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Is the Energy Transition in Indonesia Too Costly? A True Cost Accounting Projection Leveraging Artificial Intelligence, Blockchain, and Big Data

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Abstract

Indonesia faces major challenges in its transition to sustainable energy. The current pricing of electricity does not fully reflect the environmental, social, and economic impacts associated with fossil-based energy production. As Indonesia pushes toward its 2060 Net Zero Emissions target, there is an urgent need to apply True Cost Accounting (TCA) to energy projects. This study investigates how big data, artificial intelligence (AI), and blockchain technologies can support TCA calculations, making hidden costs visible and improving decision-making. Using a qualitative interpretive approach, we explore the potential of IT tools to reduce the complexity, improve the accuracy, and enhance the timeliness of cost estimations across Indonesia's diverse energy landscape. Findings suggest that advanced digital infrastructure could significantly ease the burden of TCA application, but challenges related to data sharing, standardization, and implementation remain. This research highlights the crucial role of interdisciplinary collaboration between technical and accounting fields to enable a more sustainable energy future for Indonesia.

***Keywords**: Artificial Intelligence (AI); Blockchain; Big Data; Energy Transition; True Cost Accounting.*

INTRODUCTION

Indonesia, the largest economy in Southeast Asia, is at a pivotal crossroads in its energy transition. Currently, the nation's energy mix is dominated by coal, which accounts for over 60% of electricity generation (Ministry of Energy and Mineral Resources, 2022). Despite ambitious renewable energy targets progress remains slow which targeted 23% of the national energy mix by 2025 and achieving Net Zero Emissions by 2060 (IESR, 2022). Conventional energy pricing mechanisms in Indonesia often exclude the broader environmental, social, and long-term economic costs associated with fossil fuel reliance (International Energy Agency, 2023). This "price gap" misguides investment decisions and slows down the transition to cleaner alternatives like solar, geothermal, and hydropower.

True Cost Accounting (TCA) offers a powerful framework to bridge this gap by capturing both internal and external costs, providing a more accurate financial picture of energy projects. True Cost Accounting (TCA) is a management accounting concept that estimates the full cost of products and services, including current and future, internal and external impacts, discounted into a single monetary value (de Groot et al., 2012; Huber, 2018). TCA provides insights into the complex economic, social, and ecological processes necessary for achieving sustainability (Elkington, 1997). By adjusting the prices of products and services to include externalities such as environmental degradation and social disruption, TCA aims to stimulate sustainable decision-making (FAO, 2019). In Indonesia, application of TCA remains limited, particularly in the energy sector where externalities such as carbon emissions, biodiversity loss, and public health impacts are often excluded from project cost evaluations (Setyawati & Wahyuni, 2021). Addressing these gaps could better inform policy and investment decisions aligned with national climate targets (ÓhAiseadha et al., 2020)

Meanwhile, emerging digital technologies including big data analytics, artificial intelligence (AI), and blockchain hold significant promise to enhance TCA by overcoming challenges related to complexity, accuracy, and timeliness (Gusc et al., 2022; Jarka & Biernat-Jarka, 2021). Big data enables collection and processing of massive datasets from varied sources, such as environmental sensors and operational databases, supporting real-time insights in sustainability accounting (Marr, 2016). AI enhances big data applications by automating pattern detection, predicting future scenarios, and interpreting complex environmental and social variables (Brynjolfsson & McAfee, 2017). Blockchain technology, with its decentralized ledger system, ensures data integrity and transparency in multi-stakeholder environments (Tapscott & Tapscott, 2016). These technologies can improve the measurement and monetization of externalities, enhance the traceability of impacts across supply chains, and reduce the costs and complexity associated with traditional manual methods (Gusc et al., 2022). Their integration is essential for operationalizing dynamic, accurate, and real-time TCA models suitable for Indonesia's evolving energy sector (Neofytou et al., 2020).

Although research into TCA, big data, AI, and blockchain has grown rapidly, few studies specifically address their combined application within Indonesia's energy transition context. Most existing studies focus on developed economies with advanced digital ecosystems (Lupi et al., 2021; Gusc et al., 2022). As Indonesia expands its digital infrastructure and embraces Industry 4.0 innovations, there is a timely opportunity to leverage these tools in the energy sector. This paper seeks to fill this gap by contextualizing global innovations to Indonesia's energy policy, infrastructure challenges, and sustainable development goals. This paper aims to answer a central research question: How can big data, AI, and blockchain technologies support True Cost Accounting in Indonesia's energy transition? By exploring this question, we hope to offer new pathways for more sustainable energy investments and policymaking in Indonesia.

