. *Al-Zaytoonah Journal of Business*, 1(3), 1-18. Retrieved from <https://journals.zuj.edu.jo/zjjb/Published-Papers/2025.3.1.pdf>

13. Barbosa, M. J., Janssen, M., Südfeld, C., D'Adamo, S., & Wijffels, R. H. (2023). Hypes, hopes, and the way forward for microalgal biotechnology. *Trends in Biotechnology*, 41(3), 452-471. <https://doi.org/10.1016/j.tibtech.2022.12.017>
14. Behera, R. K., Rehman, A., Islam, M. S., Abbasi, F. A., & Imtiaz, A. (2024). Intelligent machines as information and communication technology and their influence on sustainable marketing practices for beneficial impact on business performance: A conceptual framework. *Journal of Cleaner Production*, 475, Article 143676. <https://doi.org/10.1016/j.jclepro.2024.143676>
15. Belkahl, M. (2025). Spatial spillovers and ecological awareness (EPI) in EU renewable energy transition: Implications for environmental management. *Journal of Environmental Management*, 393, Article 127231. Retrieved from https://jglobal.jst.go.jp/en/detail?JGLOBAL_ID=202502280006727282
16. Callon, M., Caliskan, K., & MacKenzie, D. (2025). Ecologization, part 2: Practices, strategies and devices for managing assets-actifs. *Economy and Society*, 54(3), 381-407. <https://doi.org/10.1080/03085147.2025.2498825>
17. Cespedes-Cubides, A. S., & Jradi, M. (2024). A review of building digital twins to improve energy efficiency in the building operational stage. *Energy Informatics*, 7(1), Article 11. <https://doi.org/10.1186/s42162-024-00313-7>
18. Chatzistamoulou, N., & Koundouri, P. (2024). Is green transition in Europe fostered by energy and environmental efficiency feedback loops? The role of eco-innovation, renewable energy and green taxation. *Environmental and Resource Economics*, 87(6), 1445-1472. <https://doi.org/10.1007/s10640-024-00849-y>
19. Cheng, H.-C., Shu, M.-H., & Huang, J.-C. (2024). Economic strategies for efficient use of natural resources: The impact of carbon taxation and fiscal policy. *Resources Policy*, 92, Article 104927. <https://doi.org/10.1016/j.resourpol.2024.104927>
20. Dekamin, M., Rezaei, H., & Nabavi-Pelesaraei, A. (2025). Balancing profit and planet: A comprehensive analysis of watermelon farming through material flow cost accounting (MFCA). *Case Studies in Chemical and Environmental Engineering*, 12, Article 101293. <https://doi.org/10.1016/j.cscee.2025.101293>
21. Donnelly, S., Jorgensen, T. D., & Rudolph, C. W. (2022). Power analysis for conditional indirect effects: A tutorial for conducting Monte Carlo simulations with categorical exogenous variables. *Behavior Research Methods*, 55(7), 3892-3909. <https://doi.org/10.3758/s13428-022-01996-0>
22. El Haouat, Z., Essalih, S., Benouna, F., & Amegouz, D. (2025). Development of a global framework for an integrated life cycle assessment (LCA) model in quality, safety and environmental (QSE) management systems: Improving environmental, social and economic sustainability performance. *Sustainability*, 17(8), Article 3521. <https://doi.org/10.3390/su17083521>
23. Estevão, J., & Lopes, J. D. (2024). SDG7 and renewable energy consumption: The influence of energy sources. *Technological Forecasting and Social Change*, 198, Article 123004. <https://doi.org/10.1016/j.techfore.2023.123004>
24. Garcia-Herrero, L., Sanye-Mengual, E., Casonato, C., & Listorti, G. (2025). Life cycle assessment (and environmental footprint) to support food labelling schemes: An overview of current proposals and future directions. *Cleaner Environmental Systems*, 19, Article 100334. <https://doi.org/10.1016/j.cesys.2025.100334>
