Developing a National Digitalization Readiness Index for Developing Countries

Sponsor

United Nations Climate Technology Centre and Network

United Nations Environment Programme

(10/2023-05/2024)

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FOREWORD

As the world grapples with the severe impacts of climate change on society and the environment, it is clear that innovative approaches are needed to integrate policy, investment, and technology solutions for sustainable climate actions and infrastructure.

Digitalization offers a promising pathway for economic development and structural transformation, aligning with the global agenda for sustainable development. Utilizing digital tools, particularly in developing countries and Small Island Developing States, has the potential to significantly enhance their capacity to address technology challenges and opportunities for climate adaptation and mitigation.

Despite the numerous benefits of digitalization, there is a considerable need to understand the digital readiness of developing countries. This includes evaluating existing policy frameworks to bridge digital divides, improving climate technology literacy, raising public awareness, and understanding available finance and investment mechanisms.

The project presented in this report aims to establish a comprehensive understanding of the digital capacity (or readiness) of developing countries, with a particular focus on energy infrastructure. The National Digital Readiness Index (NDRI) has been developed to assess key facets of a country's digital readiness, including social, economic, regulatory, and technological aspects. This Index serves as a foundational tool for evaluating and enhancing a country's potential to adopt digital tools and technologies to strengthen its energy technology capacity.

While this report marks an initial step towards visualizing digital readiness in developing countries, it underscores the need for more detailed research to uncover individual countries' and regions' unique characteristics and challenges as they pursue digitalization. Moreover, it highlights the importance of a coordinated approach involving governments, international organizations, and the private sector to ensure inclusive and scalable solutions.

This project was funded by the United Nations Environment Programme and the United Nations Climate Technology Centre and Network.

May 31, 2024

UN CTCN Digitalization Implementation Partners

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Executive Summary

The United Nations Environment Programme hosts the Climate Technology Centre and Network (CTCN), a part of the UN Framework Commission on Climate Change (UNFCCC) Technology Mechanism. The CTCN's mission is to stimulate technology cooperation and enhance the development and transfer of climate technologies to developing countries.

This project focuses on strengthening developing countries' capacity to address technology challenges and opportunities for climate adaptation and mitigation by developing a “National Digital Readiness Index” to evaluate each developing country's potential for applying digital tools to transform its economic, social, and technological systems.

Ultimately, the index should guide the CTCN in promoting access to digital public goods (such as freely available and open-source software, data, and standards) that will enable;

- The design of policies that support climate risk assessments
- Planning for adaptation and resilience at the country level
- Promotion of low-emissions pathways and
- Informing climate investment decisions.

The project applies its development methods to the energy sector to demonstrate how to develop a Digital Readiness Index for developing countries. However, the same approach should be applicable to other transformational sectors, such as the water-food-energy nexus, sustainable mobility, building and infrastructure, and business and industry.

Digitalization has a profound impact on economic growth, particularly in developing countries, by reducing communication costs and enhancing access to global markets. Innovations in mobile technology, artificial intelligence, smart meters, smart buildings, and renewable technologies have expanded access to vital services such as education, communication, banking, and healthcare. This progress has notably improved financial inclusion, especially in rural areas, fostering broader economic participation. Despite these advantages, the full potential of digitalization in developing countries is often curtailed by challenges such as inadequate digital infrastructure, ineffective governance, insufficient policy frameworks, limited skills and training, and gaps in innovation and gender inclusion. Additionally, a significant digital divide persists, characterized by disparities in digital skills and access among different demographic groups, and between urban and rural areas.

Digitalization presents a promising avenue for economic development, structural transformation, and the achievement of the United Nations Sustainable Development Goals (UN SDGs). It plays a crucial role in sectors such as e-commerce, banking, and communications and in driving productivity, economic vitality, and improving quality of life. However, considerable challenges remain, including environmental impacts and the need for supportive policy frameworks to bridge the existing digital divides. Addressing these challenges requires concerted efforts from governments, international organizations, and the private sector to ensure inclusive and sustainable development.

In developing countries, digitalization facilitates the creation of sustainable energy infrastructure by integrating technological advancements with economic, social, and environmental improvements. Robust meta-analyses are crucial to fully understanding the impact of digitalization on energy infrastructure.

Meta-analyses provide a solid statistical base to identify overarching trends and research gaps, thus guiding future inquiries and investments. Employing the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method increases the transparency and integrity of these reviews, allowing for a critical assessment of biases and the validity of findings.

This report details the methodology employed in the project's meta-analysis, following the PRISMA approach and utilizing tools such as VOSviewer for bibliometric mapping to identify core research areas and seminal papers.

Eight pillars are found to be pivotal in assessing the digital readiness of the energy sector in developing countries:

- **Access & Affordability**: Examines the availability and affordability of digital infrastructure, essential for leveraging digital technologies.
- **Technological Innovation:** Focuses on a country's capacity to develop and adopt new technologies crucial for modernizing and enhancing energy systems.
- **Policy and Regulatory Frameworks:** Highlights the importance of supportive policies and regulations that promote investment in digital and energy innovations.
- **Gender and Energy Justice:** Ensures that digitalization efforts support marginalized groups, including women, promoting equitable opportunities in the energy sector.
- **Energy Transition:** Facilitates the shift from traditional to sustainable energy sources, using digital tools to integrate renewable energies and optimize systems.
- **Infrastructure:** Emphasizes the need for robust physical and digital infrastructures to support effective digitalization.
- **Skills and Capacity Building:** Focuses on developing local workforce skills in digital and energy management through targeted education and training programs.
- **Financing Solutions:** Explores financial mechanisms to fund the energy sector's digital infrastructure and technological innovations.

These pillars are analyzed to create a composite "National Digitalization Readiness Index (NDRI)," specifically for developing countries utilizing statistical techniques to compare readiness across countries and identify key differentiators. In this report, a weighted average is derived for each country. Ultimately, this research offers crucial insights into the nexus between digitalization and energy in the developing South, emphasizing the need for further analysis and policy interventions to maximize digitalization's potential for sustainable development.

The design framework for the pillars involved collecting relevant variables for each. A total of 26 variables were identified to validate the 8 core pillars. These variables are consistently available for 80 countries annually. Statistical methods were applied to aggregate these variables into a single score for each country, facilitating cross-country comparisons. Two common statistical methods were explored: the simple additive model and principal component analysis. The simple additive model provided the best results due to its ease of interpretation across different countries. The aggregate scores indicate that countries such as Singapore, the Republic of Korea, the United Arab Emirates, Japan, and Israel have high 'readiness' for digitalizing their energy sectors. Meanwhile, countries like Thailand, Oman, India, Vietnam, Costa Rica, and Kazakhstan are regarded as medium-level, with the remaining countries falling into the low-readiness category.

Nine of the 26 variables were selected to plot a radar chart, with each axis highlighting specific strengths or weaknesses of selected countries. Reviewing the NDRI results, the research team derived insights for preparing digitalization in seven key areas Reviewing the NDRI results, the research team has derived insights for preparing digitalization in seven areas: (1) Global energy transitions and insights, (2) the uneven journey of energy transition, (3) Green Growth as a catalyst, (4) digitization and green energy, (5) bridging the skills and capacity divide, (6) shaping renewable futures with policy and regulation, and (7) smart financing for energy transformation.

Along with the results of NDRI for various countries, the research team has identified applicable options for digitalizing the energy sector, particularly targeting the Republic of Korea and Thailand. First, their energy structure is reviewed to identify their unique characteristics, and second, various digitalization options, including policies and technologies, are reviewed. Using this information, the team has reviewed Korea's case of digitalization and discussed the applicability of these options to Thailand. Moreover, a small group of Koera experts have given comments on the awareness of digitalization at the field level, recognizing success factors, necessary points for improvement, and further challenges for digitalization. Through this process, the research team has identified lessons to emphasize for countries that are willing to digitalize their energy sector.

The project led to several conclusions. One of the significant barriers to digitalization in the energy sector is the lack of infrastructure, both physical and digital. High-speed, wide-coverage internet service is a critical component of digitalization, as is data collection and the organization to apply advanced technologies such as artificial intelligence (AI). In addition, there is a significant gap in the technical expertise required to manage and integrate digital technologies into the existing energy framework. Furthermore, many countries' policies and regulatory environments are not conducive to digital innovation.

Several strategies can be employed to enhance the capacity or 'readiness' of developing countries for digital transformation in the energy sector. International bodies and developed countries can partner with developing countries to share knowledge, technical expertise, and best practices. For this partnership, the developed NDRI may contribute to identifying the current condition of the target country for more efficient and effective cooperation.

A companion report was developed in this project to demonstrate the analysis used to apply the National demonstrating the application of the NDRI. The ***Digitalization Options Handbook for the Energy Sector*** tabulates the policy, strategy, and technology options to implement digitization in the South Korean energy system. The handbook is designed to help stakeholders in developing countries develop their own options considering their country's energy sector's unique characteristics and surrounding environment. The policy and technology options in Korea can be a guide for identifying the major characteristics, conditions, or surrounding environments of other countries but will differ from those of Korea.

Background

The Climate Technology Centre and Network (CTCN), hosted by the United Nations Environment Programme, facilitates the provision of information and knowledge to strengthen the capacity of developing countries to identify, design, and adapt technology solutions tailored to their needs, by fostering collaboration among the global community of climate technology experts, users, decision-makers, technology providers and investors in public and private sectors.

The Third *Programme of Work* (2023-2027) of CTCN aims to enhance transformational impact and scale across its core service areas[1] through two proven technology enablers:

- National Innovation System
- Digitalization

and five system transformation areas:

- Water-Food-Energy Nexus
- Sustainable Mobility
- Buildings and Infrastructure
- Energy Systems
- Business and Industry

Among the two technology enablers, Digitalization draws benefits of existing digital tools to accelerate and amplify impact across the five system transformation areas.

Digitalization, which refers to the integration of digital technologies into everyday life and business, stands as a cornerstone of modern economic growth and societal advancement. At its core, digitalization transforms services or businesses by shifting from non-digital or manual processes to digital ones or by upgrading from older to newer digital technologies. This evolution is powered by leaps in Information and Communication Technology (ICT), the widespread availability of internet services, mobile technology, and advanced data analytics capabilities.

Looking at *energy systems*, digital systems play an increasingly important role across the entire landscape of this transformational area, from energy generation, distribution, and consumption to the agriculture sector, in which digitalisation is becoming essential in both developed and developing countries.

The drive towards digitalization is further motivated by the quest for efficiency, cost reduction, and the need for real-time processing and analysis across various spheres of business and social interaction. The term digitalization "*to describe the manifold sociotechnical phenomena and processes of adopting and using these technologies in broader individual, organizational, and societal contexts*" (Legner et al., 2017), and involves the technical conversion of analog signals into a digital format, leading to binary digits

[1] Core service areas of CTCN include: a) Technical Assistant, b) Knowledge Sharing, and c) Fostering Collaboration between Key Stakeholders.

(Lyytinen et al. 2016; Sandberg et al., 2020). This concept has been central to computer science since the early days of computing.

Image: Dall-e Generate Image of Digitalization of Energy Systems in the Developing Countries, with Emphasis on Several of the United Nations Sustainable Development Goals.

To support CTCN's mandate to respond to country-driven requests on strengthening developing countries' capacity in addressing technology challenges and opportunities for climate change adaptation and mitigation, this project was framed to conduct an in-depth assessment of the countries' digitalization readiness focused on their energy sector. Specifically, the objective of this project was to develop a *National Digitalization Readiness Index* (NDRI) to evaluate the current readiness of developing countries and evaluate the potential of each country to transform its energy infrastructure by applying digital tools.

The NDRI is captured using eight pillars identified using literature meta-analysis and collecting relevant data to define each pillar in the energy context of the countries of developing countries. Each pillar defines a specific aspect of the energy sector in this study context.

Ultimately, the index will be employed to guide the CTCN in promoting access to digital public goods (such as freely available and open-source software, data, and standards) and further enable the design of policies supporting:

- Climate risk assessments
- Planning for adaptation and resilience at the country level
- Promotion of low-emissions pathways
- Informing climate investment decisions.

Combining the foundational pillars of renewable energy policy with the innovative NDRI framework, this comprehensive approach ensures a robust strategy for leveraging technology in tackling climate change challenges in developing countries.

Approach

Specific tasks undertaken within the frame of this project, shown in Figure 1, include:

1. Systematic literature review to gather data on measurable variables
    a. Systematic literature review (Meta-analysis)
    b. Identification of measurable variables and assessment of their qualities
    c. Identification of available data for NDRI.
2. Development of the pillars
    a. Identification of methods to create pillars (including data collection)
    b. Application of method and validation
    c. Synthesis of pillars

Application of the NDRI to the Energy Sector

a. Characterization of Energy Systems
b. Examination of Existing Energy Infrastructure
c. Evaluation of Renewable Energy Sources

In this report, the term *Digitalization* is used, which goes beyond mere digitization by leveraging digital tools to gather data, analyze trends, and improve decision-making processes.

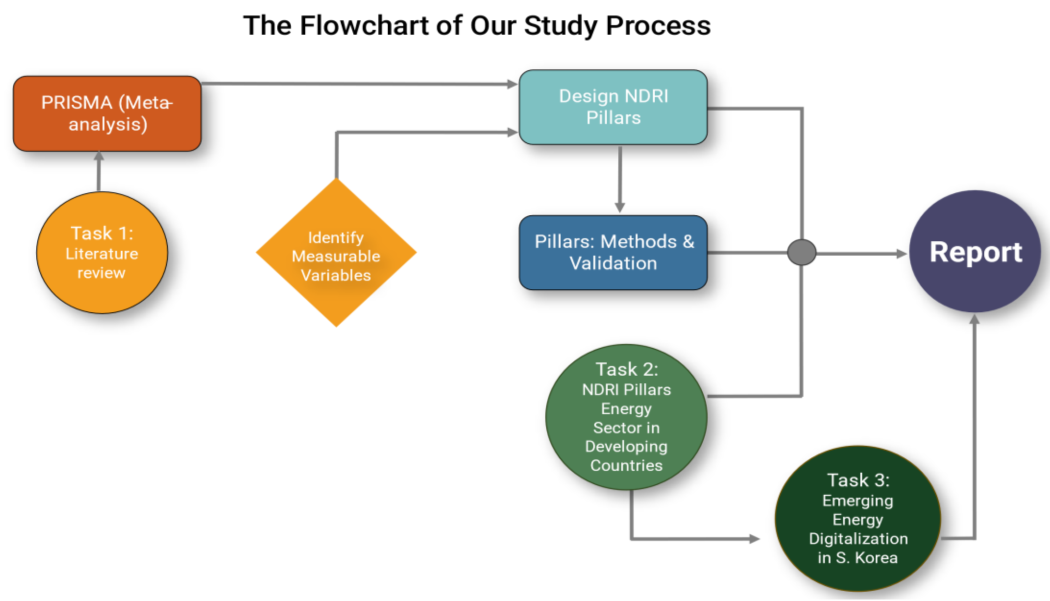

FIGURE 1 THE STUDY FLOWCHART WITH THREE TASKS AND SUB-TASKS.

This report is organized as follows:

Section 1, Digitization, presents the historical trajectory of digitalization, delineated through distinct technological waves, and illustrates a growing global divide in digital access, particularly between the Global North and South. This section then discusses the digital evolution's support for international climate goals and its close alignment with the Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure), SDG 10 (Reduced Inequalities), and SDG 13 (Climate Action).

Section 2, Methodology, describes the application of the PRISMA methodology in this study. This methodology ensures a rigorous, transparent, and replicable approach to synthesizing the existing body of research. It explains how PRISMA helped select eight critical pillars for creating the national digitalization index for renewable energy in the Developing South.

Section 3, Identify Relevant Variables, details the data collection process for these eight pillars and the creation of a composite National Digitalization for Renewable Energy Index (NDRI).

Section 4, Application and Insights, discusses the insights gained from the analysis and visualizations, emphasizing their implications.

Section 5, South Korea- Emerging Energy Tech Aiding in Transition, discusses the case study undertaken in South Korea, where emerging digital technologies are involved in the energy transition. The following section provides the conclusion. The Appendices provide additional data and methodology details, as well as statistical techniques used in the study.

Team

This project has been conducted by a multidisciplinary team of scientists and experts representing non-Annex I and Annex I countries, and the private sector.

National Institute of Green Technology (Republic of Korea)

The National Institute of Green Technology is a government-affiliated research institute under the Ministry of Science & ICT (MSIT) that provides national green technology R&D policies and coordinates related domestic/international organizations to support sustainable development of other countries based on green/climate change technologies.

The George Washington University Environmental and Energy Management Institute (United States)

The GW Environmental and Energy Management Institute conducts state-of-the-art, relevant research to promote graduate and professional education and undertakes service activities that are pertinent to the application and implementation of national and international standards for the management of environmental, energy, and sustainability challenges facing organizations and communities throughout the Nation and the world.

Chatmine Technologies (United States)

Chatmine Technologies is a science-based and woman-led, social enterprise that utilizes Big Data Analytics and AI as enablers for translating science and policy to pragmatic solutions addressing sustainable development and investments
challenges.

1 Digitalization - Past Advancements and Future Outlook

The historical trajectory of the digital revolution, marked by distinct waves of technological advancements, sheds light on the global disparity in digital access and infrastructure, particularly between the global North and South. These waves can be described, each with its distinct focus. The First Wave is the Mainframe Era (1950s-1970s), where the focus was on large, centralized computing systems accessible to few, primarily for scientific and government applications. This led to the second wave focused on the personal computer (1970s-1990s). The rise of personal computers (PCs) made computing accessible to a wider audience, fostering individual productivity and communication.

Forecasted Global Mobile 5G subscriptions (2019-2028)

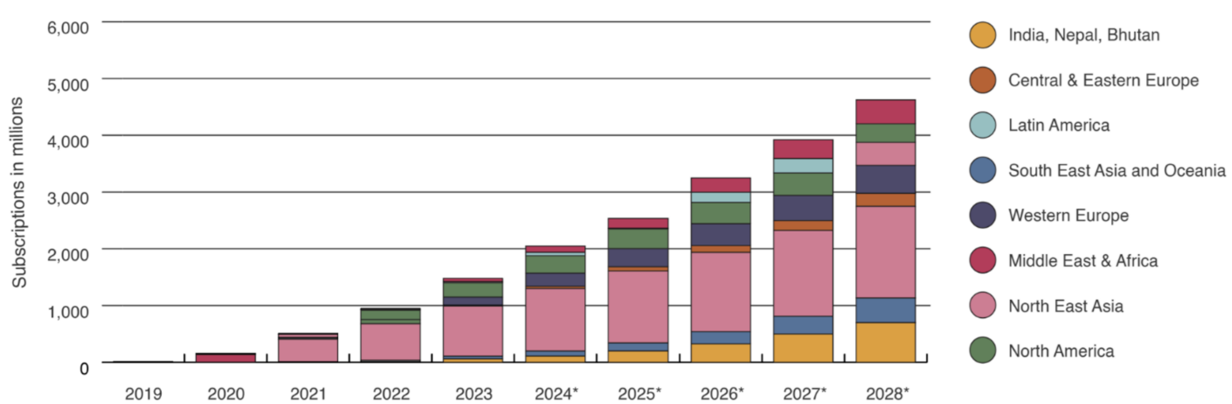

Figure 2 THE FORECASTED NUMBER OF MOBILE 5G SUBSCRIPTIONS WORLDWIDE BY REGION FROM 2019 TO 2028(IN MILLIONS)

The PC era provided the hardware infrastructure necessary for the development of user-friendly interfaces and software applications. Statista[2] reported that in 2019, about half of households globally had a computer, with higher rates in developed countries. Despite the rise in PC ownership, global sales have been declining as smartphones gain popularity. The gaming industry is driving innovation in PC design, which may translate into energy markets offering simulation, forecasting, efficiency and optimization (Makris et al., 2018; Johnson et al., 2017; Fox-Penner 2020). PCs are used for various activities, but smartphones are increasingly preferred for many tasks. The connectivity advantage of PCs may diminish with the growth of mobile broadband, particularly with 5G technology.