METHODS

In preparation for this study, the application of True Cost Accounting (TCA) in Indonesia revealed significant complexity, along with low levels of accuracy and timeliness in estimating the true cost of energy production. The true cost estimation trial for wind and coal energy in the Indonesia conducted prior to this research showed that construct is defined fractionally, and selected impacts are included in the energy cost due to the shortcomings in data availability and processing ability. In an attempt to identify a complete scale of material impacts, several were identified and monetized, as shown in Table 1.

Table 1. True Cost Accounting estimate for wind and coal energy

Cost Category	**Onshore Wind**	**Offshore Wind**	**Hard Coal**	**Coal with CCS**
Installation Costs	4.4	7.6	1.5	7
O&M Costs	1	2	0.8	1
Fuel Costs	0	0	2	2
Sum of Plant-Level Costs (a)	5.4	9.6	4.3	10
Grid Costs	1	1	0.5	0.5
Balancing Costs	0.3	0.3	0	0
Profile Costs	1.5	1.5	0	0
Sum of System Costs (b)	2.8	2.8	0.5	0.5
GHG Emissions Costs	0.1	0.09	7.11	2.34
Air Pollution Costs	0.07	0.07	1.37	1.47
Landscape and Noise Impacts	0.9	0.08	<0.1	<0.1
Loss on Biodiversity	—	0.2	0.3	—
Employment Benefits	(<0.01)	(<0.01)	(<0.01)	(<0.01)
Upstream Costs (Materials & Construction)	0.45	0.45	1.9	1.9
Nonrecyclable Material Costs	0.0000015	0.0000015	<0.0000015	<0.0000015
Sum of External Costs (c)	1.53	0.7	10.6	5.6
Total Cost (a + b + c)	**9.73**	**13.1**	**15.4**	**16.1**

The three core elements of TCA including complexity, accuracy, and timeliness, served as guiding concepts throughout the research. In the Indonesian energy context, accuracy refers to the reliability of cost estimates, the ability to trace cause-effect relationships between activities and

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their environmental or social impacts, the reduction of subjectivity and uncertainty in cost estimation, and the extent to which the data collected is detailed and dependable. Complexity was understood as the extent to which diverse indicators are needed to quantify environmental, social, and economic effects; the time and resources required for conducting a TCA analysis; the involvement of multiple academic disciplines with differing methodologies; and the challenge of integrating diverse monetization approaches and multidimensional data into a coherent, standardized scale. Timeliness, in this study, refers to the ability to process accounting data in real time, the availability of necessary data, and the extent to which real-time production data could be directly linked to monetization frameworks.

To evaluate how digital technologies such as big data, artificial intelligence (AI), and blockchain can address these challenges in the Indonesian energy sector, various categories of energy production costs were discussed with respondents. This included both internal costs (e.g., plant installation, grid connection, and maintenance) and external costs, which remain largely unaccounted for in Indonesia's current energy pricing structure. These external costs include greenhouse gas emissions, air pollution, noise and visual impacts, loss of biodiversity, and the upstream impacts of resource extraction and construction activities. The scope of this study was limited to material impacts to understand where and how IT solutions can improve TCA implementation (see Table 2). In Indonesia’s case, where fossil fuels like coal and diesel still dominate the energy mix and where renewables are growing but fragmented, identifying these cost categories with greater precision is vital. Respondents agreed that digital infrastructure and intelligent systems could enhance the transparency, integration, and effectiveness of TCA in Indonesia, but emphasized that institutional readiness and clear regulatory frameworks will be essential for scaling these technologies.

This study applies an exploratory and interpretive qualitative research design to understand how big data, AI, and blockchain technologies can support the implementation of True Cost Accounting (TCA) in Indonesia's energy sector.

