The Role of Information and Communication Technology in Advancing Sustainable Energy Transition in Developing Countries: Progress, Opportunities and Challenges

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Abstract

Sustainable energy transitions in developing countries are critical for balancing economic growth and environmental sustainability. Transitioning to renewable energy sources alleviates energy poverty and reduces reliance on fossil fuels. Information and communication technology (ICT) plays an important role in advancing the energy transition and achieving low-carbon energy utilisation by facilitating the transition of power sectors to renewable energy sources. This paper provides an overview of the role of ICT in achieving sustainable energy transition in developing countries and jurisdictions. It emphasises the significance of SDG 7 and other sustainable energy transition indices for energy access and transition, as well as presenting their status and progress in various regions, including developing countries. This paper also discusses several types of available ICT tools and methods that enable digitalization in the power sector, such as smart grids, smart metres, energy management systems, Internet of Things (IoT) for energy, and renewable energy monitoring systems, as well as the opportunities and challenges of incorporating ICT into the context of developing countries' sustainable power sector.

Keywords: Digitalization, Information, Communication Technology, Smart Grid, Sustainable Energy.

I. INTRODUCTION

Sustainable energy transitions in developing countries are crucial for balancing economic growth with environmental sustainability. Transitioning to renewable energy sources helps address energy poverty and reduce dependency on fossil fuels. Renewable energy is arguably one of the solutions for progressing the energy transition, offers a cleaner alternative and enhances energy system resilience. Thus, global energy transformation driven by renewable energy is vital to attaining sustainable development goals, especially in countries and jurisdictions with limited energy access [1].

Sustainable energy development and transition from fossil-based energy resources, globally, have been driven by declining renewable technology costs, supportive government policies, and international funding. In the context of developing countries, international cooperation and investment are crucial in overcoming financial and technical barriers. Financing renewable energy projects, for example in Africa, is a challenge but an opportunity for sustainable development [2]. Local air pollution and climate change mitigation are also major drivers for adopting renewable energy [3].

Transitioning to renewable energy in developing countries has numerous advantages, including lower emissions of greenhouse gases, better public health, and increased energy security. Renewable energy projects also boost local employment and economic development. Low-cost renewable electricity can drive the global energy transition, especially relevant for developing countries seeking sustainable solutions [4]. Long-term benefits include reducing energy costs and promoting energy access in rural areas where traditional grid connections are not feasible.

Renewable energy, including solar, wind, and hydropower, is crucial for sustainable energy transition in developing regions. Achieving 100% renewable energy targets is becoming more common even in low-income countries, as they recognise the importance of clean energy in sustainable development [5]. Integrating renewable energy into national energy grids and local solutions is a significant step towards combating climate change and fostering sustainable development globally.

Sustainable energy development is crucial for socio-economic progress in developing countries. It involves utilising renewable electricity technologies like wind turbines, solar photovoltaic, and hydropower to ensure long-term energy security and environmental preservation. This is especially important in enhancing electricity access in rural and remote areas. The transition to renewable energy is pivotal for ensuring sustainable energy access, leading to economic and environmental benefits [6]. Integrating renewable energy into national energy strategies reduces emissions of greenhouse gases, assisting in global efforts to mitigate the impacts of climate change and addressing energy poverty [7]. Overall, sustainable energy development is critical for improving the quality of life and promoting economic growth.

Information and Communication Technology (ICT) serves as one of the important tools in enhancing sustainable energy development by facilitating the transition of power sectors towards renewable energy sources. The incorporation of ICT into energy systems improves the efficiency, reliability, and accessibility of renewable energy, accelerating the transition from fossil fuels to more environmentally friendly energy solutions.

Implementing ICT in the power sector can significantly improve energy efficiency and accelerate renewable electricity deployment in developing countries [8]. ICT promotes renewable energy development in a variety of regions, including the BRICS countries, i.e., Brazil, Russia, India, China, South Africa, Iran, Egypt, Ethiopia, and the United Arab Emirates, emphasising its role in the global energy transition [9]. [10] discusses the potential of ICT to improve renewable energy integration and efficiency, particularly in smart grid technology, as well as the impact on energy systems.