Figure 2 shows the forecasted growth of Global 5G mobile subscriptions that are expected to significantly increase from 2019 to 2028, from over 12 million to over 4.5 billion subscriptions, respectively. Regions such as Northeast Asia, Southeast Asia, India, Nepal, and Bhutan are expected to have the highest

[2]https://www.statista.com/statistics/748551/worldwide-households-with-computer/#:~:text=In%202019%2C%20almost%20half%20of,was%20closer%20to%2080%20percent.

number of subscriptions. The fifth generation (5G) technology is projected to drive the growth of the Internet of Things (IoT) market in the upcoming years by enabling faster data speeds, ultra-low latency, and increased availability for connecting machines and devices. By 2023, connected cars are anticipated to have the largest installed base of 5G IoT endpoints worldwide, with over 19 million installed endpoints, including in India and China.

The third wave was the Internet era (1990s-present), where the Internet revolutionized global communication and information sharing, facilitating data exchange and fostering global collaboration. The interconnectedness of the Internet age provided the massive datasets and communication infrastructure needed for significant advances in several fields, including commerce, trade, agriculture, and government operations. This phase of the internet is still happening in developing countries, rapidly replaced by social media via mobile phones. The fourth wave is the mobile and social media era (2000s-present), in which the proliferation of mobile devices and social media platforms transform how individuals access information, connect with others, and consume content. The explosion of data generated through mobile devices and social media interactions has further fueled AI development, particularly in areas like machine learning and personalization algorithms.

The fourth wave of digitalization is allowing computers to understand and generate human language. AI (Artificial Intelligence) is playing an increasingly prominent role in various domains, including machine learning (enabling computers to learn from data without explicit programming), natural language processing (allowing computers to understand and generate human language), computer vision (equipping machines with the ability to "see" and interpret visual information) and large language models (revolutionizing marketing, education, and other fields with automation, personalization, and content generation). The US and China are the leading players in this field. AI is currently being utilized in diverse areas such as performing repetitive tasks efficiently, freeing up human time and resources (writing, administrative work, etc.), assisting healthcare professionals in analyzing data and making informed decisions, and identifying and preventing fraudulent activities in finance and other sectors. Experts (references) project continued advancements in AI capabilities, leading to further integration into our lives. However, ethical considerations, potential job displacement, and the responsible development of AI remain crucial aspects of navigating this technological advancement in digitalization. AI is dominant in China,[3] where the market size is expected to show an annual growth rate (CAGR 2024-2030) of 17.95%, resulting in a market volume of US$104.70bn by 2030. In global comparison, the largest market size will be in the United States (US$106.50bn in 2024).

1.1 Comparing Global North and South in Digitalization

The United States, the European Union, and some members of the Organization for Economic Co-operation and Development (OECD) are at the forefront of global digitalization efforts, boasting a well-developed digital infrastructure, advanced technological capabilities, and a digitally literate population. These countries have invested in R&D and have strong investments in digital infrastructure development

[3] https://www.statista.com/outlook/tmo/artificial-intelligence/china#market-size

and initiatives, aiming to bridge the digital divide and promote digital inclusion. The pace and scope of digitalization differ across the global north and global south. The focus of this report is on developing countries or the developing South. Figure 3 shows the global economy where the two developed regions labeled as 1 and 2 are differentiated from developing economies.

Global Economy – Classes of Developing Countries

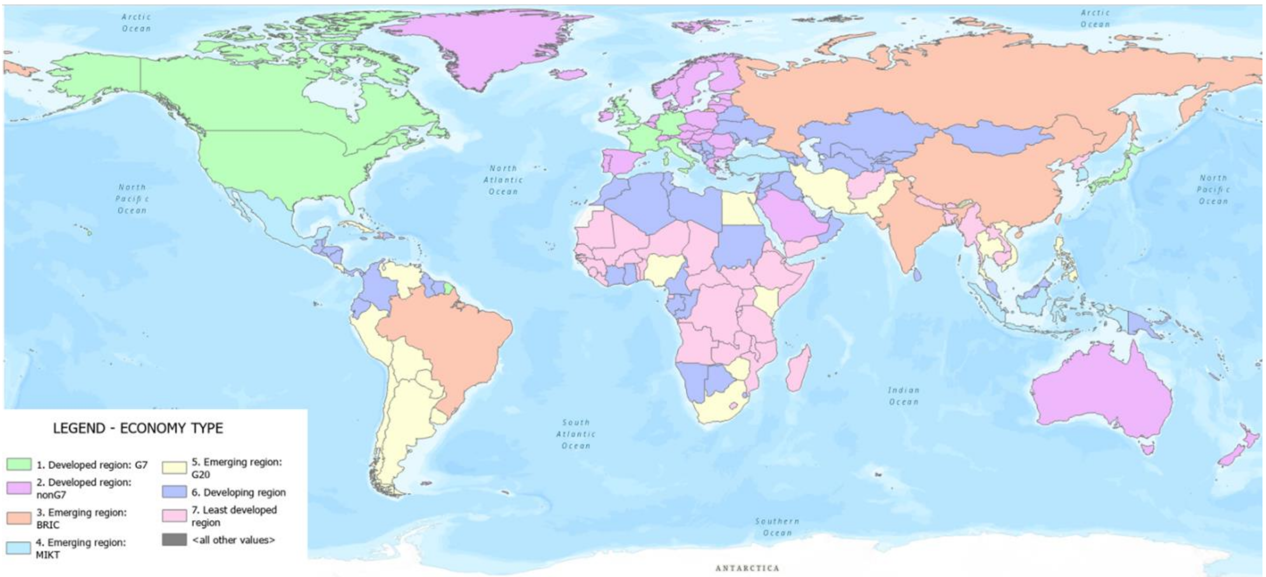

FIGURE 3 DEVELOPING ECONOMIES IN ASIA, LATIN AMERICAN, AFRICA AND EASTERN EUROPE DENOTED AS CLASSES 3-7 IN THE LEGEND (SOURCE: WORLD BANK).

In Figure 3, developing regions are differentiated from the emerging regions, e.g., BRIC (including Brazil, Russia, India, and China) and MIKT (including Mexico, Indonesia, S. Korea, and Turkey). While Japan belongs to the group of G7 countries (United States, Canada, UK, France, Italy, and Germany), it is included in the current study to provide a contrasting example in Asia. Saudi Arabia is classified as a non-G7 developed region.

Digitalization has emerged as a transformative force in global economies, reshaping industries, labor markets, and the very essence of economic transactions and governance. The adoption of digital technologies fosters economic growth by enhancing e-commerce, banking operations, and communications, contributing to productivity and economic expansion. However, a clear divergence exists between developed and developing nations (Matthess and Kunkel, 2020). The former not only utilize but also produce digital technologies and have mature infrastructures that amplify the benefits of ICT investments. Conversely, developing countries, particularly those in SSA, face information costs and infrastructural deficiencies that hinder the efficient adoption and utilization of ICT. Digitalization can influence sectoral productivity and labor movements, potentially leading to unequal benefits and risks such as skill bias (Matthess and Kunkel, 2020). It also mentions opportunities for developing countries to diversify in traded goods and services through digitalization but raises concerns about their positioning in global markets and value chains compared to developed countries. Gender disparities in digitalization need to be addressed to create more inclusive, sustainable economies (Jamil, 2021; Goel & Vishnoi, 2022). Figure 4[4] shows mobile cellular subscriptions. Many countries in Africa and India have shown rapid increases in cell phone penetration.

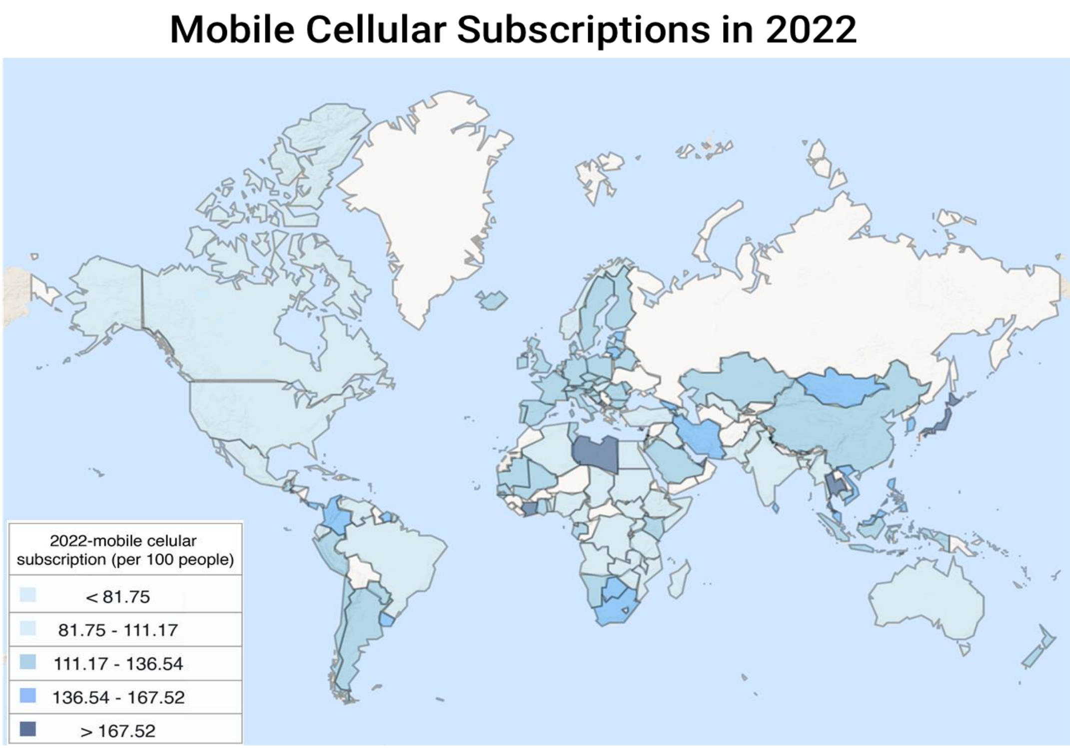

FIGURE 4 MOBILE CELLULAR SUBSCRIPTIONS (PER 100 PEOPLE) IN 2022 .

1.2. Research Themes

Digitalization plays a pivotal role in economic growth, especially in developing countries, by reducing communication costs and facilitating access to global markets. Mobile technology innovations have spurred GDP growth in African countries and profoundly changed people's lives by providing essential services like banking and health care. Nevertheless, the potential of digitalization in driving economic growth in developing countries is often hampered by extractive institutions and a lack of competitive markets. The digital divide remains a significant global issue (Bagchi, 2005; Murthy et al., 2021; Schwab, 2017), with an estimated 5.3 billion people worldwide using the Internet, leaving 2.7 billion still offline.

This divide is even more pronounced in the developing South, particularly in Africa, where only 40% of the population has Internet access, and in the least developed countries (LDCs) and landlocked developing countries (LLDCs), with a mere 36% connectivity rate. This disparity underscores the urgent

[4] https://data.worldbank.org/indicator/IT.CEL.SETS.P2

need for digitalization to foster inclusive and sustainable economic growth and development. Prior research highlights several key areas where digitalization significantly impacts developing countries:

Economic Prosperity through Structural Change: Developing countries are exploring digital technologies to drive economic transformation towards prosperity, moving beyond traditional agricultural and industrial sectors. The integration of digital technologies is seen as a path to enhanced productivity, job creation, and a transition to knowledge-based economies. However, the impacts of digitalization on structural change are complex and multifaceted, requiring further investigation to fully understand its potential and limitations (Matthess & Kunkel, 2020).

Economic Growth through Digitalization and Foreign Direct Investment: Evidence from developed countries indicates that digitalization, alongside foreign direct investment, significantly contributes to economic growth. Developing countries can learn from these experiences, integrating digitalization into their economic strategies to boost growth and welfare (Kusairi et al., 2023).

Digitalization and Environmental Sustainability: Digital technologies offer opportunities for environmental sustainability. They enable more efficient resource use and contribute to the reduction of carbon footprints through smarter infrastructure and reduced material consumption. However, the environmental impact of digitalization is a double-edged sword, as the production and operation of digital technologies themselves consume significant amounts of energy and resources (Myovella et al., 2020).

1.3. Case Study: Sub-Saharan Africa

The transformative potential of digital technologies in developing countries, particularly in Sub-Saharan Africa (SSA), is evident in improved accessibility and financial inclusion facilitated by mobile banking, alongside the burgeoning roles of e-commerce and telecommunications. The impact of digitalization on economic growth in SSA, though promising, highlights a stark divergence from OECD economies (Odhiambo, 2022; Ofori and Asongu, 2021; Wentrup et al., 2016). While developed nations not only consume but also produce digital technologies bolstered by mature infrastructures, SSA faces infrastructural and cost barriers that impede efficient ICT adoption and utilization. Yet, digitalization's role in SSA is increasingly significant, enhancing business innovation and offering solutions to logistical challenges through improved trade efficiency and infrastructure development. Moreover, the penetration of ICT, particularly mobile technology, alters the dynamics of foreign investment and economic growth in SSA, emphasizing the critical role of internet-centric factors. Despite the growth in internet users driven by algorithmic capitalism, the digital divide, especially the urban-rural gap, remains pronounced, calling for targeted policy interventions.

While digitalization has the potential to transform economies and societies, bridging the digital divide, particularly in regions like the SSA, requires addressing the underlying challenges of high ICT costs, infrastructural deficiencies, and institutional barriers. Mobile banking represents a bright spot in this landscape, offering a pathway to financial inclusion and economic participation for the unbanked population. However, realizing the full benefits of digitalization in developing countries necessitates concerted efforts to improve infrastructure, reduce costs, and foster an enabling environment for digital innovations.

Despite the leapfrogging in ICT adoption in Africa, a significant digital divide persists, exacerbated by disparities in digital skills and access between different demographic groups and urban-rural areas. Mobile banking, exemplified by services like M-Pesa in Kenya, has emerged as a critical tool for financial inclusion, enabling individuals, especially in rural areas, to access financial services and participate in the economy more fully. Sub-Saharan Africa, while experiencing unprecedented access to mobile communications since 2000, has lagged in internet usage, with internet penetration standing at 24.4% in 2018 (ITU, 2018[5]). High costs, poor infrastructure, and inadequate energy supplies have been major barriers to digital readiness in the region.

To summarize, digitalization plays a pivotal role in economic growth, especially in developing countries, by reducing communication costs and facilitating access to global markets. Innovations in mobile technology have not only spurred GDP growth in African countries but have also profoundly changed people's lives by providing essential services like banking and health care. Nevertheless, the potential of digitalization to drive economic growth in developing countries is often hampered by extractive institutions and a lack of competitive markets. Despite the leapfrogging in ICT adoption in Africa, a significant digital divide persists, exacerbated by disparities in digital skills and access between different demographic groups and urban-rural areas. Mobile banking, exemplified by services like M-Pesa in Kenya (McBride & Liyala, 2023) has emerged as a critical tool for financial inclusion, enabling individuals, especially in rural areas, to access financial services and participate in the economy more fully.

1.4. Alignment with the UN Sustainable Development Goals (SDGs)

For the developing South, digitalization offers a promising path toward economic development, structural change, and the attainment of the United Nations Sustainable Development Goals (UN SDGs). It empowers economic growth by enhancing sectors such as e-commerce, banking, and communication, thereby contributing to increased productivity and expansion. Despite the potential benefits, challenges such as digital divides, environmental impacts, and the need for supportive policy frameworks remain. Addressing these challenges requires a concerted effort from governments, international organizations, and the private sector to ensure that digitalization leads to inclusive and sustainable development. Digitalization in the developing South aligns with several UN SDGs, including:

Gender Equality (SDG 5): Policies supporting digital employment and valuing women's participation in the digital economy are essential for achieving gender equality (SDG 5) and supporting economic growth. Figure 5 shows the global gender inequality index, with higher numbers of inequality in regions including

[5] https://www.itu.int/en/mediacentre/Pages/2018-PR40.aspx

Mali, Niger, Chad, and the Democratic Republic of Congo in Africa, Afghanistan, and Papua New Guinea in Asia. Women with digital work experience, particularly in China, have shown that digital employment policies and the value attributed to digital work significantly predict women's intentions to engage in digital employment. This suggests that well-designed digital employment policies can encourage more women to participate in the digital economy, contributing to broader economic development goals (Wang et al., 2020; 2023).

Gender Inequality Index (2020)

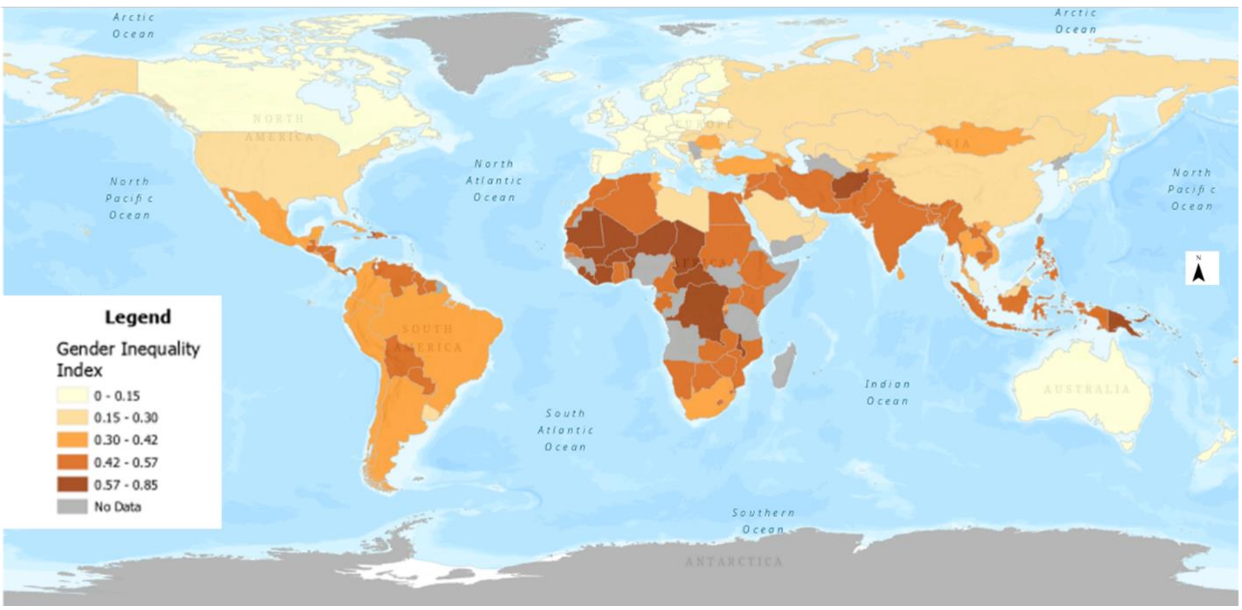

Figure 5 GENDER INEQUALITY INDEX IN 2020 WHERE DARKER COLORS (0.57-0.85) HAVE THE WORST INEQUITY.

SDG 9 (Industry, Innovation, and Infrastructure): Promotes infrastructure development, industrialization, and innovation, with digitalization acting as a catalyst for achieving these targets. The adoption of digital technologies under SDG 9 is transforming industries by creating new job opportunities in the digital economy. However, this transition also presents challenges, such as the need for upskilling and reskilling workers to meet the demands of new digital roles. Countries are encouraged to invest in education and training to support workforce adaptation to these changes. Technological innovation positively impacts energy efficiency, which is crucial for sustainable industrial processes in the Industry 4.0 era, particularly in the Middle East and North African (MENA) countries. This innovation can lead to economic growth while also promoting sustainable development goals (Kihombo eta l., 2021; Chen et al., 2021).

Digital social innovation plays a significant role in fostering job creation and economic growth, especially in developing countries. By leveraging digital technologies, new forms of entrepreneurship and business models are emerging, offering solutions to social problems and contributing to sustainable economic development. This innovation is crucial for achieving SDG 9 by promoting digital inclusion and enabling access to digital services and employment opportunities (Qureshi et al., 2021). Digitalization offers new pathways for women's employment, potentially reducing gender disparities in the labor market.