Table 2. Description of the true costs in the cost price of energy in Indonesia

Type of Cost	**Description**
Installation Costs	Includes capital investment, refurbishment, assembly, decommissioning, and financing costs, often measured in Levelized Cost of Energy (LCOE) terms (Samadi, 2017).
Fuel Costs	Refers to the price of fuel used for energy generation, as captured in the LCOE calculation.
Non-fuel O&M Costs	Covers all fixed and variable operational costs not related to fuel, including wages, insurance, equipment, and maintenance (Samadi, 2017).
Grid Costs	Extra transmission and distribution system costs incurred when integrating new power generation into the grid (Holttinen et al., 2011).
Balancing Costs	Costs of maintaining grid stability and flexibility through reserve contracting to manage supply-demand fluctuations (Samadi, 2017; Mattman et al., 2016).
Profile Costs	Additional capital and operational costs caused by a new energy plant, including overproduction impacts from renewables (Samadi, 2017).
GHG Emission Costs	Costs to society due to greenhouse gas emissions contributing to climate change, reflected as carbon pricing.
Air Pollution	Environmental and health damages from pollutants like SO_2, NOx, fine particles, heavy metals, and dioxins released during fossil fuel extraction and use (Samadi, 2017).
Landscape & Noise Impacts	Effects on human welfare due to visual and auditory disruptions caused by power plants, which may lower property values (Samadi, 2017).
Impacts on Biodiversity	Damage to ecosystems that may threaten the survival of plant and animal species (Epstein et al., 2011).
Employment Benefits	Economic and social benefits from job creation, including reduced government unemployment costs.
Upstream Costs	Environmental and energy costs from resource extraction and material

	production needed for power plants, including emissions (Greenstone & Looney, 2012; Jensen, 2019).
Downstream Costs	Long-term environmental costs of non-recyclable components and waste streams that affect future generations (Shokrieh & Rafiee, 2020; Jensen, 2019).

Following established practices in sustainability accounting research (Gray, 2010; Burritt & Schaltegger, 2014), the methodology is structured around an inductive reasoning approach. The research uses a qualitative method to gather rich insights into the socio-technical challenges of applying TCA enhanced by IT tools. The study integrates perspectives from energy experts, accounting professionals, IT specialists, and policymakers involved in Indonesia's energy transition (Bhattacherjee, 2012).

Table 3. Expert Background

Respondent	Field of Expertise	Date & Duration of Interview
R1	Doctoral student, Universitas Gadjah Mada (studied Indonesian energy market)	04 Januari 2025, 45 min
R2	Expert in big data & AI, Institut Teknologi Bandung (ITB)	12 February 2025, 45 min
R3	Expert in IT for accounting and control, Universitas Indonesia	13 February 2025, 1.5 hours
R4	Energy systems integration, Energy Academy Indonesia	14 February 2025, 1 hour 45 min
R5	Doctoral student, Universitas Gadjah Mada (studied renewable projects)	17 February 2025, 45 min
R6	TCA and ESG reporting expert, Deloitte Indonesia	28 February 2025, 35 min
R7	Climate change modelling, Badan Riset dan Inovasi Nasional (BRIN)	29 February 2025, 1 hour 5 min
R8	Professor of Accountancy, Universitas Airlangga	11 March 2025, 45 min
R9	Expert in blockchain for energy, Indonesian private tech consultant	12 March 2025, 30 min
R10	Expert in social impact of mining, Yogyakarta	13 March 2025, 1 hour 30 min (joint session)
R11	IT and big data application, PlanBe Indonesia	13 March 2025, part of 1 hour 30 min session
R12	Expert in digital marketing systems, PlanBe Indonesia	13 March 2025, part of 1 hour 30 min session
R13	Carbon footprint & sustainability, PlanBe Indonesia	13 March 2025, part of 1 hour 30 min session
R14	Wind farm owner, South Sulawesi	15 April 2025, 5 hours
R15	PV installation manager, Central Java	25 April 2025, 2 hours 15 min
R16	CEO of national energy company, 25+ years' experience	26 April 2025, 2 hours 30 min

Primary data was collected through semi-structured interviews conducted with 16 experts from various sectors including renewable energy companies, technology firms, public institutions, and NGOs between January to April 2025. Respondents were selected using purposive sampling to ensure diversity in expertise and perspectives. This study focuses primarily on the electricity generation sector, particularly coal, solar, and geothermal energy projects in Java-Bali and Sumatra regions. Other sectors such as transportation and manufacturing are acknowledged but not directly

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analyzed. Limitations include potential biases due to sample size and the exploratory nature of the study, which restricts generalization.