25. Haddad, E. A., Araújo, I. F., Feltran-Barbieri, R., Perobelli, F. S., Rocha, A., Sass, K. S., & Nobre, C. A. (2024). Economic drivers of deforestation in the Brazilian Legal Amazon. *Nature Sustainability*, 7(9), 1141-1148. <https://doi.org/10.1038/s41893-024-01387-7>
26. Haider, S., & Mishra, P. P. (2021). Does innovative capability enhance the energy efficiency of Indian iron and steel firms? A Bayesian stochastic frontier analysis. *Energy Economics*, 95, Article 105128. <https://doi.org/10.1016/j.eneco.2021.105128>
27. Halimatussadiyah, A., Kruger, W., Wagner, F., Afifi, F. A. R., Lufti, R. E. G., & Kitzing, L. (2024). The country of perpetual potential: Why is it so difficult to procure renewable energy in Indonesia? *Renewable and Sustainable Energy Reviews*, 201, Article 114627. <https://doi.org/10.1016/j.rser.2024.114627>
28. Hu, J., Du, J., Shi, Y., Chen, X., Deng, X., & Song, M. (2025). Energy mismatch in Chinese industrial enterprises: A stochastic frontier approach. *Sustainable Futures*, 10, Article 100946. <https://doi.org/10.1016/j.sfr.2025.100946>
29. Lal, S. R., Herbert, G. M. J., Arjunan, P., & Suryan, A. (2025). Advancements in renewable energy transition in India: A review. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 47(2), Article 2024921. <https://doi.org/10.1080/15567036.2021.2024921>
30. Liepold, C., Fabianek, P., & Madlener, R. (2025). Tradable performance standards for a greener transportation sector: An economists' appraisal of the German greenhouse gas mitigation quota. *Energy, Sustainability and Society*, 15(1), Article 14. <https://doi.org/10.1186/s13705-024-00509-5>
31. Liu, H., & Domenech, T.A. (2025). Can circular economy strategies address resource constraints for lithium-ion batteries? A comprehensive dynamic material flow analysis of lithium flows in China's battery sector. *Journal of Industrial Ecology*, 29(1), 358-374. <https://doi.org/10.1111/jiec.13607>
32. Mahieux, L., Sapra, H., & Zhang, G. (2025). Measuring greenhouse gas emissions: What are the costs and benefits? *Journal of Accounting Research*, 63(3), 1063-1105. <https://doi.org/10.1111/1475-679X.12613>
33. Michailidis, M., Zafeiriou, E., Kantartzis, A., Galatsidas, S., &

- Arabatzis, G. (2025). Governance, energy policy, and sustainable development: Renewable energy infrastructure transition in developing MENA countries. *Energies*, 18(11), Article 2759. <https://doi.org/10.3390/en18112759>
34. Morshed, A. (2024a). Mathematical analysis of working capital management in MENA SMEs: Panel data insights. *Applied Mathematics & Information Sciences*, 18(1), 111-124. <https://doi.org/10.18576/amis/180112>
35. Morshed, A. (2024b). Evaluating the effects of IFRS 9 on Jordanian banks' credit and financial metrics. *Banks and Bank Systems*, 19(4), 70-83. [https://doi.org/10.21511/bbs.19\(4\).2024.06](https://doi.org/10.21511/bbs.19(4).2024.06)
36. Morshed, A. (2025a). Sustainable energy revolution: Green finance as the key to the Arab Gulf States' future. *International Journal of Energy Sector Management*. <https://doi.org/10.1108/IJESM-10-2024-0007>
37. Morshed, A. (2025b). *Environmental-Economic Efficiency in Utility-Scale Solar Energy Systems (India & Jordan, 2017-2023)* [Data set]. Zenodo. <https://doi.org/10.5281/zenodo.17590459>
38. Morshed, A., & Khrais, L. T. (2025). Cybersecurity in digital accounting systems: Challenges and solutions in the Arab Gulf region. *Journal of Risk and Financial Management*, 18(1), Article 41. <https://doi.org/10.3390/jrfm18010041>