Connection SDG 5 and 9

- The acquisition of digital skills and competencies is strongly correlated with women's social inclusion in the labor market. Institutional measures and policies set to develop digital infrastructure, networks, and legal frameworks for digitization are vital for national frameworks supporting the digital economy. These policies are essential for empowering women and ensuring their participation in the labor market, thereby advancing toward achieving SDG 9 and other related sustainable development goals (Livingstone et al., 2023; Correa et al., 2020).
- Implementing SDG 9 has significant implications for jobs, women, and employment, particularly in the digital economy. While digitalization presents opportunities for economic growth and innovation, it also poses challenges that require targeted policies and investments in education and training. Promoting women's participation in the digital economy through supportive policies and enhancing digital skills are crucial steps toward achieving inclusive and sustainable development.

SDG 10 (Reduced Inequalities): Aims to reduce inequality within and among countries, which digitalization can facilitate by providing equal access to information and opportunities. Sustainable Development Goal 10 (SDG 10) aims to reduce inequalities within and among countries. Digitalization can significantly contribute to this goal by offering equal access to information and opportunities, enhancing inclusivity, and fostering economic and social development across diverse communities.

Digital health technologies can provide people with communication or swallowing disabilities greater access to self-determined healthcare, thereby advancing SDG 10's aim of reducing inequalities and supporting SDG 3's goal of good health and well-being. Increased access to multimodal communication strategies and user-centered co-design that enables digital health autonomy can progress toward reduced inequalities (Perera et al., 2023; Bachmann et al., 2022).

Forms of social, human, and digital mobility can contribute to reduced inequalities and positive development outcomes. An approach prioritizing equality of opportunity over equality of outcomes and focusing on mobility equity encompasses people's equal capacity and freedom to be mobile in empowering ways. This includes ensuring the equal and inclusive regulation of mobility in all its forms, including digital mobility, to reduce inequalities within and among countries (Dar & Ahmad, 2022; Hackl, 2018).

<u>Digital social innovation (DSI):</u> This utilizes digital technologies for developing innovative solutions to social problems, addressing issues like poverty, inequality, social exclusion, and marginalization. DSI initiatives, often led by social entrepreneurs, government agencies, NGOs, or corporations under corporate social responsibilities, leverage digital platforms to provide access to information, services, and opportunities for marginalized communities. This directly contributes to reducing inequalities and achieving SDG 10 by facilitating equitable participation in the digital society and economy (Qureshi et al., 2021).

Promoting digital education aligns with **SDG 4** (**Quality Education**) and indirectly supports SDG 10 by enabling equal opportunities for all children, regardless of gender or socio-economic status. Digital education technologies can improve essential skills like collaboration, problem-solving, and global awareness, thereby reducing inequalities in access to quality education and information (Ricard et al., 2020; Ingram et al., 2022).

SDG 17 (Partnerships for the Goals): Encourages effective partnerships and cooperation, which are essential for sharing digital technologies and knowledge among countries. Sustainable Development Goal 17 (SDG 17), titled "Partnerships for the Goals," underscores the vital role of building effective partnerships and cooperation at global, regional, national, and local levels to achieve sustainable development. This goal highlights the importance of leveraging digital technologies and fostering knowledge sharing between countries to ensure the successful implementation of all 17 SDGs. Here, we explore how digitalization supports SDG 17 and its impacts on fostering international collaboration:

Strengthening Global Partnerships through Digitalization: SDG 17 advocates for enhancing North-South, South-South, and triangular regional and international cooperation on and access to science, technology, and innovation. SDG 17 identifies the need for partnerships that can provide such support, thereby fostering the development of innovative digital products and services that contribute to achieving the SDGs (Piaggesi & Landázuri, 2021). Digital technologies, including the internet and mobile platforms, enable the sharing of knowledge, resources, and best practices across borders more efficiently than ever before. This digital connectivity facilitates the formation of partnerships that can address global challenges such as climate change, poverty, and inequality more effectively (Cooper & French, 2018).

The integration of digital transformation (DX) initiatives with the SDGs within enterprises emphasizes the need for a unified approach to leveraging digital technologies for sustainable development. A digital SDGs framework facilitates the combination of knowledge for SDGs and DX, streamlining efforts towards achieving the goals while maintaining a competitive advantage through digital innovation (Yamamoto, 2022). The pandemic has highlighted the critical role of digital technologies in ensuring continuity in education, healthcare, and commerce during crises. A systems thinking approach that incorporates digital connection as an integral component of the SDGs can foster inclusivity and resilience, enabling all segments of society to benefit from digital advancements. This approach suggests the need for a new, dedicated SDG focused on digital connectivity to ensure equitable distribution of digital resources (Clark, 2022).

In conclusion, SDG 17's focus on partnerships is instrumental in mobilizing digital technologies and knowledge sharing to achieve the Sustainable Development Goals. Digitalization plays a critical role in facilitating these partnerships, enhancing international cooperation, and ensuring that the benefits of technological advancements are shared globally, thereby contributing to sustainable and inclusive development.

1.5. Compare and Contrast to Developed Countries in the Energy Sector.

Global energy consumption encompasses a comprehensive measure of energy use across various sectors, including electricity, transportation, and heating. An interactive chart provides a country-wise breakdown of primary energy consumption, showcasing the total energy footprint of nations around the globe. We are using the following resources to discuss the significance of the energy sector in the developing south, using data from the World Bank, Our World in Data, IEA, and World Economic Forum, as well as scientific journals.

Focusing now on electricity production, we delve into a specific segment of the previously discussed energy landscape. While energy consumption at large includes electricity alongside transportation and heating, it's essential to distinguish that electricity represents just a fraction of a country's overall energy use. Figure 6[6] displays "Energy use per person," which is measured in kilowatt-hours (kWh) per person. This metric refers to the primary energy consumption per individual using the substitution method. The data for this graph is sourced from the U.S. Energy Information Administration (2023). The timeline spans from 1965 to around 2022, illustrating long-term trends in energy consumption for each country. The United States leads in energy use per person, with a peak and a slight decline over time, but still remaining significantly higher than other countries listed. South Korea shows a steady and sharp increase over time, indicating a growing energy consumption per capita. France, China, and the United Kingdom have displayed moderate increases in energy use per person over the years. Thailand and India show gradual increases from a lower baseline, suggesting that their per capita energy use is rising but is still much lower than the other nations on the graph. It's important to note the varying starting points for each country, reflecting different levels of energy consumption in the baseline year of 1965.

The trajectory of global energy and climate initiatives is progressively reliant on policy choices within emerging and developing nations. This diverse category encompasses regions from Africa to Latin America, including least developed to middle-income countries, burgeoning demand leaders like India and Indonesia, and key energy producers. These nations typically exhibit low per capita energy consumption, yet their expanding economies and increasing wealth signal substantial growth potential. The pivotal challenge lies in identifying development frameworks that fulfill citizen aspirations without replicating the carbon-intensive paths previously taken by other economies. The decreasing costs of essential clean energy technologies present a significant chance to forge a new, less carbon-intensive growth trajectory. Failure to seize this clean energy opportunity in these regions could critically undermine global efforts to combat climate change and achieve sustainable development objectives.

[6] The data for this graph is sourced from the U.S. Energy Information Administration (2023) and the Energy Institute - Statistical Review of World Energy (2023). The population data is based on various sources from 2023. The graph is accredited to OurWorldInData.org with a Creative Commons BY license.

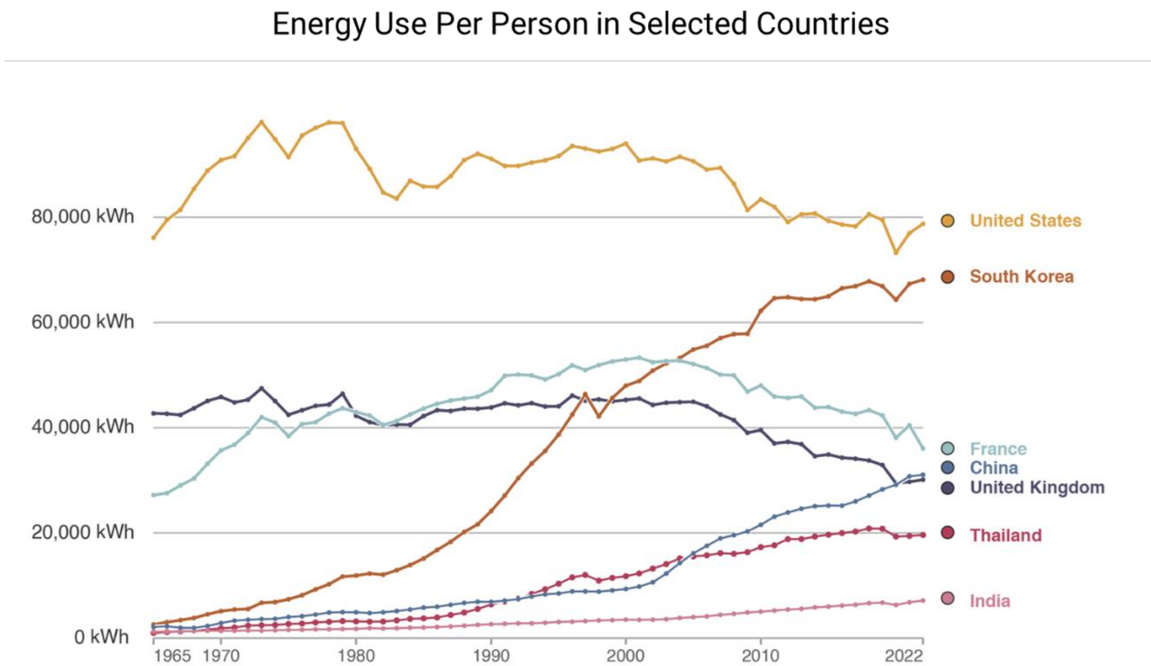

FIGURE 6 ENERGY USE PER PERSON MEASURED IN KILOWATT-HOURS (KWH) PER PERSON.

The investment gap in clean energy has been exacerbated by the COVID-19 pandemic, with developing and emerging economies housing two-thirds of the global populace yet attracting a mere fraction of clean energy investments. Despite accounting for a small portion of global financial wealth, these regions have witnessed a 20% decline in energy sector investments since 2016, exacerbated by financing challenges and the pandemic's economic repercussions. This financial shortfall threatens the swift and sustainable recovery needed in these areas.

Current development trends in these economies indicate a surge in emissions, expected to increase by 5 gigatonnes (Gt) over the next two decades under existing policy scenarios. Conversely, emissions are projected to decrease in advanced economies and stabilize in China. However, a significant uptick in clean energy investments could alter this trajectory, necessitating a more than sevenfold increase in annual clean energy capital to over USD 1 trillion by the end of the 2020s. Achieving this would facilitate a move towards net-zero emissions by 2050, bringing extensive economic and societal advantages contingent upon substantial improvements in both domestic and international investment climates.

Transitioning towards sustainable development hinges on the enhancement of clean power, grid infrastructure, and energy efficiency. As electricity consumption in these economies is poised to triple compared to advanced economies, the affordability of wind and solar power positions them as preferable options. Investments in these areas, alongside energy efficiency and electrification efforts, are crucial for substantial emissions reductions to meet international climate targets. Concurrently, addressing the broader aspects of rapidly urbanizing and industrializing economies is essential. This includes transitioning fuels and sectors like construction and shipping, necessitating efficiency improvements and fuel shifts towards cleaner alternatives.

The cost-effectiveness of emissions reduction in these regions is notable, with costs estimated at approximately half those in advanced economies. Therefore, investing in clean energy within developing and emerging economies represents an efficient strategy for climate change mitigation. However, achieving this demands a focus on accessibility and affordability alongside substantial increases in public and private capital. The need for an international catalyst to amplify clean energy investments is critical, emphasizing the importance of a coordinated global approach to finance the energy transition in these economies.

A comprehensive set of priority actions has been outlined to mobilize the necessary capital for clean energy transitions, including bolstering international support, addressing investment risks, and scaling up private capital for clean energy sectors. These actions aim to foster a conducive environment for clean energy projects, enhance local access to capital, and incentivize sustainable investments, thereby paving the way for a transformative energy transition in emerging and developing economies.

1.6. Discuss the Urgency of Climate Action and the Potential of Digitalization for a Cleaner Energy Sector, Particularly in Developing Countries.

The energy sector faces the dual challenges of decarbonization and extending access to modern energy services. Digital technologies offer pathways to enhance climate resilience and ensure energy delivery at the lowest cost. This section explores the digital transformation in the energy industry, particularly in electricity networks, driven by technology advances, cost reductions, and widespread connectivity. Investments in digital grid technologies and electric vehicle charging infrastructure underscore the potential of digital innovations to address climate change and support clean energy transitions.

The energy sector stands at a crucial juncture, facing the dual challenges of decarbonization and extending access to modern energy services, especially to underserved communities in the developing south. Digital technologies emerge as a vital enabler in this context, offering pathways to enhance climate resilience and ensure the delivery of energy at the lowest cost. Digital technologies and data have significant potential to speed up clean energy transitions in the energy sector. They can assist in integrating more renewable energy sources into electricity systems, enhance grid reliability, improve energy efficiency in end-use sectors, and reduce emissions. Additionally, digital services like video conferencing provide low-emission travel alternatives and promote a shift towards low-emission choices.

Recent years have witnessed a rapid digital transformation in the energy industry, particularly in electricity networks, driven by advances in technology, cost reductions, and widespread connectivity. Investments in digital grid technologies have surged by over 50% since 2015 and are projected to constitute 19% of total grid investment by 2023. The distribution segment has become a key focus, accounting for over 75% of digital expenditure. Notably, investments in electric vehicle charging infrastructure doubled in 2022 compared to the previous year. Digital innovations hold the key to addressing some of the most persistent problems related to climate change, a sentiment echoed by George, Merrill, and Schaerbeek (2021). According to a report by the World Economic Forum (WEF), created in partnership with PwC, titled "Harnessing Technology for the Global Goals [7]," digital advancements are pivotal in bolstering our defenses against climate-induced hazards, cutting down carbon emissions, and facilitating the journey towards achieving a net-zero carbon footprint. This report underscores the potential of digital solutions to revolutionize and streamline processes across sectors such as industry, agriculture, and manufacturing through automation. It also highlights the promise of Artificial Intelligence (AI) in slashing global emissions by 4% by the year 2030, as stated by the World Economic Forum & PwC (2021).

The push for renewable energy sources has seen a significant uptick. According to a report by the International Renewable Energy Agency (IRENA) in 2021[8], employment in sustainable and cleaner energy sectors, particularly in solar and wind, has been growing rapidly year after year. This trend of adopting more environmentally friendly energy practices is evident across various industries engaged in producing and utilizing technological products and services. Studies have shown that stakeholder conviction in energy management can lead to greater participation in Green Information Systems/Technology (IS/IT) initiatives (Wright & Nyberg, 2015; Nyberg & Wright, 2022). In the management of workplace infrastructures, the use of sensors and actuators for managing water and energy in smart buildings (including restrooms, ventilation, and air quality) and in smart devices (such as air conditioners and lighting) has been acknowledged for its positive environmental impact (Zarindast, Sharma, & Wood, 2021).

Several international initiatives are working to accelerate the adoption of digitalization in the energy sector. These initiatives include:

- The International Energy Agency (IEA) Digital Demand Driven Electricity Networks (3DEN)[9] The initiative provides analysis and policy guidance for emerging economies on digitalization for power system decarbonization and resilience. It includes a smart grid pilot program administered by UNEP and funded by the Italian Government. The IEA 3DEN initiative also launched a significant report, "Unlocking Smart Grid Opportunities in Emerging Markets and Developing Economies," during a special event in June 2023.

    - 3DEN contributes to and works in coordination with the IEA Clean Energy Transitions Programme (CETP)[10], which The CETP focuses on three pillars: accelerating national transitions, multilateral coordination, and enabling global energy dialogue.

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[7] https://www3.weforum.org/docs/WEF_Harnessing_Technology_for_the_Global_Goals_2021.pdf
[8] https://www.irena.org/publications/2021/Aug/Renewable-energy-statistics-2021
[9] https://www.iea.org/programmes/digital-demand-driven-electricity-networks-initiative
[10] https://www.iea.org/programmes/clean-energy-transitions-programme

- The IEA Technology Collaboration Programmes (TCPs)[11] are informing policymaking related to digitalization to speed up clean, efficient, and secure energy transitions, focusing on areas such as smart grids, user-centered energy systems, electronic devices, and networks, industry, and buildings.
- The Mission Innovation (MI)[12] Green Powered Future Mission aims to demonstrate that by 2030 power systems can effectively integrate up to 100% variable renewables, with digitalization playing a key role.
- The Energy Efficiency Hub's Digitalization Working Group[13] is gathering best practices on policies and measures related to digitalization.

Despite these advancements, international bodies such as the IEA and the United Nations Environment Programme (UNEP) highlight that policymakers and industry stakeholders must intensify their efforts to fully leverage digitalization for accelerating clean energy transitions. This entails implementing supportive standards, policies, and regulations that prioritize innovation and interoperability while addressing cybersecurity and data privacy risks.

To summarize, the urgency of climate action, particularly in developing countries, underscores the potential of digitalization to support a cleaner energy sector. Digital technologies and data can accelerate clean energy transitions, integrate renewable energy sources, improve grid reliability, and promote low-emission choices. International initiatives aim to accelerate digitalization in the energy sector, highlighting the need for supportive policies and regulations to leverage digitalization for clean energy transitions fully.

2. Methodology

Digitalization plays a transformative role in enabling a sustainable energy infrastructure in developing countries (encompassing regions such as Africa, Latin America, and Asia) by bridging technological advancements with significant strides in economic, social, and environmental sectors. In order to attain a comprehensive understanding of the impact of digitalization on the energy infrastructure in these regions, conducting meta-analyses is imperative for drawing reliable and comprehensive conclusions from a wide range of studies. Such analyses consolidate evidence from key decision-makers and stakeholders, including planners, policymakers and regulators, investors, and researchers, aiming to minimize bias and bolster the validity of findings by amalgamating all pertinent data.

Meta-analysis enhances the statistical foundation necessary to unearth overarching trends and pinpoint well-researched areas and consensus points while identifying research gaps and thereby informing future inquiries and investments. However, the methodology employed in these analyses must be rigorous to prevent inaccuracies. While meta-analysis has its merits, it also harbors limitations, such as

[11] https://www.iea.org/about/technology-collaboration
[12] The Mission Innovation (MI) Green Powered Future Mission
[13] https://energyefficiencyhub.org/

a predisposition towards publishing positive outcomes and potentially skewing the overall insights. Clearly, recognizing both the successes and setbacks in digitalization efforts is crucial for achieving a balanced and more realistic perspective on the role of digitalization in enabling a sustainable energy infrastructure in developing countries. Our methodology is shown in Figure 7. In the context of renewable energy and digitalization in the countries of developing countries, a meta-analysis proceeded as follows:

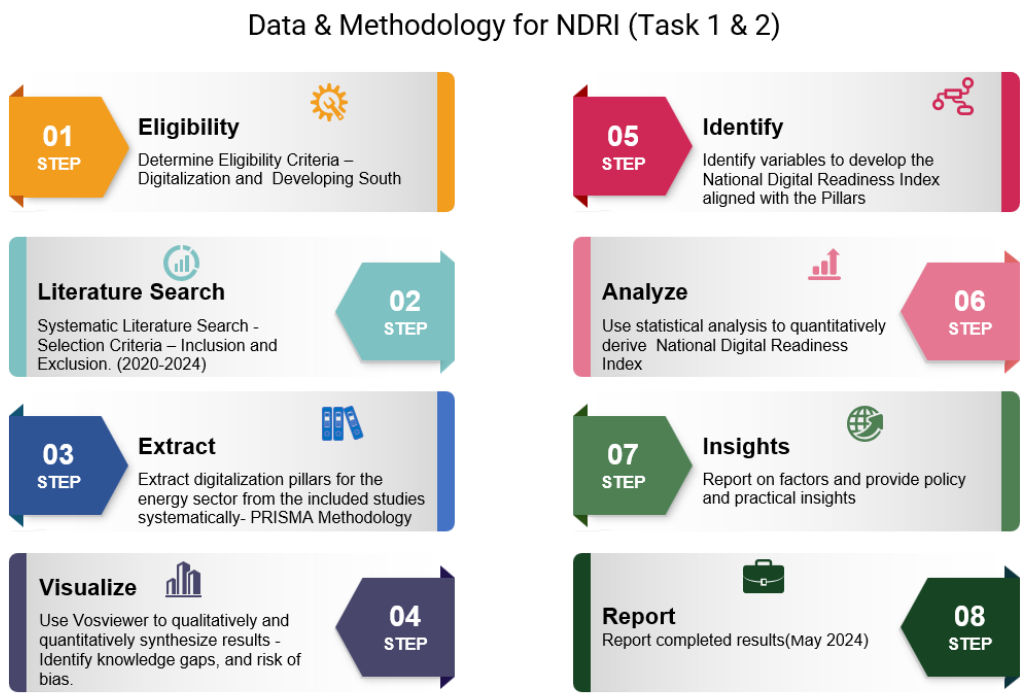

FIGURE 7 FLOWCHART DESCRIBING THE APPROACH UNDERTAKEN TO DEVELOP THE NATIONAL DIGITAL READINESS INDEX.