Although studies on the importance of ICT in supporting sustainable energy transition are widely available, the literature on this topic in the context of developing countries is somewhat limited. It further limits the ability of developing-country policymakers and practitioners to leverage ICT for energy transition fully. There is, for example, still much to learn about the innovative applications of ICT in African nations' electricity sectors, which could provide valuable insights for sustainable energy development [11]. While the digital economy, aided by ICT, is critical in driving renewable energy penetration, there is a need for additional research in this area in developing countries [12]. The integration of ICT for optimising energy management systems and renewable energy deployment towards sustainable energy transition in developing countries, i.e., the use of ICT to enable data-driven decision-making, is still limited. These indicate the gap for additional studies, particularly in understanding how ICT can be effectively implemented in less developed countries' contexts.

This paper seeks to address the above-mentioned gap by providing an overview of ICT integration for sustainable energy transition in developing countries and jurisdictions. It focuses on the importance of Sustainable Development Goal 7 (SDG7) for energy access and transition and presents its status and progress across various regions, including developing countries. This paper also discusses several types of available ICT tools and methods that enable digitalisation in the power sector, as well as the opportunities and challenges of integrating ICT into the context of developing countries' sustainable power sector.

The urgency and importance of this study stem from several critical factors that highlight the role of ICT in today's energy transition progress in developing countries. These critical factors include meeting global climate goals and sustainable development targets with ICT as a key enabler, improving energy access with ICT-supported decentralised energy solutions, and fostering long-term economic growth through the use of efficient, flexible, and sustainable energy infrastructure and data communication, both of which rely heavily on ICT. As a result, without timely adoption of ICT, many developing countries risk falling further behind in achieving universal energy access, and thus a sustainable energy transition.

II. SUSTAINABLE ENERGY DEVELOPMENT GOAL 7

A. The importance of SDG7 on Energy Access and Transition

Sustainable Development Goal 7 (SDG7) ensures everyone has access to reliable, affordable, sustainable, and modern energy, essential for driving global economic growth, improving human well-being, and combating climate change. SDG7 emphasizes the need to increase the share of renewable energy generation, enhance energy efficiency, and expand access to clean energy solutions, particularly in developing countries where energy poverty remains a critical challenge. Achieving SDG7 requires a concerted effort to integrate renewable energy technologies into energy systems worldwide, which is crucial for sustainable transition [13].

SDG7 is not only critical for promoting sustainable energy development, especially in areas where energy poverty remains a significant impediment to economic growth and social progress. The emphasis on increasing access to renewable energy technologies is consistent with global efforts to progressively shift away from fossil energy and mitigate the impact of climate change. This transition is required to combat climate change and provide clean, sustainable energy solutions that can power economic activity and improve the quality of life in developing countries. For example, financing renewable energy projects in Africa is critical to meeting SDG7 because it directly addresses the continent's energy access issues [2]. Advancing renewable energy penetration is important in driving the global energy transition, which is required to meet the SDG7 targets in low-income countries [1].

B. The Progress of SDG7 in Several Regions

Policymakers and stakeholders can track the annual progress of SDG7 across regions, countries, and jurisdictions while planning and formulating updated strategies aiming to achieve SDG7 targets. Table 1 shows several SDG7 sub-indicators and their progress in East and Southeastern Asia, Sub-Saharan Africa, and Oceania. The dataset presented in Table 1 is gathered from [14].

Table 1. SDG7 Progress in Several Regions

SDG7 Indicators	Regions	Progress (in 2021 or *2020*)
Rural electricity access rate (%)	Eastern and Southeastern Asia	88
	Sub-Saharan Africa	29
	Oceania	47
Rural clean cooking access rate (%)	Eastern and Southeastern Asia	68
	Sub-Saharan Africa	5
	Oceania	7
Renewables share in total final energy consumption (%)	Eastern and Southeastern Asia	*14.8*
	Sub-Saharan Africa	*70.8*
	Oceania	*14*
Renewable power generation capacity (watts per capita)	Southeastern Asia	143
	Sub-Saharan Africa	38
	Oceania	72

Table 1 shows the progress and challenges in achieving SDG7 in these regions, including varying levels of access to electricity and clean cooking solutions in rural areas, and the deployment of renewable energy. SDG7 has prioritised energy access and renewable energy alongside energy efficiency. While Southeast Asia’s energy access is high, with countries such as Thailand, Malaysia, and Vietnam having access to electricity for all or nearly all of their rural populations, energy access is significantly lower in the rural areas of Myanmar and Cambodia.