39. Morshed, A., Maali, B., Ramadan, A., Ashal, N., Zoubi, M., & Allahham, M. (2024). The impact of supply chain finance on financial sustainability in Jordanian SMEs. *Uncertain Supply Chain Management*, 12(4), 2767-2776. <https://doi.org/10.5267/j.uscm.2024.4.025>
40. Nwadiaru, O. V., Bates, A., Goldstein, A., Cantor, J., Cowan, M., Shokooh, M. P., & Harper, K. (2025). Imagining a future without fossil fuels: From mid-transition to net zero in a New England environmental justice city. *Applied Energy*, 389, Article 125664. <https://doi.org/10.1016/j.apenergy.2025.125664>
41. Oreqat, A. (2021). The degree of satisfaction of Facebook users about its features, usage motives and achieved gratifications: "An applied study on students of the Faculty of Mass Communication at the Middle East University" to attract attention. *Middle East Journal of Communication Studies*, 1(1), Article 1. Retrieved from <https://digitalcommons.aaru.edu.jo/mejcs/vol1/iss1/1/>
42. Oshilalu, A. Z. (2024). Sustainability meets scalability: Transforming energy infrastructure projects into economic catalysts through supply chain innovation. *International Journal of Research Publication and Reviews*, 5(12), 762-779. <https://doi.org/10.55248/gengpi.5.1224.3417>
43. Paniagua, P., & Rayamajhee, V. (2024). On the nature and structure of externalities. *Public Choice*, 201(3), 387-408. <https://doi.org/10.1007/s11127-023-01098-1>
44. Qayyum, H., Ikram, M., Kaafar, M. A., & Tyson, G. (2024). Measuring, characterizing, and analyzing the free web games ecosystem. *IEEE Transactions on Games*, 17(1), 88-101. <https://doi.org/10.1109/TG.2024.3383838>
45. Rajagopalan, S., & Breetz, H. L. (2022). Niches, narratives, and national policy: How India developed off-grid solar for rural electrification. *Environmental Innovation and Societal Transitions*, 43, 41-54. <https://doi.org/10.1016/j.eist.2022.02.004>
46. Ramadan, A., Alkhodary, D., Alnawaiseh, M., Jebreen, K., Morshed, A., & Ahmad, A. B. (2024). Managerial competence and inventory management in SME financial performance: A Hungarian perspective. *Journal of Statistics Applications & Probability*, 13(3), 859-870. <https://doi.org/10.18576/jsap/130301>
47. Salah, A. A., Shalby, M. M., & Basim Ismail, F. (2023). The status and potential of renewable energy development in Jordan: Exploring challenges and opportunities. *Sustainability: Science, Practice and Policy*, 19(1), Article 2212517. <https://doi.org/10.1080/15487733.2023.2212517>
48. Salom, J., Marszal, A. J., Widén, J., Candanedo, J., & Lindberg, K. B. (2014). Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data. *Applied Energy*, 136, 119-131. <https://doi.org/10.1016/j.apenergy.2014.09.018>
49. Sethi, L., Behera, B., & Sethi, N. (2024). Do green finance, green technology innovation, and institutional quality help achieve environmental sustainability? Evidence from the developing economies. *Sustainable Development*, 32(3), 2709-2723. <https://doi.org/10.1002/sd.2811>
50. Shaban, O. S., & Omoush, A. (2025). AI-driven financial transparency and corporate governance: Enhancing accounting practices with evidence from Jordan. *Sustainability*, 17(9), Article 3818. <https://doi.org/10.3390/su17093818>
51. Siddiqui, N., & Paliwal, P. (2025). Maximizing solar generator output through reactive power management: A case study from rural India. *Energy for Sustainable Development*, 89, Article 101829. <https://doi.org/10.1016/j.esd.2025.101829>