2.1. Systematic Review

Our research question is specific to the domains of renewable energy and digitalization in developing countries. We used Web of Science articles and included disciplines such as energy, environmental sciences, engineering, and relevant social sciences. We performed a systematic literature review across the Web of Science database to collect studies that relate to the research question, using a combination of keywords and subject-specific terms.

> Search criteria –*The search term "developing countries" was expanded by adding "Africa, Latin America, or Asia" to the list of active keywords. Note that if an article did not mention any of these terms/regions or the term "developing country," it would most likely NOT be included in the study. Since our meta-analysis is more related to coarser geographies, specific country-level information was included later in the PRISMA analysis.*

We extracted relevant data, such as the topic areas, geographic location, type of renewable energy technology, measures of digitalization, and the main outcomes. We extract the following statistics. Table 1 presents the number of citations generated for specific search terms between three different timespans: 1984 (earliest) to 2024, 2014-2024, and 2020-2024. As evident, applying additional filters, e.g., "developing countries" OR Africa OR "Latin America" OR Asia, reduces the number of citations, implying that literature on energy and digitalization in these specific regions is sparse. Digitization and energy seem like good starting points for getting the broadest results since they are the focus of our analysis. We tried the other three terms on the table based on reviewing the literature.

We used the terms climate change and energy to check if there is volume on this topic without including the term digitization. Thus, we synthesized the broad themes further through this PRISMA analysis to highlight insights (Step 2). Regarding the specific details about the citation numbers provided in Table 1, the increase or decrease in the number of citations over time could suggest trends in research focus and interest in the field. The initially selected literature was filtered from Table 1. A total of 150 articles were selected for analysis based on time (2020-24) and inclusion and exclusion criteria (based on regions and journal topics) that were further refined using PRISMA.

The literature selection process is pivotal within the PRISMA framework, which provides a minimum set of evidence-based items for reporting systematic reviews and meta-analyses. We utilized the "analyze results" feature of online databases, such as the Web of Science, alongside VOSviewer's capabilities (Step 3), which enabled us to identify literature based on specific criteria, including publication years, document types, and citations. Such precision aids in selecting studies central to the research question while ensuring the synthesis of data reflecting the breadth and depth of the subject matter.

We examined the variation, or heterogeneity, among the results of different studies and assessed for publication bias, which can occur when the published literature is not representative of all completed studies. So, countries such as China may be overrepresented, while Malawi or countries of the Sub-Saharan region are underrepresented.

TABLE 1 TOTAL NUMBER OF CITATIONS (/COUNTS) RECORDED FOR EACH SEARCH CRITERIA (USING WEB OF SCIENCE) AND TIMEFRAME. INDICATES THE FIRST YEAR AT WHICH A SPECIFIC TERM WAS REFERRED IN THE LITERATURE. + DENOTES A WILDCARD SEARCH TERM WHERE THE WORK DIGITAL** WOULD FIND ALL WORDS BEGINNING WITH DIGITAL, INCLUDING DIGITIZATION.

Search criteria (# of citations)	1984-2024	2014-2024	2020-2024
climate change AND "renewable energy"	15715	13367	8556
digitalization AND energy	2719 (2014 on)	2719	2344
“digital readiness” AND energy	7 (2018 on)	7	4

"climate change" AND "energy transition"	2278	2215	1808
"climate change" AND "renewable energy" AND ("developing countries" OR Africa OR "Latin America" OR Asia)	1586 (1989* on)	1354	927
digitalization AND ("developing countries" OR Africa OR "Latin America" OR Asia)	1077	1032	880
digitalization AND energy AND ("developing countries" OR Africa OR "Latin America" OR Asia)	115 (2002* on)	108	92
Digital** AND energy AND ("developing countries" OR Africa OR "Latin America" OR Asia)	3122 (1990* on)	2416	1411
"digital readiness" AND energy AND ("developing countries" OR Africa OR "Latin America" OR Asia)	0	0	0
climate change" AND "energy transition" AND ("developing countries" OR Africa OR "Latin America" OR Asia**)**	287 (2008* on)	281	242

2.2. PRISMA Meta-Analysis: Develop Pillars or Dimensions

As shown in Figure 7 (Step 2), we adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method, which is a widely recognized standard for conducting and reporting systematic reviews and meta-analyses (Panic et al., 2013). The logic behind the PRISMA approach is to enhance the clarity, transparency, and integrity of reporting in systematic reviews and meta-analyses.

- PRISMA aims to make the review process open and transparent, thereby allowing readers to assess the strengths and weaknesses of the review. It helps in detecting biases in the review process.
- PRISMA is an instructional guide for authors to accurately report their methodology and findings.

During the systematic literature review, the fifty key articles are grouped and analyzed according to their central theme, research question, and region, resulting in the construction of eight pillars. Together, these categories are an integral part of the digitization of energy in the design of the National Digitalization Index of the Developing South. Figure 8 illustrates the eight pillars from the PRISMA methodology.

National Digitalization Readiness Index

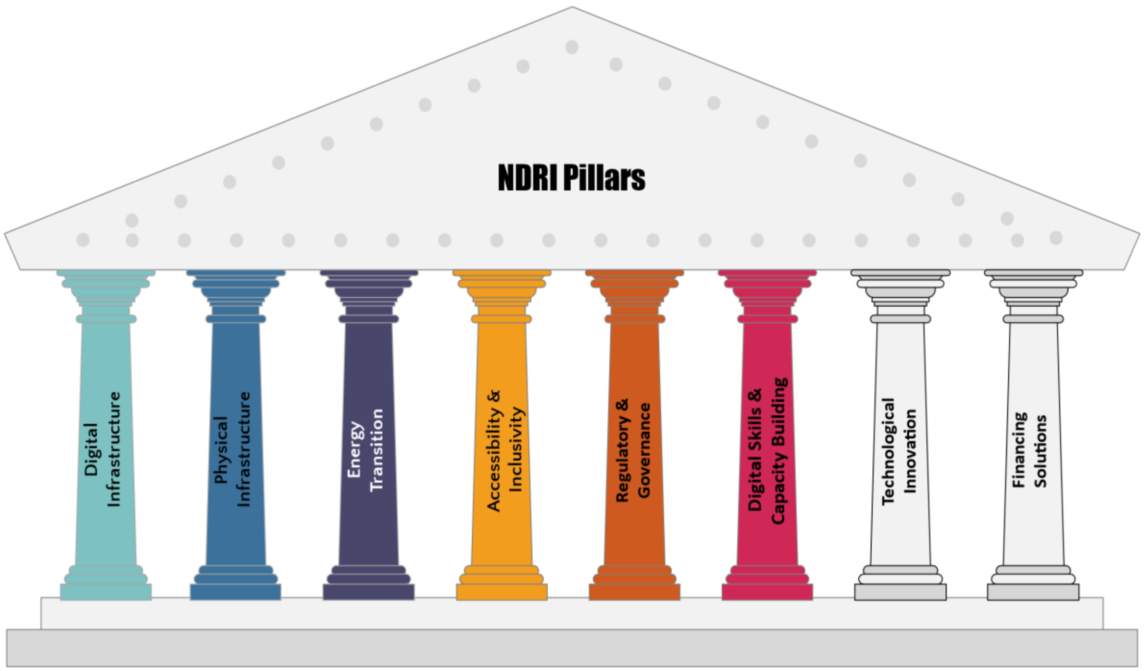

FIGURE 8 EIGHT DIMENSIONS IDENTIFIED BY APPLYING OUR PRISMA METHODOLOGY.

The National Digitalization Readiness Index (NDRI) plays a crucial role in evaluating the preparedness of developing countries' energy infrastructure for digital transformation. This readiness is assessed through eight pillars, each highlighting different aspects vital for understanding and enhancing the effectiveness of digital tools in these regions.

1. **Access & Affordability:** This pillar is essential as it examines the availability and affordability of digital infrastructure in developing countries. Access to reliable and affordable internet services is foundational for leveraging digital technologies in the energy sector.
2. **Technological Innovation:** The focus here is on the capacity of countries to develop and adopt new technologies. Technological innovation is critical for modernizing energy systems and making them more efficient and sustainable.
3. **Policy and Regulatory Frameworks:** Effective policies and regulatory environments are crucial for fostering an ecosystem that can support digital transformation in the energy sector. This includes laws and regulations that encourage investment in digital infrastructure and innovation.
4. **Gender and Energy Justice:** This pillar addresses the inclusivity of digitalization efforts, ensuring that they also support marginalized groups, including women. It emphasizes creating equitable opportunities in the energy sector through digital tools.
5. **Energy Transition:** This refers to shifting from traditional energy sources to more sustainable ones, aided by digital technologies. Digital tools can facilitate the integration of renewable energy sources into the grid, optimizing energy distribution and consumption.

6. **Infrastructure**: Robust physical and digital infrastructure is a prerequisite for effective digitalization. This includes not only energy infrastructure but also the telecommunications networks that support digital applications.
7. **Skills and Capacity Building**: Developing the necessary skills and knowledge among the local workforce is vital to sustain digitalization efforts. This involves education and training programs that focus on digital skills and energy management.
8. **Financing Solutions:** Financial resources are necessary to support digitalization initiatives. This pillar looks at the availability of financial mechanisms that can drive investments in digital infrastructure and technologies in the energy sector.

2.3. VOSViewer Visualization

Figure 7 (step 3) is the VOSviewer (Eck and Waltman, 2009), a tool for constructing and visualizing bibliometric maps, shown in Figure 7 (Step 3), was integrated into this framework to identify core research areas, seminal papers, and leading subject-matter experts, thereby aligning with PRISMA's comprehensive literature examination ethos. Such an approach also unveils research voids crucial for addressing PRISMA's requirement to identify uncharted or insufficiently researched topics. The visualization highlights the scarcity of literature specifically addressing energy and digitalization in some of the predefined geographies. This scarcity underscores the importance of synthesizing broad themes to distill insights, emphasizing the need for further research in this domain (additional results presented in Appendix A).

We used the VOSviewer to examine the results and identify themes, and consider the last four years for graphing the knowledge network of 714 keywords (150 articles). We filtered the keywords by selecting only those that passed a threshold of 3 (i.e., they had to have three numbers of occurrences across citations). By weaving together bibliometric mapping with the PRISMA-guided review process, the research not only adheres to high standards of transparency and reproducibility but also provides a clear rationale for study selection, offering invaluable insights into the digitalization-energy nexus in the Developing South.

3 Identify Relevant Variables

To develop a Digitalization Index, a comprehensive methodological approach is required that considers factors of digitalization relevant to climate action and sustainable development. Drawing from methodologies used in existing research, such as the formation of composite indices to measure digital competitiveness and sustainable development (Corrocher & Ordanini, 2002; Singh & Jyoti, 2023), the index needs to integrate various elementary indicators into a cohesive measurement tool. There are many factors, including relevance, measurability, comparability, data sources, and error margins, that guide the selection of variables explained below. Appendix A shows the list of indicator variables used in the analysis.

Relevance: Selecting relevant indicators for a digitalization index requires focusing on sustainability and climate action. The significance of local energy sustainability indicators is key in planning and action. These indicators, including those related to digitalization, must be relevant to climate action, providing a framework for both assessment and action-planning (Neves et al., 2015).

Measurability: Ensuring the measurability of indicators involves identifying reliable data sources and methods. For example, Bizikova et al. (2019) emphasize the importance of indicators' selection driven by relevance for decision-making, considering data availability and practical issues in agriculture.

Comparability (Indicators for Cross-Regional and Temporal Comparisons): It is crucial that indicators be comparable across different regions and over time. For example, Feldmeyer et al. (2019) developed an indicator set to measure urban climate resilience and monitor adaptation activities, ensuring comparability.

Identifying Data Sources with Uncertainty and Margin of Error: Identifying potential data sources for each indicator is important, considering uncertainty and margin of error. Such sources include:

I. Government Agencies: Ministry of Energy, Ministry of Telecoms, National Statistics Office, etc.
II. International Organizations: World Bank, International Energy Agency (IEA), The International Renewable Energy Agency (IRENA), UN Global Pulse, etc.
III. Industry Associations and Research Institutions: Energy sector associations, research centers, academia, etc.
IV. If needed, incorporating geospatial data (e.g., satellite imagery) relevant to climate vulnerabilities and offshore wind.

3.1 Synthesis of Pillars

Given that data availability and reliability vary depending on the country's context, the index methodology should consider data quality issues and potentially utilize data imputation techniques where necessary. As shown in Table 2 and Figure 9, we outline eight pillars that capture digitalization readiness across the countries of the developing South, based on 26 data variables that are fitted into the eight dimensions. We do not have consistent data on financing solutions across all these countries and hence we eliminated it in the analysis. Each variable is described and sourced in Appendix B.

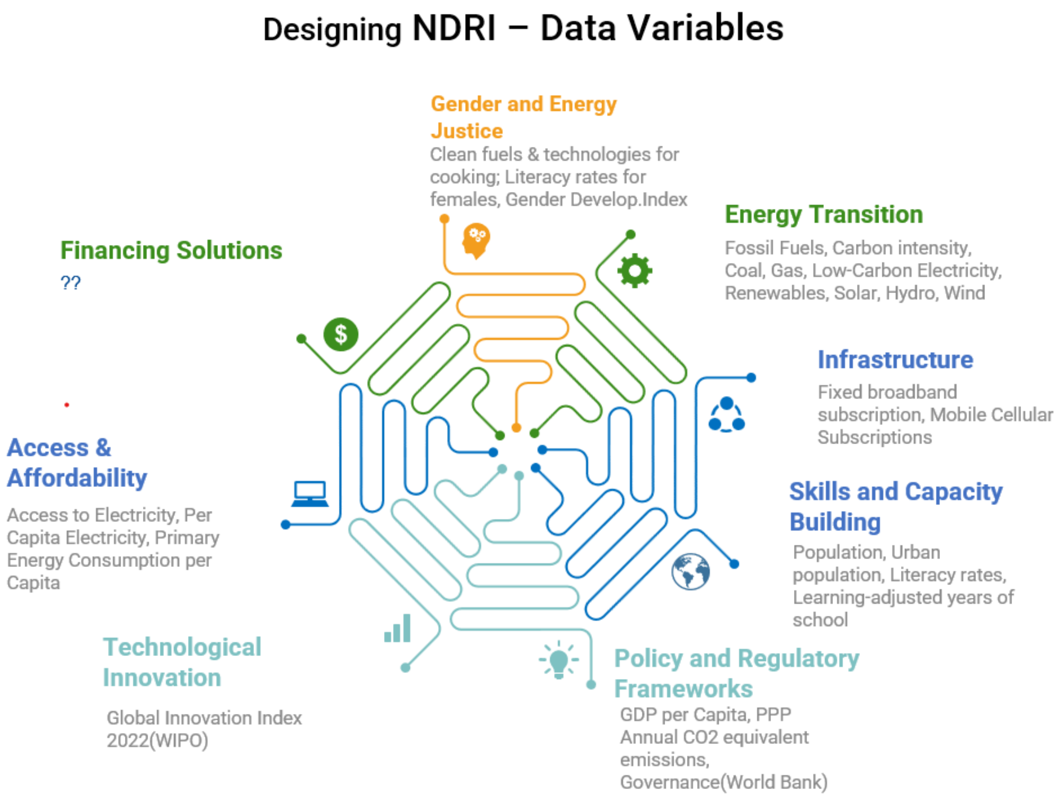

FIGURE 9 PRISMA DIMENSIONS ON NATIONAL DIGITALIZATION INDEX OF THE DEVELOPING COUNTRIES

To evaluate the current readiness of developing countries' energy infrastructure for digitalization and the potential for transformation using digital tools, we synthesized eight pillars of the National Digitalization Readiness Index (NDRI) and described each using relevant variables from the study.

Access & Affordability: This pillar examines the accessibility and affordability of electricity and digital tools to the general population. Factors like per capita electricity consumption and primary energy use are essential to understand the existing energy framework and its capacity to support digitalization.

Technological Innovation: The Global Innovation Index provides a view of a country's current status in innovation, which is pivotal for digitalization. Innovation in energy technologies can be a strong indicator of a country’s readiness to implement digital tools.

Policy and Regulatory Frameworks: The governance of a country, including laws, regulations, and policies regarding technology and energy, sets the foundation for digital transformation. GDP per capita and CO_2 emissions can also indicate economic and environmental priorities that may influence digital readiness.

Gender and Energy Justice: This pillar focuses on ensuring equal access to digital and energy resources for all genders. Variables like literacy rates for females and the Gender Development Index give an insight into gender disparities that may affect the adoption of digitalization.

Energy Transition: The shift from fossil fuels to renewable sources is a vital part of energy digitalization. Data on carbon intensity and the mix of energy sources, such as coal, gas, renewables, solar, hydro, and wind, illustrate a country's current energy landscape and its potential for digitalization.

Infrastructure: The state of the current infrastructure, including the prevalence of fixed broadband and mobile cellular subscriptions, is fundamental to digital readiness. A robust infrastructure is essential for deploying digital tools.

Skills and Capacity Building: For digital tools to be effectively implemented, the population must have the necessary skills. Urban population statistics, literacy rates, and learning-adjusted years of school reflect the human capital available to leverage digital technologies.

Financing Solutions: Assessing the financing mechanisms available within a country is critical for digital transformation. It would be beneficial to look at the availability of capital for investment in digital infrastructure and the willingness of the public and private sectors to invest in these technologies. This particular pillar lacks consistent data for all developing countries, so we did not include it in our analysis.

By analyzing these pillars in the context of developing countries, we can evaluate their readiness for digital transformation in energy infrastructure and the potential impact of digital tools on their development trajectories.

TABLE 2 USING PRISMA METHODOLOGY, WE IDENTIFIED 8 THEMES OR DIMENSIONS FOR FURTHER ANALYSIS BASED ON 26 VARIABLES. SEE APPENDIX B.

ISO Code for the country	
Entity	
Continent	Eight Dimensions or Pillars
Per capita electricity - kWh	Access & Affordability
Primary energy consumption per capita (kWh/person)	Access & Affordability
Access to electricity (% of population)	Access & Affordability
Low-carbon electricity - % electricity	Energy Transition
Renewables - % electricity	Energy Transition
Solar - % electricity	Energy Transition
Wind - % electricity	Energy Transition
Coal - % electricity	Energy Transition
Fossil fuels - % electricity	Energy Transition
Gas - % electricity	Energy Transition
Hydro - % electricity	Energy Transition
Proportion of population with primary reliance on clean fuels and technologies for cooking (%)	Gender and Energy Justice
Gender Development Index	Gender and Energy Justice
Literacy Rate Female	Gender and Energy Justice
Mobile cellular subscriptions (per 100 people)	Infrastructure
Fixed broadband subscriptions (per 100 people)	Infrastructure
Carbon intensity of electricity - gCO2/kWh	Policy and Regulatory Frameworks
Annual CO2e emissions (per capita)	Policy and Regulatory Frameworks
Governance (World Bank)	Policy and Regulatory Frameworks
Population (2020)	Skills and Capacity Building
GDP per capita	Skills and Capacity Building
Learning-Adjusted Years of School	Skills and Capacity Building
Urban Population	Skills and Capacity Building
Literacy Rate All Genders	Skills and Capacity Building
Literacy Rate Male	Skills and Capacity Building
Global Innovation Index (WIPO)	Technological Innovation

3.2 NDRI Index - Statistical Analysis

We collected data on 26 variables from all developing countries to validate eight dimensions identified using the PRISMA methodology, which frames digitalization studies conceptually and empirically across these regions. We used statistical methods to condense these variables into an aggregate NDRI score. We explored two common statistical methods, assessing their strengths before selecting the most appropriate one for creating the NDRI and decided to use the first, the simple additive model.