As shown in Table 1, rural electricity access and clean cooking are particularly difficult in Sub-Saharan Africa and Oceania. Meanwhile, renewable’s share of total energy consumption in the regions shown in Table 1 appears to be low in comparison to other regions, particularly when variable renewables such as wind and solar are considered. Meanwhile, Sub-Saharan Africa's 70.8% achievement is attributed to the use of solid biofuels, primarily for cooking.

In terms of installed renewable electricity, there has been a steady increase in the deployment of renewables in Southeast Asia, particularly in solar and wind, which has been bolstered by regional initiatives and national policies aimed at lowering reliance on fossil fuels and promoting cleaner energy, as well as the decline in wind and solar technology costs over the last decade. However, while the regional average for installed renewable electricity-generating capacity may rise, it does not accurately reflect the disparities within individual countries.

C. Other Indicators for Sustainable Energy Transition

In addition to SDG7, a variety of metrics have been proposed and used as proxy indicators for tracking and monitoring energy transition. A recent study has presented and analysed 57 sets of indicators based on several assessment criteria, including stakeholder engagement, linkages, representatives, conceptual framework, and transparency of indicator selection and application [15]. Based on the criteria used, the Energy Indicators for Sustainable Development (EISD) [16] is considered the most comprehensive and robust. EISD comprises social, economic, and environmental dimensions, as the main framework. While only a few of the assessed indicators received a higher score than the majority of the indicators (this includes the Renewable Energy Sustainability Index, Indicators for Sustainable Development Goal 7, Energy Security Index, and Aggregated Energy Security Performance Indicator), the construction of such an index was heavily influenced by the availability of datasets and other variables.

As a result, policymakers and stakeholders have multiple options for selecting and implementing the most relevant indicators. Indicators for sustainable energy development will continue to evolve as new methods and frameworks are developed and considered important in light of current and future circumstances. Recent technological advancements, particularly digitalisation of energy infrastructure and data, can be viewed as a key driver in the development of new indicators. Integrating information and communication technology has been viewed as critical to improving the status and progress of sustainable energy development, particularly during the energy transition period. Incorporating technological dimensions, especially digitalization and ICT integration matrices into indicators is becoming an intriguing idea and new research in the area of study, especially in developing countries’ energy transition.

III. DIGITALISATION AND ICT INTEGRATION

This paper applies a literature review-based analysis to the topic of the potential of Information and Communication Technology (ICT) in advancing sustainable energy transition in the context of developing countries. The analysis particularly reviews combined issues of the status and progress of SDG7 and the potential of ICT implementation in the power sector as a key enabler and catalyst for energy transition towards net zero carbon emission of the regions. This section particularly discusses the literature around the concept and roles of digitalisation of ICT in the power sector, an overview of ICT-based key technologies, and ICT implementation in developing countries. As this paper focuses on the literature review, data collection and analysis regarding the data have been limited to the current status and progress of several relevant indicators of sustainable energy development in the developing countries regions, such as those presented in Table 1 in Section 2, and some achievements on the progress of ICT deployment.

This study applies several stages for the literature review on the discussed topic. The first step is defining the topic, i.e., the role of ICT in advancing sustainable energy transition in developing countries. It is followed by collecting the appropriate literature from the ScienceDirect database using several keywords. These include the progress, opportunities and challenges. These specific terms limit the searched literature. The obtained literature has undergone further screening mainly through the abstracts and conclusions of the topic. Finally, the selected literature has been analysed and included in this research.