Interview questions were designed around key constructs of TCA implementation: complexity, accuracy, timeliness, and technology adoption. Respondents were also introduced to a conceptual TCA model adapted for Indonesia to guide the discussion. Thematic analysis was used to process the interview data (Braun & Clarke, 2006). Interview transcripts were coded according to major themes: challenges in current cost accounting, potential of IT tools, barriers to integration, and policy implications. Coding was conducted manually and cross-validated among the research team to enhance reliability.

RESULT AND DISCUSSION

Respondents highlighted that one of the key challenges in applying TCA to Indonesia's energy projects lies in the diverse and fragmented nature of data sources. Many noted that government databases, private sector records, and environmental monitoring systems operate in silos. This fragmentation makes it difficult to perform comprehensive assessments without significant manual effort (Unerman and Chapman, 2014). Participants emphasized that integrating big data analytics could help automate data collection and analysis across multiple systems. Some suggested leveraging national digital transformation initiatives to build centralized energy and environmental databases to support TCA efforts (Samadi, 2017).

The True Costs Accounting (TCA) process is broken down into four main steps that guide the identification, measurement, assessment, and communication of environmental, social, and economic costs (See Figure 1).

The process begins with Step 1: Goal and Scope Definition, where the system boundaries and objectives are clearly established. This includes creating a process flow diagram and determining which impacts will be measured. This foundational step ensures consistency and focus throughout the TCA analysis.

In Step 2: Inventory Analysis, data collection takes place through multiple sources. One pathway involves gathering measured data directly from farmers via questionnaires, while the other incorporates default values obtained from existing databases or literature. These two streams of input feed into a central inventory analysis, where the required data is compiled to evaluate sustainability impacts across the system.

Step 3: Impact Assessment evaluates the collected data using established methodologies. The results feed into two key tools: the Indicator System, which calculates specific cost categories such as natural eco-costs (N-Eco-costs), social eco-costs (S-Eco-costs), and economic eco-costs (Eco-costs), and the Interpretation phase, where these findings are translated into actionable insights. The output here is an improvement plan that identifies potential interventions or policy changes.

Step 4: Communication involves sharing the results with stakeholders. This may include product branding strategies that reflect the true cost of production, helping consumers and decision-makers better understand the sustainability of products.