Simple Additive Models: Simple additive models, where all variables are summed for each country, are easy to understand and implement. They require minimal statistical knowledge and can quickly provide a rudimentary ranking of countries based on the sum of observed variables. They are transparent and Intuitive. The process and results of additive models are straightforward, making it easy for policymakers and non-specialists to interpret and use the outcomes for decision-making. However, this approach treats all variables equally, disregarding the relative importance or weight of different variables. It fails to capture the complex interrelationships and synergies among variables. By summing variables without considering their nature (e.g., positive or negative impacts on the outcome of interest), additive models might oversimplify the analysis, leading to potentially misleading conclusions. We use this technique in this report in two ways: normalized scores and standardized scores.

The Composite Score formula based on Normalized Scores is:
Composite Score $=(w_1 \times \text{Normalized Score}_1)+(w_2 2 \times \text{Normalized Score}_2)+\cdots+$
$(w_n \times \text{Normalized Score}_n)$,

Data normalization is done in two ways:

(i) where Normalized Score for Min-Max Scaling= (Value - Min) / (Max - Min). This process rescales the value between 0 to 1. OR
(ii) where the Normalized Score for Z-score Normalization= (Value - Min) / (Standard Deviation).

The score indicates how many standard deviations an element is from the mean. This process rescales the value to Z scores ranging between 0 plus or negative 3 and above.

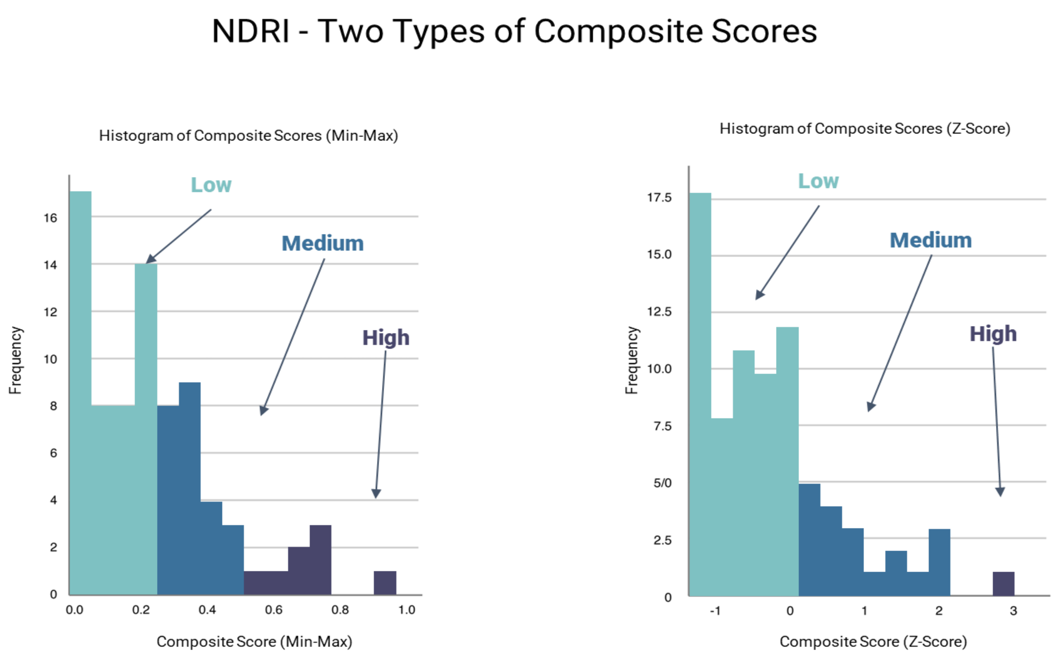

Figure 10 HISTOGRAM OF COMPOSITE SCORES USING MIN-MAX AND Z-SCORE METHODS OF ESTIMATION

Figure 10 shows the Histogram of Composite Scores. This graph, in the left panel of Figure 10, shows the distribution of scores normalized between the minimum and maximum values using the Min-Max Scaling. The right panel shows the standardized scores, which have a mean of zero. The distribution is more centered, as expected from Z-scores, and also appears right-skewed. In both panels, high (marked in both figures by an arrow) and extreme left in each panel, show countries including Singapore, the Republic of Korea, Qatar, the United Arab Emirates, Japan, and Israel. Medium in the two panels includes countries such as Thailand, Oman, India, Vietnam, Costa Rica, and Kazakhstan. Low in both panels include Cameroon, Zimbabwe, Angola, Myanmar, Iraq, Mali, and Guinea. Appendix C shows the complete list of countries organized into groups based on the standardized scores. Each variable is weighted equally in this analysis but could be weighted differently depending on the purpose.

Figure 11 shows a many-country radar chart for examining NDRI differentiation based on some key variables, including Per capita electricity(kWh), Govt Effectiveness Rank, Innovativeness Score, Fixed broadband subscriptions (per 100 people), GDP per capita, Proportion of population with primary reliance on clean fuels for cooking (%), Renewables in electricity and Access to electricity (% of population) out of the 26 variables. It clearly shows the overall pattern in the high, medium, and low composite-scored countries displayed in Figure 10. Singapore scores high in Government Effectiveness Rank and GDP per capita. South Korea scores high in innovativeness and broadband subscriptions. Brazil has more renewables in its electricity, followed by Chile. Mali and Guinea are the lowest in terms of overall NDRI variables, represented in Figure 10.

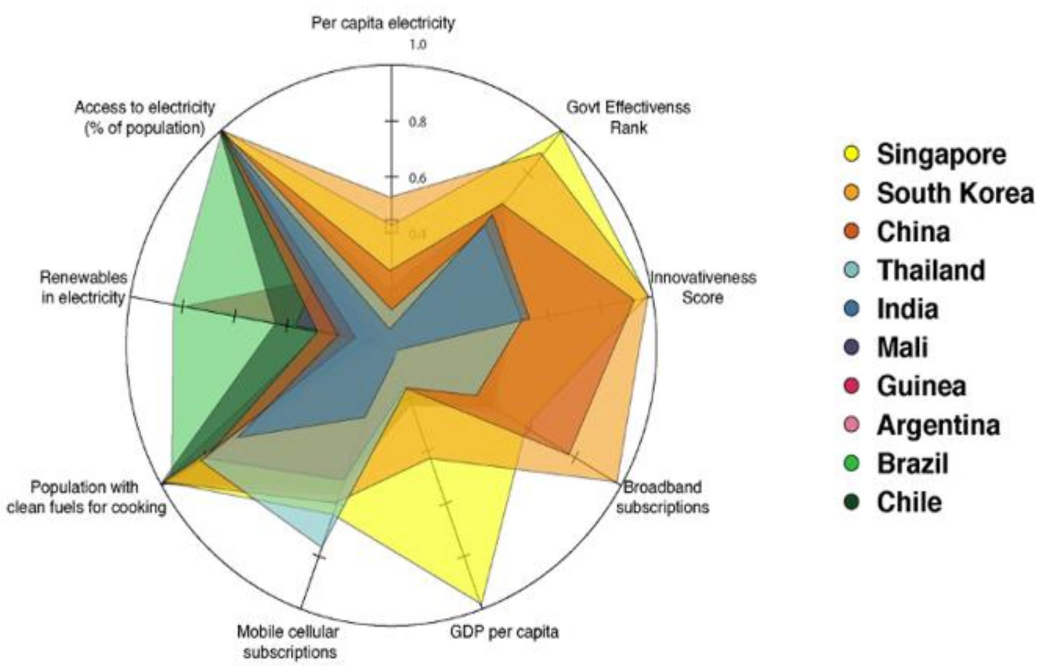

FIGURE 11 RADAR CHART SHOWING 10 COUNTRIES DIFFERENTIATED ON NINE VARIABLES DEFINING NDRI.

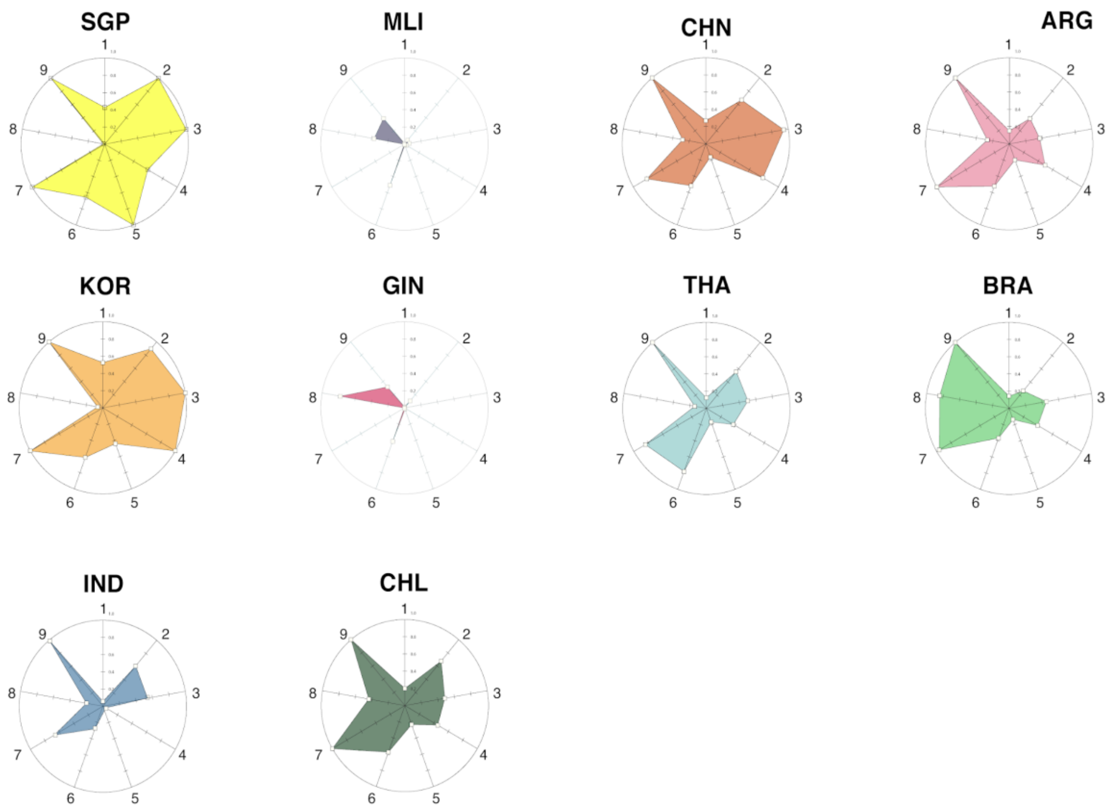

FIGURE 12 RADAR CHARTS FOR SINGAPORE (SGP), SOUTH KOREA (KOR), CHINA (CHN), THAILAND (THA), INDIA (IND), MALI (MLI), GUINEA (GIN), ARGENTINA (ARG), BRAZIL (BRA), CHILE, (CHL).

In Figure 12, nine axes representing key variables are represented for ten countries where 1 - Per capita electricity(kWh), 2 - Govt Effectiveness Rank, 3 - Innovativeness Score, 4 - Fixed broadband subscriptions (per 100 people), 5 - GDP per capita, 6 - Mobile cellular subscriptions, 7 - Population with primary reliance on clean fuels for cooking (%), 8- Renewables in electricity and 9 - Access to electricity (% of population). The area of each radar chart indicates the magnitude of the NDRI in each country. Mali and Guinea have the smallest sizes, while Singapore and Korea have the largest. India has achieved greater access to electricity while it has lower scores on other variables displayed in Figure 12.

The simple additive method produces clear results of NDRI and validates what experts have highlighted in our meta-analysis. Thus, our variable selection and pillars explain digitalization's role in developing countries' energy sectors. Appendix C details the second method used in the analysis based on Principal Component Analysis (PCA). We may use both methods for a future publication to discuss our results.

4.0 Applications and Insights

In this section, we provide our insights from the project and add to the discourse on global energy transitions that reveal a complex landscape where various factors, such as economic capabilities, political will, and technological access, play crucial roles. The shift towards renewable energy, particularly in developing countries, is driven by the necessity to combat climate change, enhance energy security, and reduce dependency on fossil fuels.

Despite the progress, regions face uneven advancements due to diverse influencing factors. For example,

- China's leadership in solar panel production contrasts starkly with its reliance on coal, showing the persistence of traditional energy systems.
- Similarly, Brazil's fluctuating success with biofuels underscores the volatility of energy policies reliant on singular strategies.

The narrative extends to green growth, advocating for economic development synchronized with environmental sustainability.

This approach suggests that developing countries can bypass traditional industrial phases, moving directly to greener technologies and practices, thus attracting foreign investments and enhancing local economies. Furthermore, digitization emerges as a transformative force in the energy sector, particularly in managing renewable energy sources through advanced grid systems and IoT applications. Blockchain technology, highlighted for its potential to democratize energy distribution in Africa, underscores the technological innovations reshaping energy infrastructure. While technological and economic strategies are advancing, significant disparities in capability and access across regions highlight the critical need for tailored policies and international collaboration to ensure a just and equitable energy future for all. We discuss these trends below.

We highlight the complexities and intricacies involved in transitioning to renewable energy sources, urging a multifaceted approach that accommodates differences in economic, environmental, and societal factors in seven areas:

Global Energy Transitions and Insights: We examined the complex landscape of global energy transitions, emphasizing the interplay between economic capabilities, political will, and technological access. The report notes uneven advancements across regions, with specific examples like China’s leadership in solar technology juxtaposed against its reliance on coal and Brazil’s fluctuating success with biofuels.

The Uneven Journey of Energy Transition: The discussion here centers on the global ambition to achieve universal access to modern, sustainable energy by 2030, as outlined in SDG7. It portrays the shift toward renewable energy as imperative for combating climate change and enhancing energy security while highlighting the variation in transition pace due to differing regional capabilities and political motivations.

Green Growth as a Catalyst: This segment argues that green growth represents a significant economic development opportunity, especially for developing countries. It suggests that these regions can leapfrog traditional industrial stages by adopting green technologies and practices, which can attract foreign investment and foster local economic growth.

Digitization and Green Energy: The transformative role of digitization in the energy sector is emphasized, particularly through advancements in smart grid management and the integration of renewable energy sources. The potential of blockchain technology to democratize energy distribution in developing regions like Africa is highlighted as a key innovation.

Bridging the Skills and Capacity Divide: This section addresses the critical challenges of technological access and skilled workforce development in energy transitions within developing regions like Africa and Asia. It stresses the need for investment in education and international collaboration to bridge these gaps and advance sustainable energy solutions.

Shaping Renewable Futures with Policy and Regulation: The narrative shifts to the importance of crafting comprehensive policy frameworks and regulations to support sustainable energy transitions. The role of community empowerment and international collaboration in fostering these transitions is underscored, with case studies from India and other regions illustrating strategic efforts.

Smart Financing for Energy Transformation: The focus here is on innovative financing models that make renewable energy technologies accessible and affordable for lower-income households and businesses in developing countries. The text discusses various financial strategies to support the clean energy shift, including blended and international climate finance.

Each of these areas are detailed and the full text can be provided if needed.

5. Technology Options and Case Study for Digitalization in the Energy sector

5.1 Overview

Based on the previous analysis, we have identified that Korea and Singapore show high performance in their energy sector digitalization. They both have high access to electricity, low electricity consumption (which might be considered a result of improving efficiency), government effectiveness, innovation capacity, and use of clean fuels. However, the assessment result shows that these countries relatively lack renewables in electricity. In particular, Korea shows a very high performance in using broadband subscriptions, which may be regarded as one of the core backbones of digitalization. Moreover, among the developing countries that have been reviewed by this index, Thailand, Argentina, Brazil, and Chile have shown high performance in mobile cellular subscriptions. This may be understood to have the potential of 'leap-frogging' to digitalization instead of following the conventional path for development.

Considering the assessment results, data availability, ease of contact with practitioners, and other perspectives, the research team has targeted two countries, the Republic of Korea and Thailand, to briefly check the applicability of the index and review their efforts for digitalizing their energy sector. The NDRI shows that Korea is quite advanced in digitalizing the energy sector, which can deliver some benchmarkable solutions in both technology and policy for digitalization; and that Thailand is regarded to have great potential in digitalizing their energy sector with consideration of the government's strong commitment to transform their energy sector to improve efficiency through digitalization and reduce carbon emissions.

In this chapter, we review the energy sectors of two countries (chp. 5.2), identify various digitalization options that have been introduced and applied in Korea (chp. 5.3), and analyze the applicability of the Korean case in Thailand (chp 5.4). Finally, we identify the lessons learned from Korea's digitalization efforts in the energy sector and highlighted the most urgent component that should be prioritized for digitalization (chp. 5.5). Throughout this process, we consider different levels of analysis, including country scale, regional or urban scale, and buidling scale. By reviewing these different levels, we aim to provide practical information and lessons for those interested in initiating digitalization in their energy sector.

5.2 Energy sector review – Republic of Korea and Thailand

5.2.1 Energy consumption at the national level

Republic of KOREA

Korea's total energy consumption rebounded quickly from a 4.4% decline in the second half of 2020, caused by the sharp economic slowdown due to the spread of COVID-19. However, it fell again by 4.0% in the first half of 2023. The ongoing domestic and international economic slowdown that began in the latter half of 2020, coupled with a decline in industrial production activities, accelerated the decrease in energy consumption. By energy source, oil, coal, and natural gas saw rapid declines, while nuclear power remained stagnant and renewables and other energy sources saw slight increases.

During the target period, the conventional energy sources such as oil, coal, and gas have decreased (5.2%, 6.3%, 6.8% year-on-year each) compared to the previous year, while nuclear and renewable energy sources have increased slightly (6.0% and 3.8% year-on-year each). Although the power generation sector led the growth of renewable and other energy consumption, the growth of renewable and other power generation slowed down significantly, which was caused by the slowdown in the growth of solar power facilities due to high-interest rates resulting in dampened investment sentiment and strengthening of related regulations.

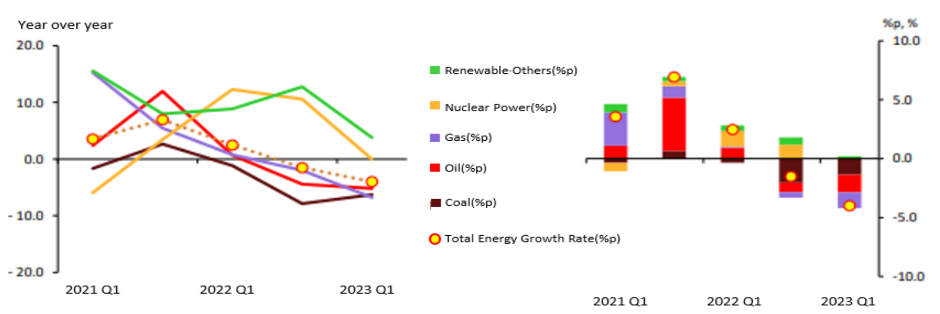

FIGURE 13 ENERGY CONSUMPTION OF KOREA BY SOURCE (SOURCE: KOREA ENERGY ECONOMICS INSTITUTE, 2023).[14]

[14] Korea Energy Economics Institute. (2023). 2024 Korea energy demand outlook: 2023 Second half. Ulsan: Korea Energy Economics Institute.

THAILAND

The Thai government announced the Power Development Plan 2018 (PDP 2018), covering the 20-year period from 2018 to 2037. A key feature of this plan is the significant increase in the share of natural gas, rising from 37% to 53%, contrary to the previous plan's goal of reducing gas consumption to below 40%. For other energy sources, the share of coal has been reduced from 23% to 12%, the share of renewable energy is maintained at 20%, and nuclear power has been excluded.

The main difference from the previous plan is a significant decrease in the amount of self-generation, including renewables, cogeneration, and thermal power, and a significant increase in power purchases from neighboring countries. New hydropower and thermal power generation will decrease by 76.2% and 76.5%, respectively, compared to the previous plan, while imports will increase by 297.6%, from 1473 MW to 5857 MW.