A. The Concept and Roles of Digitalisation of Information and Communication in the Power Sector

Digitalisation refers to the integration of digital technologies that advance the flow of energy and data information and communication of electricity generation, distribution, consumption, and storage. One of the ultimate aims is to transform traditional energy systems into more efficient, flexible, and sustainable networks. In light of energy transition, digitalisation is key to enhancing the efficiency and security towards sustainability of energy systems, supporting the way for a cleaner and more resilient power sector [17]. Digitalisation of the power sector is essential for the successful integration of variable renewables and the transition to a low-carbon society [18]. The adoption of digital technologies in the power sector also supports the development of smart grids, which are crucial for managing the variability of renewable energy-based electricity generation [19]. As digitalisation continues to advance, it opens new opportunities for innovation in the power sector, such as smart cities and advanced energy storage [20].

Digitalisation in the power sector is intricately linked with ICT, which serves as the backbone of digital transformation. ICT enables seamless communication between various components of the energy system, allowing for real-time data collection and analysis. This connectivity is essential for the development of smart grids, which rely on advanced communication networks to monitor and control energy flows. ICT enhances the capabilities of digital systems within the power sector, leading to more responsive and adaptive energy networks. The integration of ICT with energy systems not only optimises the operation of power grids but also facilitates the deployment of more distributed energy resource plants, such as rooftop solar photovoltaics and small-scale wind turbines.

B. Overview of ICT-based Key Technologies

In the power/energy sector, various types of ICT-based technologies are applied to improve the efficiency, reliability, and security of energy systems. Some key types of ICT-based technologies include smart grids, smart meters, energy management systems, The Internet of Things (IoT) for energy, and renewable energy monitoring systems.

Smart grids utilise advanced ICT systems to manage energy use from generation to consumption in a way more efficient. They incorporate real-time monitoring, automated control, and bidirectional data communication to optimise the flow of electricity and integrate renewable energy sources. Smart grids are crucial for enabling demand response programs and improving the reliability of the network. The integration of ICT in smart grids facilitates better management of energy distribution and consumption [10].

Smart meters play an important role in modernizing the energy sector by providing supporting functionalities that help the smart grid optimise energy use [21]. These ICT-based devices provide detailed and real-time energy consumption data to both consumers and power producers. Moreover, they enable dynamic pricing, energy usage monitoring, and remote billing, which help in improving energy efficiency.

Energy Management Systems (EMS) are ICT-based systems designed to monitor, control, and optimise the performance of energy systems. They are widely used in industrial, commercial, and residential settings to manage energy consumption and reduce costs. These systems help in load forecasting, demand-side management, and integration of utility-scale as well as distributed renewable electricity generating plants. ICT-driven energy management systems can lead to substantial improvement in energy efficiency and operational efficiency [22].

IoT devices are increasingly being used in the energy sector to create interconnected networks of devices that communicate and work together to improve energy efficiency. These include sensors, smart appliances, and connected devices that monitor and control energy usage in real-time. IoT application in the energy sector is critical for enabling smart grid functionalities and enhancing energy management. IoT devices can be applied in energy storage systems and for monitoring real-time environments. The role of IoT in creating smarter and more responsive energy systems is highlighted in [23]. ICT-based monitoring systems can be employed to track variable renewable energy systems' performance and output. These devices collect energy production data, system efficiency, and weather conditions, which are substantial for optimising the operation of renewable energy generating plants.

C. Studies and Progress of ICT Implementation for Power Sector in Developing Countries

There are several publications on the status of ICT implementation in developing countries' power sectors. A recent study outlined three critical aspects of implementing smart grids in Bangladesh: identifying the key adaptations required, developing a cost model based on multi-stream data and inputs, and reporting on the current power sector scenario for supporting smart grids [24]. Another study investigated the feasibility, challenges, and opportunities for smart grids in Brazil [25]. The study also examined the Brazilian power sector and its trends, as well as the current state of smart metering deployment in pilot projects. The authors argued that Brazil requires increased utility-scale energy storage capacity, as well as regulation and a new business model that allows for the implementation of decentralised energy technology.

The implementation progress of green IoT technologies, including for smart grid applications in developing countries, is reviewed and discussed in [26]. Green cloud computing and green data centres are two examples of green IoT technologies. The study also highlighted several achievements in green IoT implementation on smart grids, including in Nepal, China, Morocco, and Kazakhstan.