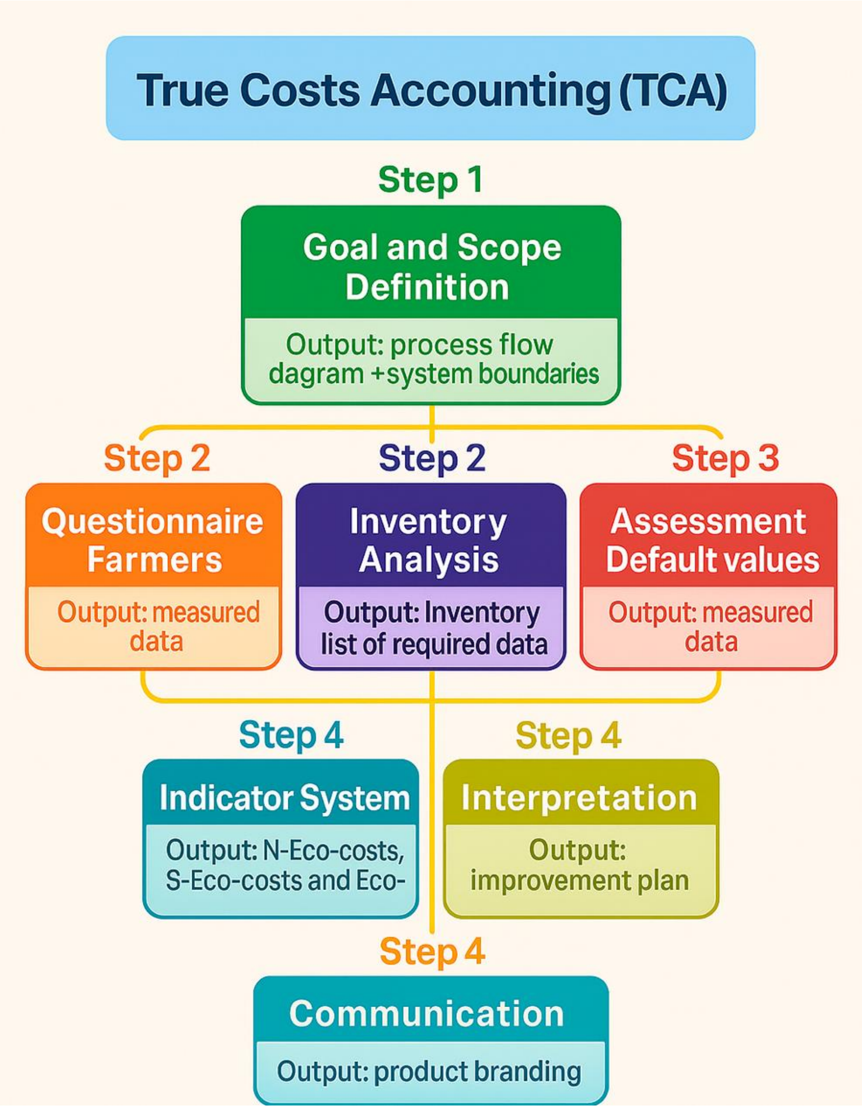

Figure 1. True Cost Accounting Flow Chart (TCA)

Previous research (Bosma, 2020; Jerneck et al., 2021; Sullivan and Hannis, 2022) agreed that AI models could significantly improve the accuracy of TCA estimations by analyzing complex interactions among variables such as emissions, biodiversity loss, and community health impacts. Machine learning algorithms were noted for their potential to predict long-term costs more reliably than traditional accounting methods. However, challenges remain in defining standard methodologies for monetizing social and ecological impacts in the Indonesian context. Several respondents suggested adopting internationally recognized frameworks, such as the Social Cost of Carbon (SCC) and Life Cycle Assessment (LCA) methodologies, but adapted to local realities.

Timeliness emerged as another critical factor. Several stakeholders pointed out that by the time environmental impact data is collected and processed manually, the information may already be outdated. This lag undermines the decision-making process for sustainable investments. The integration of Internet of Things (IoT) devices and blockchain technology was proposed as a solution for real-time data acquisition and immutable record-keeping. Respondents emphasized that blockchain-enabled reporting systems could foster trust and transparency between investors, regulators, and communities.

Despite optimism about digital solutions, several practical barriers were identified, including high implementation costs, limited digital literacy among local actors, regulatory uncertainty, and concerns over data privacy and ownership. Respondents called for strong government leadership in standardizing TCA methodologies, incentivizing digital innovation, and facilitating partnerships between technology providers, energy companies, and academic institutions.

In Indonesia, energy prices similarly fail to reflect the full environmental, social, and

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economic externalities of energy production. Stakeholders interviewed during this study expressed limited exposure to the concept of True Cost Accounting (TCA), and the estimations developed in the preparation phase were received with notable interest. When shown the true cost breakdown — particularly including external costs such as air pollution, biodiversity loss, and upstream environmental damage — many respondents acknowledged that current planning and pricing frameworks lack tools to integrate these dimensions.

Participants from renewable energy companies in Java and Sumatra, especially those operating solar and wind farms, noted the absence of standardized procedures to measure or report externalities. One wind project manager in South Sulawesi, for example, shared that during routine inspections, technicians had discovered bird nesting activity on turbine towers. Although this was seen as a sign of low ecological disturbance, the operator admitted there was no formal mechanism to monitor or document such impacts. Others mentioned that wind farms often attract insects and birds, indirectly integrating with local ecosystems, but no baseline data or evaluation frameworks exist to assess these dynamics. Operators of coal-fired power plants under PLN's generation business units expressed similar observations.

According to a manager in East Kalimantan, air pollution data is collected for regulatory compliance, but the broader social or health-related costs — such as respiratory disease in nearby communities — are not monetized or included in project financial assessments. Several interviewees argued that including such external effects during the investment planning phase would make mitigation more effective, but current project appraisal systems do not support this. A consistent challenge mentioned across both fossil and renewable operators was the absence of a methodology or institutional mechanism to quantify and account for such impacts. Respondents recognized that decisions made at the development stage are more flexible and cost-effective to adjust than retroactive modifications, but the lack of integrated cost accounting prevents this.

A new theme also emerged early in the interviews: the challenge of implementing TCA in Indonesia's policy and business environment. This theme recurred frequently and was added as a distinct result area. Respondents emphasized that while there is growing awareness of environmental costs — particularly in relation to ESG reporting and carbon markets — the institutional readiness to adopt TCA remains low.