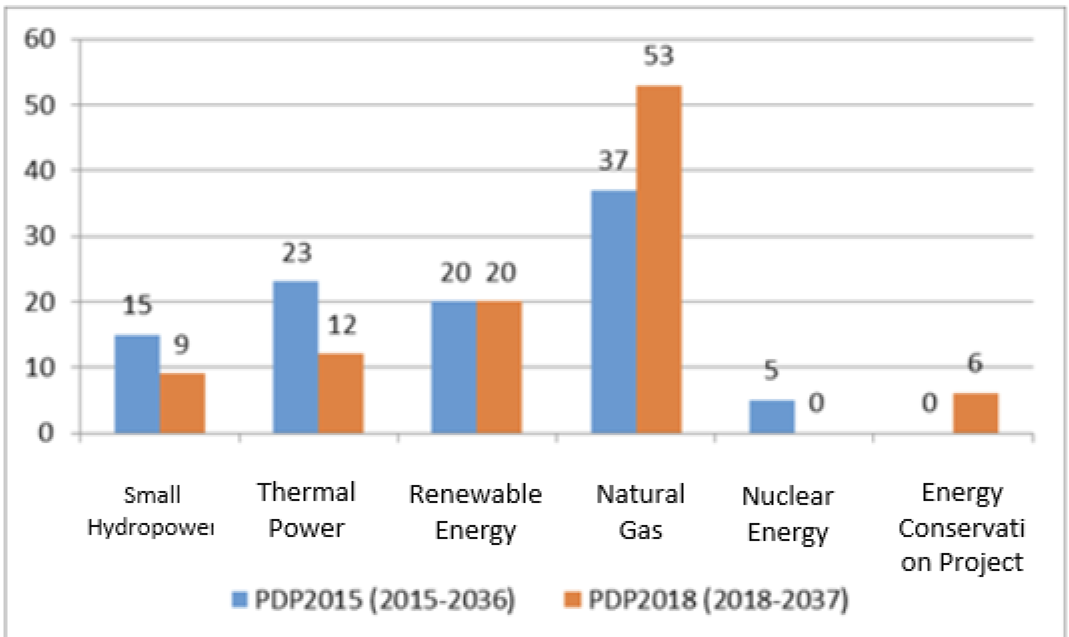

FIGURE 14 COMPARISON OF POWER GENERATION SHARES BY SOURCE IN THAILAND (UNIT: %) (SOURCE: ENERGY POLICY PLANNING OFFICE).

5.2.2 Energy management and operation system at the national level

Republic of KOREA

In Korea, the other energy sources such as oil (petroleum), coal, and gas are managed similar to other countries. However, Korea has a unique management and operation structure for electricity. To first review the surrounding environment and characteristics of electricity consumption in Korea, the Korean power industry is characterized by (1) having a high dependency on foreign energy sources (approximately 97%), (2) power generation is focused on southern areas while consumption is focused on metropolitan areas which result in long-distance transmission.

The structure of the Korean electricity system is shown in the figure below. The Korea Electricity Power Corporation (KEPCO) is the central control tower for managing power generation, distribution, and trading. As KEPCO is the control tower, there are 6 major power generation companies that generate electricity, district electricity companies managing local distribution, and smaller private companies for trading and market operation. KEPCO orders and purchases the generated electricity from producers and manages to distribute it to consumers through its transmission and distribution system. The government supervises the generation and distribution of electricity. Recently, Korea has expanded the electricity market to personnel; those generating electricity through small renewable facilities can also sell electricity to KEPCO.

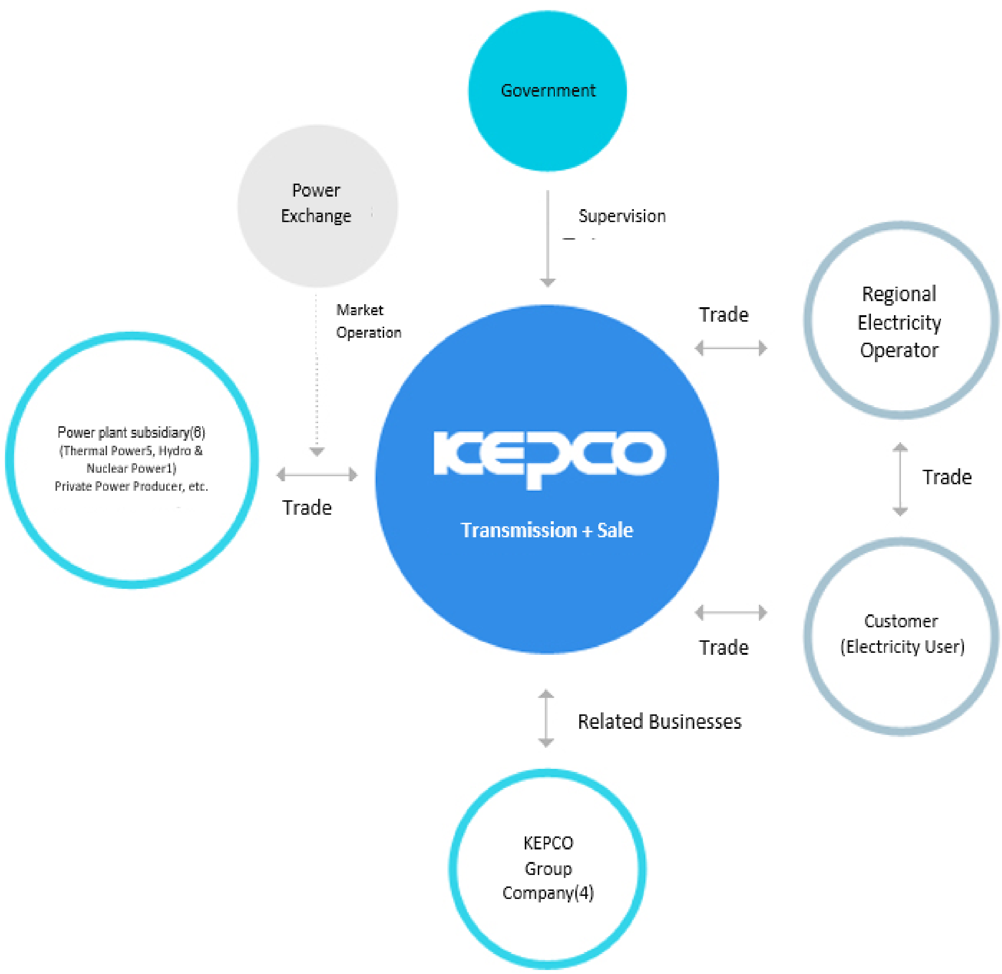

FIGURE 15 ENERGY (ELECTRICITY) MANAGEMENT FRAMEWORK IN KOREA.[15]

[15] https://home.kepco.co.kr/kepco/KO/C/htmlView/KOCCHP001.do?menuCd=FN05030301

THAILAND

The energy governance of Thailand is organized as follows: First, the Ministry of Energy (MOE) is responsible for setting measures, regulations, supervision, control decisions, and energy policy plans and actions for energy operations. The Energy Policy and Planning Office (EPPO) promotes energy conservation and renewable energy, recommends energy policies, and presents integrated management plans.

Energy policy is overseen by the National Energy Policy Council (NEPC) and the MOE, which is composed of four departments: EPPO, Department of Mineral Fuels (DMF), Department of Energy Business (DoEB), and Department of Alternative Energy Development and Efficiency (DEDE). The NEPC is responsible for reviewing the EPPO's policy proposals. There are 3 state-owned enterprises under the MOE: EGAT, Petroleum Authority of Thailand (PTT), and Bangchak Corporation Public Company Limited (BCP). In addition, there is also the Energy Regulatory Commission of Thailand (ERC), which is independent and monitors overseas operations in the energy sector. The Thai Industrial Standards Institute (TISI) is responsible for setting standards of compliance with international guidelines, inspecting and certifying the standards of products, and promoting and developing national standards.

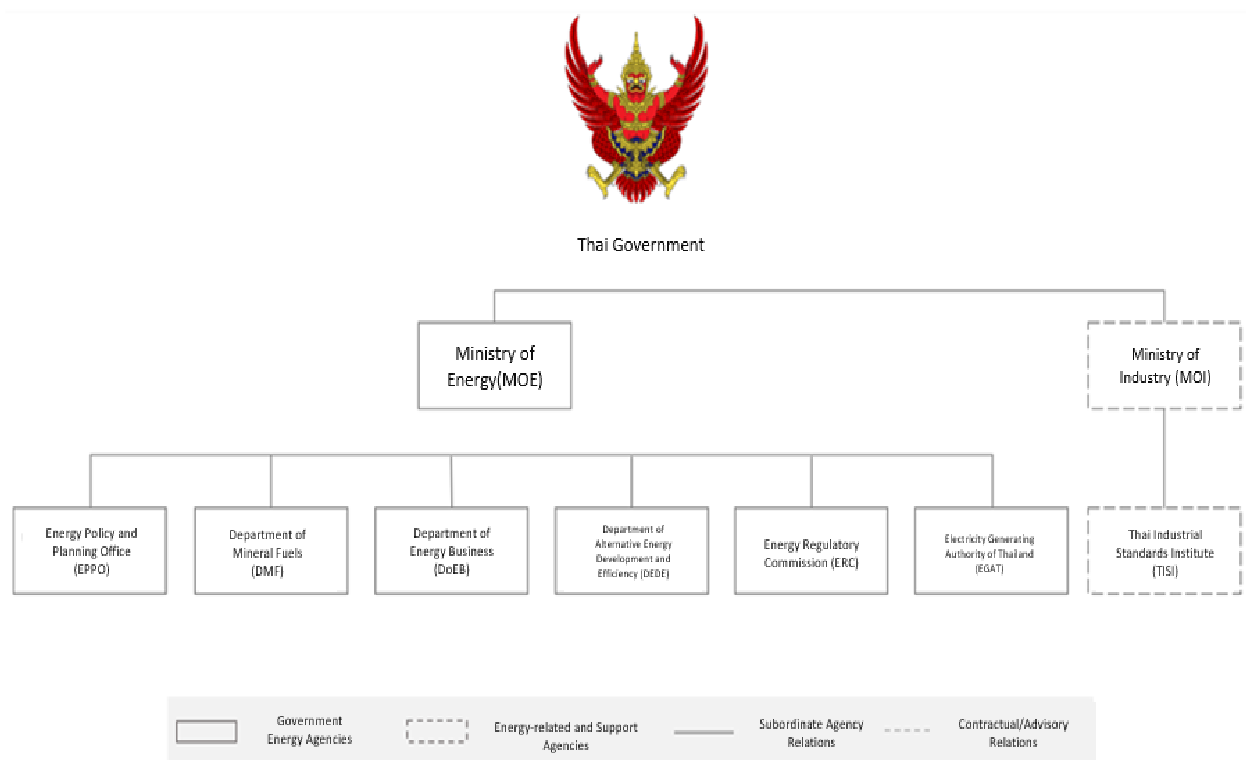

FIGURE 16 ENERGY (ELECTRICITY) MANAGEMENT FRAMEWORK IN THAILAND (SOURCE: KETEP, N.D.).

5.3 Digitalization options for the energy sector

To digitalize the Energy sector, countries worldwide are developing policies to promote digitalization, and various technologies are being introduced worldwide; some technologies may be in the early stages, such as research and development, while others are practically applied. In this report, we have (1) investigated policy options, including strategies and plans, of Korea and Thailand to promote digitalization in the energy sector and (2) investigated rising and promising technology options for digitalization in the energy sector that are currently being applied in Korea.

The major purpose of this introduction is to show what kind of options may be applicable after identifying the current condition of digitalization in each country's energy sector. Korea has been a leading country in terms of digitalization, resulting in the application of various digital options in various fields. However, these technology options should be carefully reviewed and analyzed before being applied to other countries because the major characteristics, conditions, or surrounding environment differ from those of Korea. Nonetheless, this introduction is expected to help stakeholders in developing countries develop their own options considering the unique characteristics and surrounding environment of their country's Energy sector.

5.3.1 Policy and strategy options

<u>Republic of KOREA</u>

In Korea, the digitalization of the energy sector is promoted through various policies and strategies. Representatively, "The Fourth Basic Plan for Sustainable Development," "The New Government's Energy Policy Direction," and "The Third Basic Plan for Intelligent Power Grid" include major plans to promote digital transformation in the energy sector. Especially, expansion of renewable energy, promotion of energy efficiency, and the application of digital technologies to achieve carbon neutrality are identified in these plans. In particular, developing an intelligent power grid using ICT technologies is being promoted as an important project to optimize electricity supply and demand, improve energy efficiency, and support sustainable electricity production and consumption. Intelligent microgrids, power storage systems, and smart electricity metering systems are being introduced to support the integration of renewable energy into the power grid and enhance energy efficiency in buildings, systematically supporting the establishment of an overall decentralized energy system. (More details for each policy and strategy are shown in Appendix F).

<u>The Fourth Basic Plan for Sustainable Development (2021-2040)</u>: A 20-year development plan in Korea has been being developed since 2006 to implement the international agreements of low-carbon sustainable development and promote national sustainability. The recent sustainable development plan, the 4th version, covers the period of 2021 – 2040. In this plan, the energy sector is related to the tasks of Goal 7, which is producing and consuming energy in an eco-friendly manner. More detailed terms related to energy also include the targets of using digitalization for sustainable development.

The Third Basic Plan for Intelligent Power Grid (2023): The Korean government has been establishing basic plans to promote intelligent power grids every 5 years. This plan aims to optimize the supply and demand of electricity by monitoring real-time data using ICT, promoting the development, demonstration, use, and diffusion of related technologies, promoting the industry, and enhancing the efficiency of electricity production and consumption.

The 1st National Carbon-Neutral Green Growth Plan (2023-2042): This plan is the highest-level statutory plan for achieving carbon neutrality and green growth in Korea. It contains sector and annual emission reduction targets and mid- to long-term policy directions. The plan covers the next 20 years and will be established and implemented every 5 years. Due to the large portion of carbon emissions, this plan also mentions targets and policies to reduce carbon emissions in the energy sector through innovative technologies, including digitalization.

THAILAND

Thailand's energy sector policy is overseen by the Ministry of Energy and the National Energy Policy Committee (NEPC). The NEPC's main tasks are to recommend national energy policy, management, and development schemes to the government and set Thailand's energy tariff structure. The majority of Thailand's electricity generation and transmission network is owned and operated by the Electricity Generating Authority of Thailand (EGAT). This state-owned company sells its power to the Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA), which are also state-owned companies. The private sector is also involved in renewable energy generation. Thailand is utilizing digital technologies in its energy transition plan for a low-carbon society. In particular, efforts are being made to utilize digital technologies to keep the energy system stable and efficient, to expand the number of electric vehicles, and to create a smart grid that integrates electric vehicle infrastructure with the existing power grid.

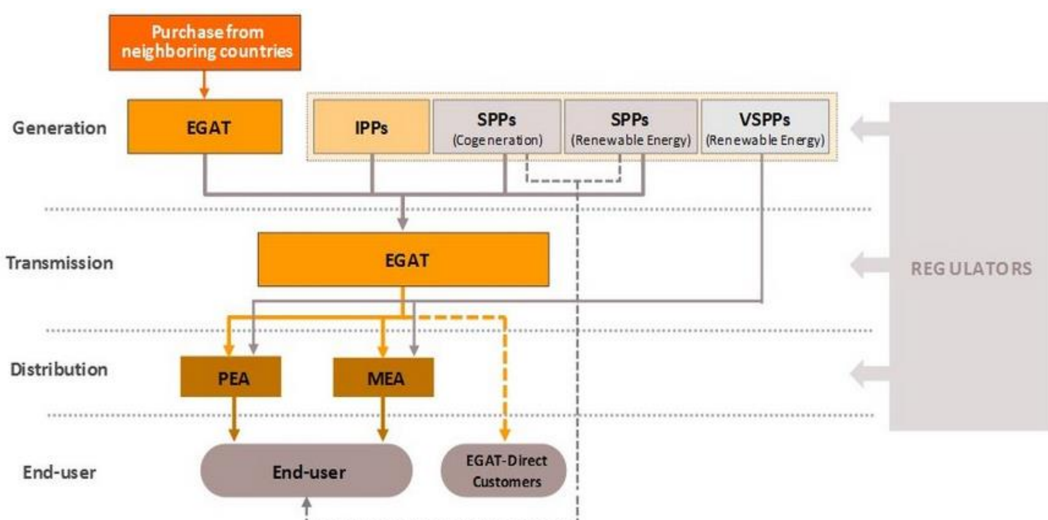

FIGURE 17 THAILAND'S ELECTRICITY SUPPLY CHAIN (SOURCE: TUNPAIBOON, 2021).

National Economic and Social Development Plan (NESDP): The NESDP is a comprehensive 5-year national development plan covering all sectors. First set in 1961, the plan serves as the basic guideline for economic and social development to improve the quality of life in Thailand. The most recently released NESDP is the 13th plan and covers the period from 2023 to 2027. The goal of the 13th NESDP is to transform Thailand into a progressive society with a sustainable value-creating economy, and a total of 13 targets have been set to achieve this goal. One of the NESDP's 13 targets, the goal of establishing a manufacturing base for electric vehicles (EVs), is one of the strategies that can be realized through the digitalization of the energy sector. The plan also includes plans for smart grid technologies to integrate the connection and management of EV charging, including an integrated platform to connect public charging stations and EV data.

Power Development Plan (PDP): Thailand's Power Development Plan (PDP) and Alternative Energy Development Plan (AEDP) are developed by Thailand's Ministry of Energy and are the centerpiece of the country's energy plan. Thailand's Power Development Plan 2018 covers the period of 2018 to 2037, and its main directions are as follows: (1) Regional balance and reliable supply of power generation, transmission, and distribution systems, (2) Ensuring power system flexibility to respond to energy crises (grid flexibility), (3) Encourage low-cost power generation to reduce consumer burden, (4) Preparing a competitive power generation system that takes into account power generation efficiency, (5) Minimize environmental impact, (6) Promote electricity generation from renewable energy sources, and (7) Expand smart grid development.

Thailand Smart Grid Master Plan (2015): This is a comprehensive plan established by the Ministry of Energy in 2015, covering the period of 2015 to 2036. This plan includes 3 focus areas: (1) establishment of ICT integration to the energy and communication sector for system modernization, (2) strategies and regulations for electricity pricing and monitoring for customer-centric reform or smart life, and (3) initiatives to develop renewable energy forecasting to promote and increase the use of renewable energy.

Energy 4.0 – The Smart Grid Project: Thailand's Provincial Electricity Authority (PEA) is partnering with a private company to implement a smart grid to transform the energy infrastructure of Pattaya. The PEA aims to lead the energy transition in Thailand, meeting with the national energy 4.0 plan to contribute to the country's economic success and ensure its competitiveness within the ASEAN society. One of the key parts of the energy transition is the digital upgrade, including power supply improvement and expanding renewable energy sources in Thailand. Pattaya will be a pilot city to showcase a new paradigm through the digital transformation of smart substations.

Electricity Generating Authority of Thailand (EGAT): The EGAT aims to promote innovation through research into the integration of digital technologies to accelerate value creation and business transformation in issues such as renewable energy, energy storage, grid modernization, and carbon capture and storage (CCS). To promote sustainable development, EGAT's operations will be modernized with digital procedures and systems that integrate technology, automation, and AI expertise into management functions, including the power plant's internal systems, carbon emission analysis, and environmental impact assessment. EGAT's infrastructure will be strengthened to support the digital transformation, including digital documents, leveraging the cloud and other innovative technologies to analyze data and modernize operational processes.

5.3.2 Technology options

The investigated technology options consider various energy system components, such as power plants, distribution systems, and monitoring systems. Moreover, this report has also reviewed education programs to introduce slightly how to enhance capacity-building for digitalization in the energy sector. A shortlist of technology options that are introduced in this report is provided as follows:

1. Digital Twin power plant
2. Intelligent Digital Power Plant (IDPP)
3. Virtual Power Plant (VPP)
4. Energy Management System (EMS)
5. Microgrid EMS
6. Advanced Metering Infrastructure (AMI) for buildings and apartments
7. AI-enabled prediction and diagnosis
8. Advanced Distribution Management System (ADMS)
9. Digital transformation education program

The major contents to introduce each option are as follows: First, (1) the concept and purpose of each technology option are introduced, and (2) technical features such as basic structure or core functionality are introduced for a clearer understanding of the technology, and at last (3) some application examples or case studies are introduced to see how these technology options are used for digitalizing the Energy sector. More details of each option are shown in the additional "Digitalization Options Handbook for the Energy Sector."