Numerous completed pilot projects in India are reviewed in [27]. The functionality of the grid includes implementing peak load management, advanced metering infrastructure, power quality and outage management system, with a target population of approximately 45,000 customers. A few larger projects have also been carried out in some urban areas, focusing on installing smart meters. In addition, the study presented several research summaries on smart grid development worldwide, including the impact of ICT integration and deployment in conjunction with other smart grid technologies.

Southeast Asian countries have also set up roadmaps and initiatives for smart grid development [28]. Vietnam, Thailand, and Indonesia are among the ASEAN members that have initiated and completed smart metre pilot projects in various locations. Using smart meters, some 1 million PLN (A vertically integrated Indonesia's state electricity company) customers in Indonesia can monitor their energy usage and load profile in real-time, as well as ongoing energy costs through a mobile application, in addition to choosing between prepaid and postpaid options for paying their electricity charges [29]. A pilot project of smart meters rollout in Pattaya, Thailand, was expected to reduce outage operational costs associated with meter reading and connection/disconnection, reduce losses and system peak load [30].

IV. OPPORTUNITIES AND CHALLENGES

Implementing ICT to advance energy transition provides numerous opportunities, particularly in terms of increasing energy efficiency and enabling the integration of variable renewable energy. ICT enables the deployment of smart grids, which are critical for managing the complex interactions between distributed energy resources and traditional power systems. These smart grids use real-time data analytics to improve energy distribution, reduce losses, and better balance supply and demand, resulting in a more reliable and efficient energy network.

Furthermore, ICT plays an important role in providing tools for precise forecasting, monitoring, and control of variable renewable energy sources. Digitalization in the energy sector enables better management of resources and encourages the use of cleaner energy solutions. Incorporating ICT into the energy transition, however, poses significant challenges, particularly in terms of cybersecurity, data privacy, and the high costs of infrastructure development.

As energy systems rely more on digital technologies, they become more vulnerable to cyberattacks, compromising critical infrastructure security and disrupting energy supply. Furthermore, the huge amounts of data produced by smart energy environments raise privacy concerns and the possibility of misusing sensitive information, which may discourage widespread adoption. Another major challenge is the significant investment required to build and maintain the necessary ICT infrastructure, particularly in developing countries with limited financial resources.

Table 2. Opportunities and Challenges of Implementing ICT in Energy Transition in Developing Countries

Aspect	Opportunities	Challenges
Energy efficiency	Enhances energy efficiency via real-time monitoring and control.	High costs for deploying smart grids and meters.
Renewable integration	Facilitates integration of renewables by managing variability.	Technical challenges with outdated infrastructure.
Data Analytics	Improves decision-making with advanced data analytics.	Lack of expertise in data management.
Grid stability	Enhances grid stability by balancing supply and demand.	Increased vulnerability to cyber-attacks.
Consumer engagement	Boosts consumer engagement with smart meters, leading to better energy usage.	Privacy concerns and resistance from consumers.
Economic growth	Drives economic growth by creating new business opportunities.	Significant investment is needed for ICT infrastructure.

Implementing large-scale smart grid infrastructure in Southeast Asia (ASEAN) and other developing regions faces several typical challenges. As shown in Table 2, these include high initial costs and investment requirements, regulatory and policy barriers (including business and financial mechanisms), technical (infrastructure) challenges and grid stability, cybersecurity risks, and human resources [28]. The widespread implementation of smart grid functionalities necessitates significant capital investment in advanced technologies, infrastructure upgrades, and qualified human resources. Many countries in these regions face financial constraints, making it difficult to allocate the funds required for these developments. This challenge is particularly acute in less developed regions, where the existing grid infrastructure may be obsolete and require extensive upgrades before smart grid technologies can be integrated.

The regulatory environment in Southeast Asia and many developing countries is still not fully conducive to the deployment of smart grids. There is frequently a lack of clear policies and frameworks to support renewable energy integration and grid modernisation. Furthermore, varying levels of policy development among ASEAN member states can result in inconsistencies in implementation, impeding regional cooperation and standardization efforts.