In general, awareness and understanding of TCA varied across stakeholder groups. Respondents from Jakarta-based regulatory bodies and international NGOs demonstrated a relatively strong grasp of sustainability frameworks. However, practitioners in provincial energy offices and local utility companies reported limited familiarity with TCA concepts. Compared to more mature regulatory systems in countries like the Netherlands or Germany, Indonesia's institutional capacity for sustainability accounting is still emerging. Some respondents expressed cautious optimism, citing recent momentum around Indonesia's Net Zero 2060 pledge and the development of national carbon pricing mechanisms. However, they also emphasized that technical guidelines, digital infrastructure, and inter-agency coordination will be critical for TCA to be operationalized in Indonesia.

TCA involves integrating diverse environmental, social, and economic impacts into a single cost estimate — a process that is inherently complex due to interdisciplinary data, various metrics, and unstandardized valuation methods. Big data and AI help reduce this complexity by automating data collection, pattern recognition, and the identification of cost drivers. These technologies allow practitioners to process large, unstructured datasets from multiple sources more efficiently (Gusc et al., 2022). For example, AI algorithms can detect cause-effect relationships, allocate impacts to specific activities, and support cost forecasting based on historical patterns. Meanwhile, blockchain contributes by securely and uniformly sharing verified data across all stakeholders, reducing fragmentation and inconsistency in data handling (Gusc et al., 2022). Standardization protocols embedded in blockchain systems further enhance efficiency in data exchange and interpretation.

One of TCA's key limitations is the subjectivity and inconsistency in quantifying and monetizing externalities — such as biodiversity loss or social impacts. AI and big data enable the development of predictive models that simulate impacts more accurately and reduce human bias. AI can build logic-based frameworks to allocate costs and identify causal chains using advanced data mining techniques, such as descriptive, predictive, and prescriptive analytics (Gusc et al., 2022).

Blockchain enhances data reliability by ensuring that measurements are tamper-proof and traceable. It verifies the integrity of data points used in valuation models, addressing the issue of unverifiable or inconsistent data sources. As a result, TCA outcomes become more objective and trustworthy. Timeliness in TCA is hindered by delays in data availability, manual reporting processes, and non-standardized timeframes. Big data infrastructure allows real-time data processing through IoT sensors, enabling immediate measurement of environmental and operational indicators (Gusc et al., 2022). AI tools process this data rapidly, turning raw inputs into actionable cost insights.

Blockchain complements this by enabling secure, automated sharing of real-time data across the entire supply chain. This interconnected data system allows decision-makers to monitor externalities and sustainability impacts as they occur, rather than relying on outdated or aggregated reports. However, the study notes that real-time processing is not always necessary or cost-effective. The cost-benefit of real-time TCA data should be carefully assessed (Gusc et al., 2022).

CONCLUSION

Indonesia's transition to sustainable energy remains constrained by the inability of current pricing mechanisms to reflect the true environmental, social, and economic costs of fossil-based electricity production. This research has demonstrated that True Cost Accounting (TCA) offers a viable framework to bridge this gap, but its implementation is challenged by issues of complexity, accuracy, and timeliness. These challenges stem from fragmented data systems, inconsistent valuation methods, and limited institutional capacity. The integration of big data, artificial intelligence (AI), and blockchain technologies shows strong potential to overcome these barriers. Big data facilitates real-time, large-scale data processing; AI enhances cost prediction and impact modeling; and blockchain ensures data transparency, trust, and security across stakeholders. Together, these technologies can improve the precision of TCA estimates, accelerate data flows, and reduce the manual workload currently hindering sustainability accounting in Indonesia’s energy sector.

However, the success of this approach depends on more than just technology. The findings emphasize the importance of developing national standards for TCA, building interoperable digital infrastructure, and fostering collaboration between government, academia, and industry. Respondents repeatedly highlighted the need for stronger regulatory frameworks, standardized cost protocols, and education around sustainability practices. Furthermore, while Indonesia faces substantial hurdles in implementing TCA, it also holds a strategic opportunity. Leveraging digital technologies not only enhances the feasibility of TCA but can also serve as a catalyst for wider reforms in sustainable energy investment and policy. With strong political will, institutional alignment, and cross-sector collaboration, TCA supported by digital innovation can become a core instrument in Indonesia’s path toward its Net Zero 2060 target.

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