1. Digital Twin Power Plant

(<u>Concept and objective</u>) Digital twin technology has emerged in response to the simultaneous and prolific development of technologies such as sensors, IoT, big data, artificial intelligence, and cyber-physical systems and to the need to leverage these technologies to increase productivity, economy, and safety in various industries. Digital twinning is a digital representation of a physical object, a 'digital copy' of the object that is used to simulate tests that are difficult to perform in the real world. Digital twin technology acts as a virtual model reflecting the properties and state of an object in real-time throughout its life cycle in dynamic terms.

In the energy sector, digital twins or digital twinning build a virtual energy supply and demand system that is synchronized with the real-world power system through digital modeling. This provides a customized energy optimization technology that creates a virtual replica of an actual power plant and reflects the operating status, performance, failure prediction, maintenance requirements, etc., using real-time data, IoT technology, Artificial Intelligence, and big data analysis. Through the application of digital twinning technology, the power plant can be maximally optimized and improved in terms of efficiency, safety, and environmental impact.

(Technical characteristics) The core technologies that make up a digital twin are diverse, but they fall into seven broad categories: (a) visualization and operations, (b) analytics, (c) multidimensional modeling and simulation, (d) connectivity, (d) data and security, (e) synchronization, and (f) federation between individual digital twins.

(Application) Digital twin technology has recently been used in various industries, including manufacturing, aviation, power generation, transportation, healthcare, and smart cities. The application of digital twinning in each industry ranges from produce design to plant operations, performance analysis, personalized service delivery, and policy validation. In the energy sector, digital twinning is being applied to power plants, as the first application of digital twinning to power plants was introduced by General Electrics (GE) in 2015 with the concept of a 'digital power plan.' The digital power plant aims to improve energy productivity by increasing power generation efficiency through maximizing optimization using digital twinning (GE Report Korea, 2019). Representative examples of applying this technology in Korea are those of the Korea Hydro and Nuclear Power Co., POSCO, and the Korea South-East Power Co., Ltd.

FIGURE 18 SCREENSHOTS OF THE DIGITAL TWIN POWER PLANT OF KOEN (SOURCE: KANG, 2024).

2. Intelligent Digital Power Plant (IDPP)

(Concept and objective) The IDPP is a power plant aiming to achieve high productivity and efficiency by utilizing the latest technologies, such as artificial intelligence (AI), to monitor and predict the performance of the power plant in real-time. Using data analytics, AI, and machine learning, the IDPP aims to prevent failures, improve energy efficiency, and optimize operations of the power plant (Park et al., 2023). The IDPP aims to reduce costs for power generation by applying digital and intelligent technologies to optimize the operation and maintenance (O&M) of facilities and improve efficiency using collected data.

(Technical characteristics) IDPP is a 'smart' power plant operated through a network based on the operation and maintenance data of power plants, including a technology that predicts the condition of facilities in advance through AI and big data analysis to minimize power generation OPEX by preventing failures and increasing asset operation efficiency. IDPP has the advantage of paying attention to various micro-signals that can detect equipment failures or abnormal operations. In the IDPP, vibration, pressure, and temperature sensors are installed in each power plant facility, and the information is collected in real-time. This information is then transformed into new data through intelligence and digitalization and is used to optimize the operation and maintenance of power generation facilities. Based on the data collected and analyzed, the IDPP can identify the optimal operating conditions and timing of maintenance.

(Application) As known in the name, IDPP is mostly developed and used by power-generating organizations. In Korea, the two representative organizations that apply IDPP are the Korea Electric Power Corporation (KEPCO) and the Midland Power Co. Ltd. (KOMIPO). KEPCO has developed 16 intelligent applications ('apps') that monitor and predict the status of major facilities in power plants using machine learning and implement the results on actual sites. Moreover, KEPCO built a data center based on a digital platform named "Power generation big data platform" with government support, which is an integrated system enabling to connect and share various operation data.

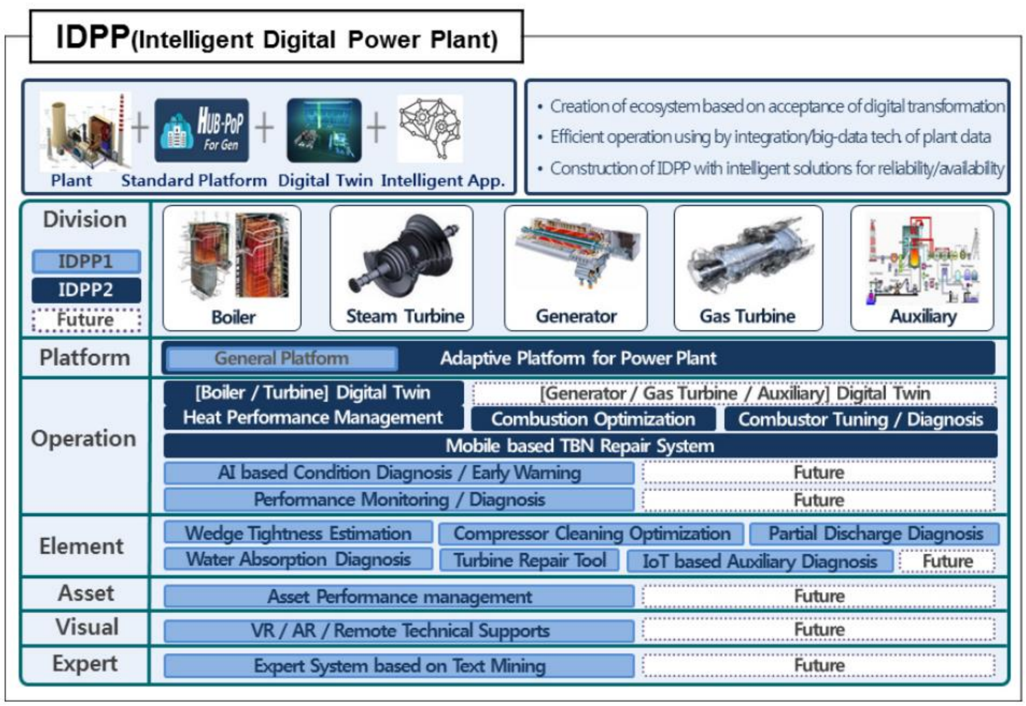

FIGURE 19 IDPP COMPONENTS AND STAGES (SOURCE: LEE, 2020).

The KOMIPO is building smart power plants based on big data and AI-based predictive diagnostic systems and has established a platform named" KOMIPO-MIRI." The overall composition of the first phase of the MIRI platform consists of a power generation operation information system (Smart-PIS), an equipment early warning system (Smart-EWS), and an efficiency monitoring system (Smart-EMS).

3. Virtual Power Plant (VPP)

(Concept and objective) With consideration of coping with climate change, the energy system is changing from fossil-fueled power generation to renewable energy, which results in a 'Distributed Energy Resource (DER)' in which various small-sized power generation sources such as solar power and fuel cells are distributed. In this regard, a system that gathers, integrates, and manages power generation sources that are widely distributed throughout the region or even the country is required. The virtual power plant (VPP) is a system or platform that uses information and advanced communication technologies (ICT) to optimize energy production and distribution. Instead of physically developing a large power plant, the VPP uses ICT and artificial intelligence (AI) to collect, predict, control, and manage scattered energy sources that meet the characteristics of renewable energy. By connecting small-size energy producers on a platform and operating them as a single power plant, VPPs can predict the power generation and demand of distributed energy resources and strategically produce, store, distribute, and trade energy accordingly. This option, VPP, makes it possible to minimize the problem of renewable energy output limitation caused by surplus electricity at certain times.

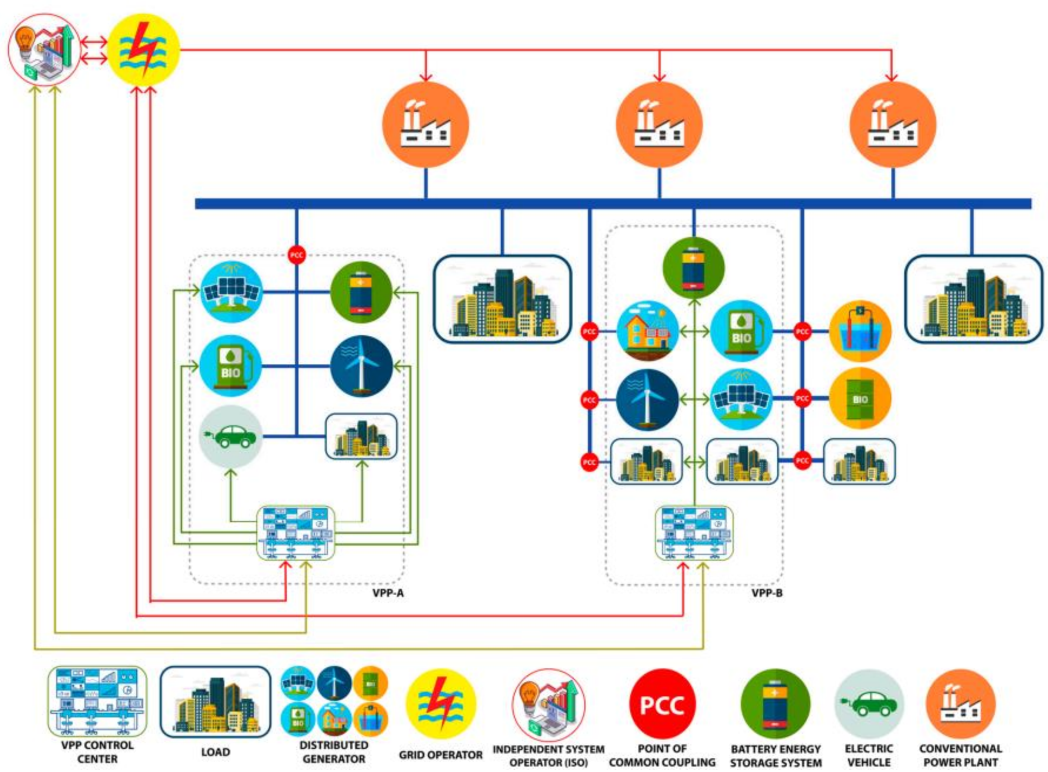

Figure 20 Illustration of virtual power plant distribution (Source: Setiawan et al., 2024).[16]

[16] The red line indicates communication between the VPP and the utility operator, the yellow line indicates communication between the VPP and the system operator, and the green line indicates communication within the internal VPP.

(Technical characteristics) VPPs monitor power consumption and supply in real-time, transmitting the measurement results to the electricity provider's control system. This system uses AI to analyze the data and sets the appropriate power generation and supply routes for power plant operation. For instance, if an industrial park powered by wind energy experiences reduced power output due to environmental factors, a large thermal power plant usually needs to operate to prevent a power outage. However, VPP technology can transfer excess power from neighboring areas to the industrial park, maintaining grid stability without additional power generation.

(Application) SK Ecoplant, a leading Korean environmental and energy company, has entered the VPP-based power mediation business. SK Ecoplant has signed an agreement with 91 renewable energy plants in Jeju island and started a 50 MW power mediation business with these small renewable power plants. SK EcoPlant launched 'Power ZEN', a bidding platform based on renewable energy generation forecasts. Power ZEN provides data on the status of the power system, including power generation forecasts and power transmission. It is characterized by the ability to determine the actual power supply capacity. Through this platform, renewable energy intermediaries will receive incentives from the power exchange, which operates the power market based on high renewable energy generation forecasts (SK Ecoplant Newsroom, 2023). Another private company, Hanhwa Solutions Co. Ltd, is making efforts to enter the VPP market starting with Australia through M&A and investment. The company acquired a US software company that sells systems to control solar power generation facilities and ESS through data analysis and VPPs.

Moreover, the Korean government is promoting the expansion of distributed energy sources to improve problems caused by the centralized power system. One of them is the K-VPP. Since February 2019, Korea has implemented the Small Power Mediation Business System, which enables electricity generated or stored from small-scale power resources to be collected and traded on the power market. Various providers are participating in the system.

4. Energy Management System (EMS)

(Concept and objective) The EMS[17] is a comprehensive framework and a set of practices designed to optimize the utilization, monitoring, and control of energy resources within an organization or facility. It can play a pivotal role in achieving energy efficiency, cost saving, and sustainability. EMS collects energy consumption data from a variety of sources, including sensors, meters, and utility bills, analyzes the data to identify trends and efficiency information, and helps to take action to save energy.

(Technical characteristics) With a clear energy consumption analysis, EMS can identify areas where energy is being wasted and take action to improve efficiency, leading to direct cost savings. As a result, the energy system may be more sustainable by reducing the environmental impact through reducing

[17] https://www.metron.energy/blog/ems-energy-management-system-definition/

carbon emissions. The EMS also supports compliance with energy-related regulations and standards such as the ISO 50001.

(Application) Several private companies in Korea are developing EMSs. The following are the representative cases. (1) POSCO DX, POSCO E&C: These companies specialize in engineering, automation, system integration, and IT outsourcing systems. They are currently focusing on smart technology and digital transformation solutions, and they launched Smart EMS in 2013, which is an energy efficiency solution that analyzes energy usage data to improve efficiency and detect maintenance needs. (2) KT is the first company in Korea to develop and provide a cloud-based building EMS. Based on the KT Cloud service, they have achieved cost saving of up to 47% in construction and 67% in operating costs compared to conventional BEMS methods. KT's smart building BEMS offers remote energy management services through their integrated control platform, allowing building management professionals to monitor real-time conditions and respond remotely. The platform includes features like "predicted peak hours" for power usage analysis and a GIS-based map to dispatch technicians efficiently, even during off-hours

5. Microgrid EMS

(Concept and objective) Microgrid (MG) technology provides users with attributes such as improved power quality, reliability, sustainability, and green energy through an energy control and management system (EMS). The microgrid concept was proposed to create a self-contained system composed of distributed energy resources that can operate in an isolated mode during grid disturbances. A microgrid EMS is the software and hardware system that efficiently manages and optimizes energy. It coordinates energy production and consumption within a microgrid by making optimal decisions about generation, storage, and load. It plays an important role in managing the variability of renewable energy sources, optimizing interaction with the grid, and reducing energy costs.

(Technical characteristics) A microgrid EMS provides control technology that enables coordination between different energy resources and loads, maintaining voltage and frequency stability, and improving energy efficiency. The system can ensure reliable operation both when the microgrid is connected to the grid and when it is operating independently. It can also provide in-depth control strategies for energy management. The major characteristics of microgrid EMS are shown in various cases. For example, the growing number of industries and businesses is increasing the demand for reliable and cost-effective power. Microgrids are small-scale electricity supply networks that provide power to these industries and businesses that can meet their demand. Moreover, microgrids are emerging as a technology that can quickly restore distributed power systems after physical or cyber damage. The technology advancements and updates in IoT are also leading the development of intelligent microgrids, a key component of the future smart grid. Intelligent microgrids are attempting to integrate IoT architectures with technologies for applications aimed at developing countries, controlling, monitoring and protecting microgrids.

(Application) Real-world testbed implementation of an EMS prototype: The UCLA Smart Grid Energy Research Centre and the Korea Institute of Energy Research have developed and deployed an advanced EMS prototype to validate its functionality in a real-world environment. The system has demonstrated that it can communicate with various energy devices and perform energy management tasks efficiently[18].

6. Advanced Metering Infrastructure (AMI) for buildings and apartments

(Concept and objective) AMI is an integrated fixed-network system that enables two-way communication between utilities and customers. The system collects, stores, analyses, and displays energy usage data, enabling utilities to monitor electricity, gas, and water usage in real time.

(Technical characteristics) The AMI system comprises smart meters, a communication network, and a data management system. Smart meters record overall consumption at hourly intervals, and the recorded data is transmitted to the utility company at least once a day. This eliminates the step of manually verifying consumption and allows for a faster response time in the event of a power outage. AMI systems can also monitor power usage patterns, improve demand response programs, detect and manage outages, remotely connect and disconnect, detect theft, and much more. As mentioned, AMI systems are a form of the Internet of Things (IoT), combining sensors, smart meters, communication networks, and data management systems. It can help companies and households save costs and increase efficiency by enabling real-time monitoring and control of energy, gas, water, and others. Typical digital technologies used include artificial intelligence (AI), big data, and cloud computing, which play a key role in data collection, analysis, and processing.

(Application) As of 2021, the United States utilities have installed more than 110 million AMI systems or 70 percent of all installed electricity meters. This allows for real-time monitoring of energy usage and enhances the implementation of demand response programs that can signal consumers to use energy more efficiently.

7. AI-enabled prediction and diagnosis

(Concept and objective) The AI is used for prediction and diagnosis to predict equipment failures and hazardous conditions within energy systems to prevent potential disasters and accidents. There are devices to monitor physical infrastructure to predict equipment failures and system safety risks and analyze the interactions between different elements of the energy system, enabling better identification and response to unpredictable hazardous situations.

(Technical characteristics) The machine learning and deep learning algorithms are used to process large amounts of data and learn complex patterns to make predictions and diagnoses. Through monitoring equipment and infrastructure at facilities in real-time, historical data is combined to predict likely failures to plan maintenance and prevent accidents. Moreover, data such as weather conditions, geography, and

[18] Lee, E. (2016). Design and implementation of a microgrid energy management system. Sustainability, 8(11), 1143.

various environmental factors are also included in the analysis to predict potential risks of energy facilities.

(Application) Various enterprises worldwide are applying AI technology for risk management.

E.ON: The company combines drone imagery and AI to conduct virtual inspections of power lines to proactively identify potential issues, making the maintenance process more efficient and safe.

Shell: Shell also combines AI and IoT technologies to automatically identify safety risks in the workplace and enable rapid response, reducing safety incidents and lowering operating costs and environmental impact.

Rhizome: Using AI to combine performance data from the power grid equipment with global climate models to predict the probability of grid failure due to climate extreme events and prioritize responses to counter them.

8. Advanced Distribution Management System (ADMS)

(Concept and objective) ADMS is a software platform that helps manage and optimize power distribution. This system supports automated outage restoration, including the ability to optimize grid performance. Moreover, the system (1) locates, isolates, and repairs possible faults on the grid, (2) optimizes voltage/voltage-ampere responses, (3) saves energy through voltage reduction in the distribution grid, (4) manages peak demand, and (5) supports microgrids and electric vehicles.

(Technical characteristics) The ADMS enables integrated control, reliability, and forecast of the power grid. It is a mix of centralized and decentralized control methods that (1) improves the grid performance through real-time optimizing power flows, (2) utilizes data to evaluate the effectiveness of grid control algorithms, and (3) integrates management systems such as locating failures for recovery. This system improves the reliability, safety, and operational efficiency of the grid by providing reliable and efficient energy management that overcomes the limits of traditional grid management systems to reduce outage times and costs.

(Application) ADMS is applied globally for efficient grid management.

India: As a part of India's 'Smart Grid Vision and Roadmap', the ADMS based on ETAP[19] (Energy Management Solutions to Design, Operate, and Automate Power Systems) model is applied to improve network performance, reduce outage restoration time, reduce substation equipment maintenance, control system training time, and enable efficient power management, transmission, and distribution.

[19] https://etap.com/

Australia: The SA Power Networks in Australia, Enel in Italy, and SICAE France in France have implemented Schneider Electric's EcoStruxure ADMS to monitor and manage the entire network, accelerate clean energy supply, optimize the grid, and manage distributed energy integration[20].

9. Digital transformation education program

In the case of digital transformation, training programs can be divided into 2 types: those conducted by public institutions and those conducted in universities.

(Public and national)

National Education Technology Plan (United States, Office of Educational Technology): The U.S. Department of Education's National Educational Technology Plan addresses the area of digital use, identifying opportunities for students to leverage technology to enhance their learning, and helping educators build their capacity to design learning experiences through technology. The latest plan focuses on three key divides: digital access, design, and use. It provides equal access to technology for both students and educators and emphasizes digital health, safety, and citizenship.