ASEAN countries face technical challenges in implementing smart grid technologies due to variability in grid reliability and the need to modernise existing infrastructures. The region's diverse power systems, some of which are outdated or insufficient, complicate the implementation of advanced grid technologies. Furthermore, integrating renewable energy sources, which are inherently variable, complicates grid stability, if not properly managed.

The increasing digitalisation of the energy sector via smart grids poses significant cybersecurity risks. ASEAN member countries must develop and implement strong cybersecurity procedures and measures to protect critical infrastructure from potential cyber-attacks. The region's varying levels of cybersecurity maturity can result in vulnerabilities that can be exploited, jeopardising the stability and security of the energy supply. Meanwhile, a lack of trained professionals in fields such as data analytics, cybersecurity, and smart grid technology impedes these systems' effective deployment and management. The development of a set of regulations that allow for the prosecution and punishment of both domestic and cross-border cybercrimes has emerged as one of the major challenges in implementing a robust and comprehensive ICT-based solution for power sector energy and data infrastructure.

Several recommendations on smart grid technologies for energy transition in ASEAN are highlighted in [31]. Countries must develop clear policies and prioritise the smart grid roadmap while maintaining consistent standards. Sustainable financing and investment, for example, should be secured through public-private partnerships and innovation financial schemes, as well as access to international funding for smart grid infrastructure development, technology deployment, and existing grid upgrades. Countries should also strengthen cybersecurity by putting in place strong security protocols, continuous monitoring and upgrades, increasing customer engagement and awareness through various programmes and incentives, and encouraging variable renewable energy integration through policies that promote distributed generation technologies and energy storage adoption.

V. CONCLUSION

This paper provides an overview of ICT's role in achieving a sustainable energy transition in developing countries and jurisdictions. ICT plays an important role in accelerating the sustainable energy transition in developing countries by improving the efficiency, accessibility, and scalability of renewable energy solutions. ICT allows for the integration of various renewable electricity generation technologies such as wind turbines, solar photovoltaics, and hydropower into existing infrastructure via smart grids, digital energy management systems, and data-driven decision-making tools. This integration not only optimises energy distribution, but it also provides improved monitoring, maintenance, and predictive analysis, all of which are critical for reducing energy loss and increasing reliability. Furthermore, ICT promotes innovation in decentralised energy solutions like microgrids and off-grid solar systems, empowering rural and underserved communities with reliable, clean electricity access.

Despite the progress and potential, major challenges remain. Developing countries frequently face barriers such as limited digital infrastructure, high technology deployment costs, and a lack of technical expertise, which impede the widespread adoption of ICT in the energy sector. Based on the literature review conducted in this study, developing countries – due to budget constraint – should prioritise building the necessary digital infrastructure and enhancing access to technology, especially in rural and underserved areas while also managing ICT costs, such as seeking low-cost-green computing infrastructure when developing ICT-based solutions that meet the needs of the current and future transition stages. While investment in smart grids, data analytics platforms, and IoT-enabled systems is one way, policies and regulatory frameworks development that encourage private sector investment in ICT-driven energy solutions and promoting education and public-private partnerships for technology transfer and capacity building, is another key. Finally, fostering regional collaboration and knowledge sharing can help overcome technical and financial barriers, especially cybercrime attacks and data security.

REFERENCES

[1] D. Gielen, F. Boshell, D. Saygin, M.D. Bazilian, N. Wagner and R. Gorini, “The role of renewable energy in the global energy transformation,” *Energy Strategy Reviews*, vol. 24, pp. 38-50, Apr. 2019, doi: 10.1016/j.esr.2019.01.006.

[2] G. Schwerhoff and M. Sy, “Financing renewable energy in Africa – Key challenge of the sustainable development goals,” *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 393-401, Aug. 2017, doi: 10.1016/j.rser.2016.11.004.

[3] Z.A. Elum and A.S. Momodu, “Climate change mitigation and renewable energy for sustainable development in Nigeria: A discourse approach,” *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 72-80, Sept. 2017, doi: 10.1016/j.rser.2017.03.040.