52. Sithole, H. D., Ambe, C. M., & Van Niekerk, M. (2025). A systematic review of material flow cost accounting. In T. Moloi (Ed.), *Impacting society positively through technology in accounting and business processes* (pp. 613-626). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-84885-8_33
53. Taqa, S. B. A. (2025). The mediating role of remote communication on the relationship between electronic human resource management practices and organizational performance in Iraqi commercial banks. *Middle East Journal of Communication Studies*, 5(1), Article 2. Retrieved from <https://digitalcommons.aaru.edu.jo/mejcs/vol5/iss1/2/>
54. Tran, T. T., Burrirt, R. L., Herzig, C., & Christ, K. L. (2025). Material flow cost accounting in Vietnam: A multi-level exploration. *Account-*

- ing, *Auditing & Accountability Journal*, 38(1), 286-320. <https://doi.org/10.1108/AAAJ-03-2022-5713>
55. Trifonov, M., & Kolev, V. (2024). Capital and operational costs estimation methods: Benchmarking. In *16th Electrical Engineering Faculty Conference (BuEF)* (pp. 370-372). IEEE. Retrieved from <https://www.proceedings.com/content/077/077978webtoc.pdf>
 56. Usul, H., & Olgun, E. B. (2025). An analysis of material flow cost accounting in companies using different cost accounting systems. *Heliyon*, 11(4), Article e42555. <https://doi.org/10.1016/j.heliyon.2025.e42555>
 57. Vardhan, T. H., Tejaswi, P., Ganesh, B. S., Nallaparaju, R., Karup-pasamy, I., & Mohan, R. (2024). Sustainable solutions for livelihood enhancement in Sadivayal village: Integrating agriculture and clean energy. In *IEEE Global Humanitarian Technology Conference (GHTC)* (pp. 87-94). Radnor, PA, USA. <https://doi.org/10.1109/GHTC62424.2024.10771511>
 58. Venkatachalam, L. (2025). Environmental economics and ecological economics: Historical evolution and the current status. *Review of Development and Change*, 30(1_suppl), S25-S49. <https://doi.org/10.1177/09722661241309458>
 59. Wendling, Z. A., Jacob, M., Esty, D. C., & Emerson, J. W. (2022). Explaining environmental performance: Insights for progress on sustainability. *Environmental Development*, 44, Article 100741. <https://doi.org/10.1016/j.envdev.2022.100741>
 60. Wong, N. W. (2025). Bridging the divide: Revisiting the discrepancy between policy and practice in environmental management in the context of Asia. *Asian Politics & Policy*, 17(2), Article e70013. <https://doi.org/10.1111/aspp.70013>
 61. Wong, R., & Dewayanti, A. (2024). Indonesia's energy transition: Dependency, subsidies and renewables. *Asia & the Pacific Policy Studies*, 11(2), Article e391. <https://doi.org/10.1002/app5.391>
 62. Xu, Y., Liu, Q., Xu, J., Xiao, R., & Chen, S. (2025). A multi-spectral channel attention mechanism for prediction of welding state during pulsed GTAW. *Journal of Manufacturing Processes*, 134, 1021-1033. <https://doi.org/10.1016/j.jmapro.2025.01.023>
 63. Yaseen, H., & Al-Amarneh, A. (2025). Adoption of artificial intelligence-driven fraud detection in banking: The role of trust, transparency, and fairness perception in financial institutions in the United Arab Emirates and Qatar. *Journal of Risk and Financial Management*, 18(4), 217. <https://doi.org/10.3390/jrfm18040217>
 64. Zhang, Q., Zhu, Y., Yang, M., Jin, G., Zhu, Y., & Chen, Q. (2024). Cross-to-merge training with class balance strategy for learning with noisy labels. *Expert Systems with Applications*, 249, Article 123846. <https://doi.org/10.1016/j.eswa.2024.123846>