[4] D. Bogdanov, M. Ram, A. Aghahosseini, A. Gulagi, A.S. Oyewo, M. Child, U. Caldera, K. Sadovskaia, J. Farfan, L.D.S.N.S. Barbosa, M. Fasihi, S. Khalili, T. Traber and C. Breyer, “Low-cost renewable electricity as the key driver of the global energy transition towards sustainability,” *Energy*, vol. 227, 120467, Jul. 2021, doi: 10.1016/j.energy.2021.120467.

[5] M.M.V. Cantarero, “Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries,” *Energy Research & Social Science*, vol. 70, 101716, Dec. 2020, doi: 10.1016/j.erss.2020.101716.

[6] M. Murshed, “Can regional trade integration facilitate renewable energy transition to ensure energy

sustainability in South Asia?" *Energy Reports*, vol. 7, pp. 808-821, Nov. 2021, doi: 10.1016/j.egyr.2021.01.038.

[7] Jonathan Cloke, A. Mohr and E. Brown, "Imagining renewable energy: Towards a Social Energy Systems approach to community renewable energy projects in the Global South," *Energy Research & Social Science*, vol. 31, pp. 263-272, Sep. 2017, doi: 10.1016/j.erss.2017.06.023.

[8] M. Murshed, "An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia," *Environmental Science and Pollution Research*, vol. 27, pp. 36254-36281, Jun. 2020, doi: 10.1007/s11356-020-09497-3.

[9] P. Tzeremes, E. Dogan and N.K. Alavijeh, "Analyzing the nexus between energy transition, environment and ICT: A step towards COP26 targets," *Journal of Environmental Management*, vol. 326, part A, 116598, Jan. 2023, doi: 10.1016/j.jenvman.2022.116598.

[10] M.H. Rehmani, M. Reisslein, A. Rachedi, M.E. Kantarci and M. Radenkovic, "Integrating renewable energy resources into the smart grid: Recent developments in information and communication technologies," *IEEE Transactions on Industrial Informatics*, vol. 14, issue. 7, pp. 2814-2825, Jul. 2018, doi: 10.1109/TII.2018.2819169.

[11] J. Kouton, "Information communication technology development and energy demand in African countries," *Energy*, vol. 189, 116192, Dec. 2019, doi: 10.1016/j.energy.2019.116192.

[12] M. Shahbaz, J. Wang, K. Dong and J. Zhao, "The impact of digital economy on energy transition across the globe: The mediating role of government governance," *Renewable and Sustainable Energy Reviews*, vol. 166, 112620, Sep. 2022, doi: 10.1016/j.rser.2022.112620.

[13] D.M. Collum, L.G. Echeverri, K. Riahi and S. Parkinson, "SDG 7 ensure access to affordable, reliable, sustainable and modern energy for all. Accessed: Sep. 3, 2024. [Online]. Available: https://pure.iiasa.ac.at/id/eprint/14621/1/SDGs-interactions-7-clean-energy.pdf

[14] IBRD, "Tracking SDG7: The energy progress report 2023," Accessed: Sep. 1, 20204. [Online]. Available: https://www.irena.org/Publications/2023/Jun/Tracking-SDG7-2023

[15] I. Gunnarsdottir, B. Davidsdottir, E. Worrell and S. Sigurgeirsdottir, "Review of indicators for sustainable energy development," *Renewable and Sustainable Energy Reviews*, vol. 133, 110294, Nov. 2020, doi: 10.1016/j.rser.2020.110294.

[16] IAEA, "Energy Indicators for Sustainable Development: Guidelines and Methodologies," Accessed: Aug. 30, 2024. Available: https://www-pub.iaea.org/mtcd/publications/pdf/pub1222_web.pdf

[17] P. Maroufkhani, K.C. Desouza, R.K. Perrons and M. Iranmanesh, "Digital transformation in the resource and energy sectors: A systematic review," *Resources Policy*, vol. 76, 102622, June 2022, doi: 10.1016/j.resourpol.2022.102622.

[18] B. Lin and C. Huang, "Promoting variable renewable energy integration: The moderating effect of digitalization," *Applied Energy*, vol. 337, 120891, May 2023, doi: 10.1016/j.apenergy.2023.120891.

[19] M. Loock, "Unlocking the value of digitalization for the European energy transition: A typology of innovative business models," *Energy Research & Social Science*, vol. 69, 10740, Nov. 2020, doi: 10.1016/j.erss.2020.101740.

[20] Energy System 4.0: Digitalization of the Energy Sector with Inclination towards Sustainability, " *Sensors*, vol. 22, no. 17, 6619, Sep. 2022, doi: 10.3390/s22176619.

[21] G.R. Barai, S. Krishnan and B. Venkatesh, "Smart metering and functionalities of smart meters in smart grid - a review," in *Proc. 2015 IEEE Electrical Power and Energy Conference (EPEC),* London, ON, Canada, 2015, pp. 138-145.

[22] L. Bastida, J. Cohen, A. Kollmann, A Moya and J. Reichl, "Exploring the role of ICT on household behavioural energy efficiency to mitigate global warming," *Renewable and Sustainable Energy Reviews*, vol. 103, pp. 455-462, Apr. 2019, doi: 10.1016/j.rser.2019.01.004.

[23] T. Ahmad and D. Zhang, "Using the internet of things in smart energy systems and networks," *Sustainable Cities and Society*, vol. 68, 102783, May 2021, doi: 10.1016/j.scs.2021.102783.

[24] M.H. Maruf, M.A. Haq, S.K. Dey, A.A. Mansur and A.S.M. Shihavuddin, "Adaptation for sustainable implementation of Smart Grid in developing countries like Bangladesh," *Energy Reports*, vol. 6, pp. 2520-2530, Nov. 2020, doi: 10.1016/j.egyr.2020.09.010.

[25] G.G. Dranka, P. Ferreira, "Towards a smart grid power system in Brazil: Challenges and opportunities," *Energy Policy*, vol. 136, 111033, Jan. 2020, 10.1016/j.enpol.2019.111033.

[26] P. Pandiyan, S. Saravanan, R. Kannadasan, S. Krishnaveni, M.H. Alsharif and M.K. Kim, "A comprehensive review of advancements in green IoT for smart grids: Paving the path to sustainability," *Energy Reports*, vol. 11, pp. 5504-5531, Jun. 2024, doi: 10.1016/j.egyr.2024.05.021.

[27] Archana, R. Shankar and S. Singh, "Development of smart grid for the power sector in India," *Cleaner Energy Systems*, vol. 2, 100011, Jul. 2022, doi: 10.1016/j.cles.2022.100011.

[28] Suwanto, N. Shani, J. Tjioe, R. Safrina, A. Dwi Wahyono and B. Suryadi, "Smart Grid in ASEAN: Overview and Opportunities to Support the ASEAN Renewable Energy Aspirational Target," Accessed: Sep. 1, 2024. [Online]. Available: https://aseanenergy.org/publications/smart-grid-in-asean-overview-and-opportunities-to-support-the-asean-renewable-energy-aspirational-target/

[29] PLN, "Press Release No. 323.PR/STH.00.01/VI/2023: PLN Segera Gunakan "AMI" Tahun Ini, Meteran Canggih yang Bikin Pelanggan Bisa Monitor Penggunaan Listrik Secara Realtime (in Bahasa

Indonesia)" Accessed: Sep. 2, 2024. [Online]. Available: https://web.pln.co.id/media/siaran-pers/2023/06/pln-segera-gunakan-ami-tahun-ini-meteran-canggih-yang-bikin-pelanggan-bisa-monitor-penggunaan-listrik-secara-realtime

[30] J.S. Jones, "Thailand – lessons from a 116,000 smart meter rollout," Smart Energy International. Accessed: Sep. 2, 2024. [Online]. Available: https://www.smart-energy.com/regional-news/asia/thailand-lessons-from-a-116000-smart-meter-rollout/

[31] N.A. Utama, "ASEAN perspective on grid reliability," ASEAN Centre for Energy. Accessed: Sep. 2, 2024. [Online]. Available: https://aperc.or.jp/file/2024/5/9/S3-3_Dr.Nuki_Agya_Utama.pdf