Digital Transformation Strategy for the Netherlands and Saudi Arabia (Digital Regulation Platform): The Netherlands and Saudi Arabia support a number of digital transformation initiatives, including investing in digital infrastructure and innovation and promoting the ethical use of digital technology and data. These strategies can ensure collaboration within and outside of government through a strong strategic governance structure, and establish clear processes, roles, and responsibilities for digital transformation. They can play an important role in the preparation of a country-specific digital transformation strategy (DTS).

National Transformation Program (Saudi Arabia, MyGov): The National Transformation Program was launched to support the Kingdom of Saudi Arabia's Vision 2030, which aims to achieve digital transformation, economic diversification, and social development. The program has achieved a number of important milestones, and future phases will continue to develop the necessary infrastructure, support digital transformation, and increase the attractiveness of the labor market to create an enabling environment for achieving Saudi Vision 2030.

Vietnam National Digital Transformation Program (ASEM Connect Vietnam): Vietnam's Digital Transformation Program recognizes the need and urgency of digital transformation across society, and focuses on developing digital infrastructure and building digital platforms. The program is particularly focused on changing perceptions of digital transformation and advancing digital infrastructure, including the development of high-speed broadband infrastructure, upgrading 5G networks, and promoting

[20] https://www.se.com/

smartphone penetration. It also focuses on building a national electronic identification and authentication system and cloud computing technologies.

(From universities and institutions)

Professional Certificate Program in Digital Transformation - MIT Professional Education: The program is to understand the core technologies of the digital revolution (blockchain, cloud computing, AI, IoT, cybersecurity) and develop the ability to operate in a global culture of innovation by combining technical skills with human leadership.

Digital Transformation Program - Stanford Online: The instructors and faculty are Stanford University professors in computer science, management science, and engineering, with an emphasis on social computing and crowdsourcing system design. The program focuses on the study of strategy and organization in uncertain and fast markets, especially in technology-based companies and high-speed industries. Topics include strategy generation, creating synergy among multi-business entities, and building alliance portfolios for entrepreneurial firms.

Leading Digital Transformation - Wharton Executive Education: Covers topics including digital disruption, identifying and proposing digital opportunities, shifting from products to platforms, organizational agility and networks, and boundary leadership. Webinars are held two months after the program to help participants consolidate course learning and share challenges and successes in real-world applications.

Digital Transformation Program - Berkeley Executive Education: This program consists of eight modules: Digital Transformation Overview, Digital Transformation Opportunities, Role of Data, Digital Transformation Process, Digital Business Models, Organization and People, Technology and Policy, and Conclusions and Action Plan. Topics include understanding the growth of subscription models, improving customer-centric processes, exploring regulatory and ethical questions around data collection and use, and learning about the use of digital technologies in various industries, including healthcare, banking, advertising, retail, transportation, and more

5.4 Analysis of Korea's case of digitalization and applicability of Thailand

Comparing Korea and Thailand based on the NDRI results, Korea shows higher performance than Thailand in (1) Access to electricity, (2) per capita electricity, (3) Government effectiveness rank, (4) Innovativeness score, (5) Broadband subscription, and (6) reliance of clean fuels. In particular, Korea shows a large difference in Government effectiveness, Innovativeness, and broadband subscription, while there is a slight difference in mobile cellular subscription and renewable energy use.

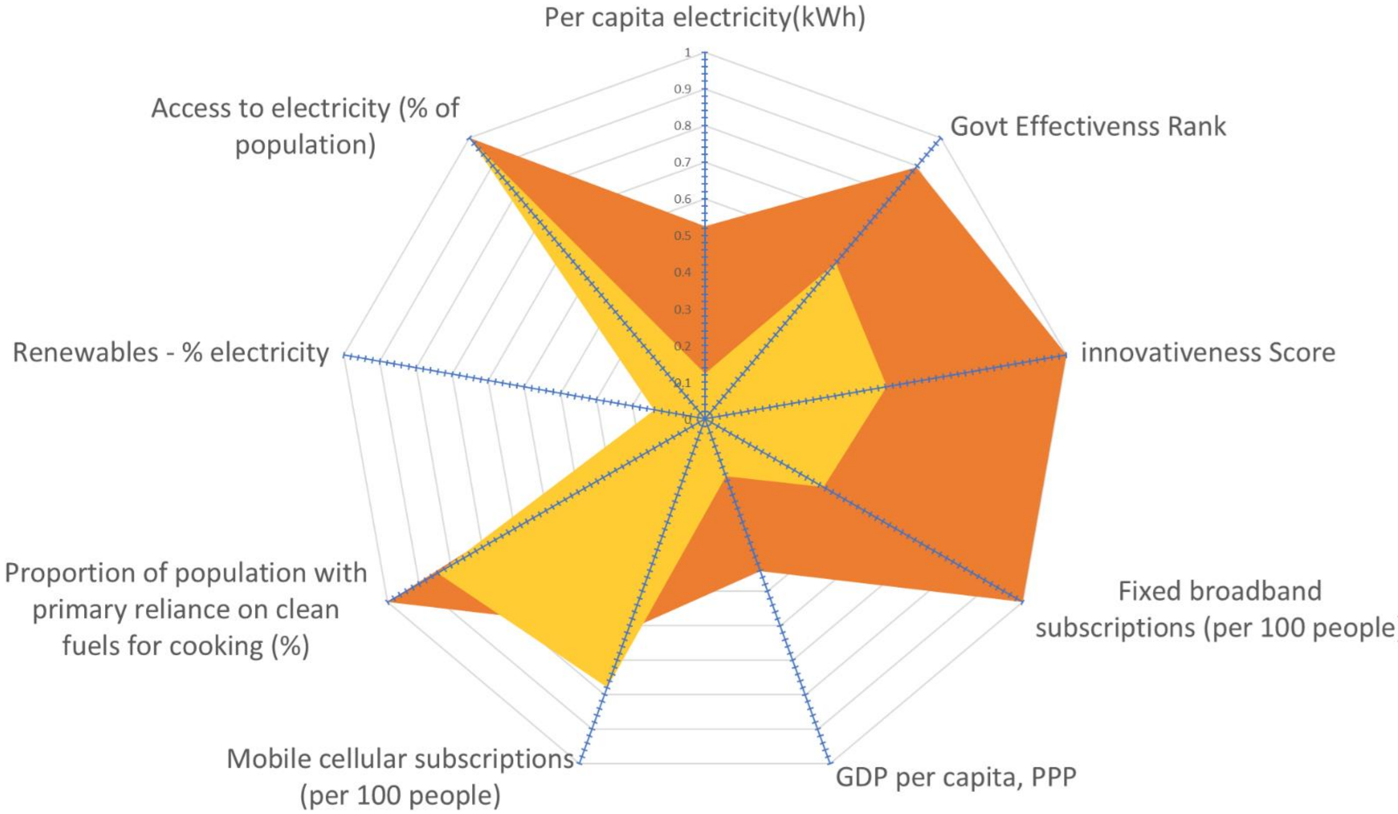

FIGURE 21 RADAR CHART COMPARING KOREA AND THAILAND.

Through the review of their energy sectors, we have identified that the electricity systems in Korea and Thailand have similar characteristics, with a public utility in charge of power generation and transmission and the private sector also involved in power generation. However, the difference between these countries is that they have different business models, the entity that sells power differs, and the centralization or decentralization structure for energy management and operation is slightly different.

In Korea, the corporation (KEPCO) operates in a system where power purchased from the electricity exchange is transported through the transmission/distribution network and sold to customers. On the contrary, in Thailand, two subsidiaries of EGAT, MEA, and PEA are in charge of power distribution and sales in urban and rural areas, respectively, and have a split monopoly. That is, Korea's energy structure is centralized regarding power sales, while Thailand is relatively decentralized by region. Moreover, the electricity market also shows this difference: the electricity market of Korea is centered on the Korea Electricity Exchange and is divided into wholesale and retail markets. On the contrary, Thailand's electricity tariff system is not categorized according to wholesale and retail but rather divided into eight categories.

Based on the NDRI assessment results, review of their energy sector, and digitalization options that are in progress, we may consider Korea to be in quite good condition for digitalization ('readiness') in the energy sector. In particular, Korea is promoting various digitalization options (technologies) along with the government's support (policies). As a result, Korea is applying various options, from conventional technologies such as real-time monitoring and data collection based on the superior ICT infrastructure to high-end technologies such as artificial intelligence, machine learning, or digital twinning.

We may use the index to find out why Korea has such good conditions for digitalizing its energy sector. As mentioned previously, Korea especially shows good performance in broadband subscription, government effectiveness, innovation, and electricity accessibility. The factors show that various enablers exist, and certain conditions are regarded to be the essential backbones for successfully achieving digitalization. For example, for intelligent digital power plants (IDPPs), the quality and coverage of the broadband internet system are the core components to achieving real-time data analysis, as a large amount of data is required to be transferred quickly in and out to meet 'real-time'. Even though Korea has good AI technology to analyze a large amount of data, without the fast and wide coverage of broadband internet, the IDPP may not be possible. Similar to IDPPs, another example will be the Advanced Metering Infrastructure (AMI) for buildings. This technology also requires the ability to transfer a large amount of data in the short term to make real-time monitoring happen.

Another component that we might emphasize is the innovativeness of adopting technologies in an educated capacity. For example, the Virtual Power Plant is an innovative concept that combines various small-scale power plants together virtually to regard them as one large-scale power plant. This requires various high-end technologies related to monitoring, control, and optimization. Adopting and applying these high-end technologies can be done by educated capacity working in the field, and challenging support for innovative approaches.

The last example we would like to introduce is the effective support by the government. As well known, policy needs to support the application of new technologies in the field. Most of the examples introduced in this report adopt artificial intelligence (AI) for automating maintenance and operation. This can easily be done as the Korean government announces the country's aim and mandate to achieve carbon neutrality and green growth and promotes clean and efficient energy generation through methods such as intelligent management. With a policy and also financial support from the government, the public and private can easily seek advanced technologies and attempt applications to advance through digitalization.

As we have gone through a 'best' case of digitalization, now we would like to look over a 'high-potential' case, Thailand. The assessment results by the NDRI show that Thailand has a similar figure (radar chart) to Korea. Thailand lacks in various aspects, such as government effectiveness, innovation, broadband subscriptions, etc. Nevertheless, one aspect to notice is the high rate of mobile cellular subscriptions. These are shown in several developing countries, which indicates the possibility of 'leap-frogging' technologies, meaning there is no need to follow the conventional development path developed countries have gone in the past. Moreover, the government of Thailand has a strong will to promote their energy sector to be carbon neutral, and they are eagerly promoting various strategies to apply renewable energy and reduce carbon emissions in the energy sector. As seen in the Korean case, digitalization can be one of the solutions to pursue carbon neutrality by improving efficiency and enabling renewable energy. To make a digital transformation by applying technology options such as IDPPs, AMIS, or VPPs, Thailand needs to establish an enabling environment, such as developing a broadband internet structure with high speed and coverage and establishing policies to promote advanced technologies. Like this, Thailand may find which country will be possible to benchmark to achieve digital transformation, as we have briefly described above, based on the NDRI assessment results.

5.5 Cornerstone for digitalizing the energy sector – lessons from Korea case study.

Digitalization requires an enabling environment to be promoted. In addition to the various aspects or characteristics discussed previously, more core values also exist. The Korean digitalization technology options in the energy sector are fundamentally based on a large amount of collected and organized data. Advanced technologies, such as machine learning, AI, and others, require a large amount of data to check its feasibility and applicability. This is also happening, especially because of the rise of AI, and many countries and international corporations are seeking to collect as much data as possible.

Digitalization is regarded to have the same aspect, and data collection and organization may be regarded as the core start for promoting digitalization. In this regard, here we would like to briefly introduce how Korea has collected and managed its data for the energy sector. (More details are shown in [Appendix E]).

In Korea, data on digitalization, not only for the energy sector but also for various information-related services in diverse sectors, are collected and provided to the public. This kind of data collection and archive provides a large amount of source data to those who have brilliant ideas about digitalization or are willing to develop digitalization options such as platforms, AI models, or cloud services. Thus, the first step of digitalization may be regarded as collecting and organizing data, especially for those directly related to digitalization in each sector. That is, data is the most essential asset for digitalization and a systemized collection and organization strategy is required from the beginning. From this perspective, we introduce representative data sources in Korea that collect information related to digitalization in the energy sector as a case study that may help those who are willing to start digitalizing their energy sector and promote digitalization options. More details of data collection are shown in Appendix E.

(Data collection through open data portals) The Open Government Data system in Korea provides public data to the private sector for business innovation and public benefit. The Open Government Data Portal (available at www.data.go.kr) offers various national priority data, including information from organizations like KEPCO, KRX, KEA, KECO, and the Ministry of Environment. These data are accessible through file downloads or Open APIs and are regularly updated

(Korea Electric Power Corporation (KEPCO)) KEPCO is a market-type public corporation under the Ministry of Trade, Industry and Energy responsible for supplying electricity. They manage a total of 245 public data, with about 18 representative datasets related to energy digitalization. These datasets primarily focus on electric vehicles, including information on charger capacity, vehicle status by region, and latitude/longitude of charging stations. Other data areas include information and communication equipment status, electricity transmission and distribution, and research and development. KEPCO's Energy Marketplace provides further data on electric vehicles through its portal.

(Korea Power Exchange (KPX)) The KPX is a quasi-governmental agency under the Ministry of Trade, Industry, and Energy responsible for operating the electricity market and the electric power system in South Korea1. It was established in 2001 when the power generation division of KEPCO (Korea Electric Power Corporation) was divided into a competitive structure. The primary goals of KPX are to ensure fair and transparent operation of the electricity market and to maintain stable and efficient operation of the power grid. As part of its responsibilities, KPX collects and manages energy digitization-related data. Some of the representative datasets include the "Status of Informationization Projects" and the "Status of Open Government Data," which are implemented by the Ministry of Information Technology. These datasets provide valuable insights into various aspects of energy management and are regularly updated.

(Other governmental and quasi-governmental organizations)

- (Korea Energy Agency (KEA)) KEA is a quasi-governmental agency under the Ministry of Trade, Industry and Energy. Established in 1980, KEA focuses on reducing carbon dioxide emissions and promoting energy utilization rationalization projects. They provide data on "Electric Vehicle Quick Charging Station Installation Status by Region," including usage (kWh), collected annually.
- (Korea Environment Corporation (KECO)) KECO, under the Ministry of Environment, contributes to environmentally friendly development. They offer data on "Status of Public Fast Chargers" and "Installation and Usage of EV Chargers." This information includes details like region, charging location, charger ID, installation year, fast charging amount, charger type, and number of charging cycles.
- (Ministry of Environment (MoE)) Responsible for environmental preservation, pollution prevention, and water resource management, MoE collects and updates data on "Electric Vehicle Quick Charging Station Supply Status." This data includes the year and number of quick charging stations.

(Other relative foundation corporations (Smart Grid Business Unit, Smart Grid Data Center))

- (Korea Smart Grid Initiative (KSGI)) KSGI is a foundation corporation established to systematically support the smart grid business, a key policy for low-carbon green growth. Their goal is to foster smart grid technology as a new growth engine through innovation in green energy technology. Under the leadership of the management support team, KSGI collects data on the "distribution status of smart grid core devices," including detailed information on "energy storage systems (ESS)" and "intelligent electricity metering systems (AMI)".

(Smart Grid Data Center) Created by the Korea Smart Grid Association (KSGA), this platform provides both domestic and overseas statistical information on smart grids, new energy industries, and research. It covers topics such as electricity, energy, power, energy data, and overseas expansion. Specific datasets include “Electricity New Business Registration Statistics” (related to power brokerage, electric vehicle chargers, and renewable energy supply) and “Intelligent Power Grid Operator Registration Statistics” (details on companies participating in demand resource trading markets).

5.6 Voices from the field considering digitalization.

Even though the National Digitalization Readiness Index evaluated the condition of the energy sector’s digitalization, these are based on data from which practical experts might have a different perspective. In this regard, we have conducted a short survey targeting a few experts who are participating in research and development, actual operation, and related project development and implementation of digitalization in the energy sector. The first two target groups were experts in Korea and Thailand, considering the difference in the implementation of digitalization options. A total of 8 people were asked for the survey, and two different versions of the questionnaire were provided (please refer to Appendix F). For a clearer understanding and to receive their opinions, the survey was done based on local languages (note that the questionnaire shown in the index is translated into English).

As a result, all 5 experts in Korea responded on time. Unfortunately, the Thailand officials and experts did not give any answers. To summarize the results, Korean experts consider digitalization in Korea’s energy sector as follows:

When asked about the level of technology and momentum for global digitalization in the energy sector, respondents in Korea rated it as medium, with an average score of 3.4 out of 5. When asked to rate the level of success in detail, digital communication and remote technologies were considered the most successful factors in Korea (3.5/4), while adoption of data and automation technology was considered fairly successful with a score of 3.0/4. On the other hand, advanced technologies utilizing AI and machine learning were considered to be in need of technology innovation, with an average score of 2.0/4. Moreover, smart grid, renewable energy integration, and the adoption of digital and cloud technologies were also regarded as needs for technology innovation. For successful digitalization in the energy sector in Korea, it was suggested that efforts to develop technologies such as (a) AI applications in power generation, transmission, and distribution, (b) energy management system (EMS), IoT, Automatic Monitoring System (AMS), cloud services, and digital twinning are needed, and (3) it was emphasized that an institutional market is necessary to promote technology development.

The most common factor affecting the level of digitalization in the Korean energy sector was recognized to be access to the internet (broadband subscriptions), followed by internet quality (speed and reliability), mobile internet adoption, access to power (energy), and technology innovation. The most lacking component was recognized as the lack of active government support. Particularly, the core technologies that are successfully applied to digitalize Korea’s energy sector were mentioned to be the smart grid technology, automation, remote, and real-time monitoring, and digitizing customer interactions. On the other hand, digital twinning, AI and machine learning, and virtual power plant technologies are considered to be relatively underdeveloped.

First, digital twinning technology is regarded to be at a significant technology level, though it is currently under-utilized due to the uncertain development goals and directions and difficulties in obtaining data from the field. Second, AI and machine learning technologies have recently been applied in the energy sector due to the development of various business models. However, the hindering policies related to opening data to the public and difficulties in server establishment and management are obstacles to applying such technologies and ensuring corresponding data quality. Finally, acceleration to apply the virtual power plant technology requires various components such as energy storage facilities (ESS, etc.), distributed application of various energy sources (renewable energy sources, etc.), and related incentives or pricing policies. Even though Korea is currently establishing several demonstration projects for virtual power plants, these are limited to fundamental technology development and policies for reorganizing the power market or ensuring the distributed energy providers are missing, hindering the acceleration and dissemination of the virtual power plant technology.

It is recognized that Korea's digitalization technology in the energy sector is world-class, and new attempts are actively being made based on mobile and internet technologies. For example, KEPCO plans to complete the deployment of Advanced Metering Infrastructure (AMI) to all customers by the end of 2024. The completion of AMI is expected to provide a foundation for utilizing various digital technologies, such as high-quality big data management. Moreover, a two-way energy-sharing ecosystem is to be established by merging the power grid and data collection and analysis.

The challenge that experts identify for digitalizing Korea's energy sector is to create new opportunities by implementing an energy (power) platform that utilizes digitalization technology to connect various energy industry participants (network operators, customers, utilities, app developers, etc.) spatiotemporally and share generated data through cloud services to provide solutions for improving efficiency and optimize production and consumption. Moreover, since 2023, KEPCO has been operating an online open portal system for power data, but the data is currently limited to certain parts such as EV charging stations, and it is difficult to obtain data for failure prediction of substations and power equipment, and energy data management technology is necessary to ensure that personal information security and national energy security is not compromised. It is worth paying attention to projects such as the next-generation EMS and ADMS (Next-generation Advanced Distribution intelligent Management System), which show that energy distribution projects with clear targets and purposes of application can be successfully implemented. In addition, the necessity of easing regulations and maintaining a consistent policy direction for digitalization options to be applied in the energy sector was emphasized to improve the energy market.

6. Conclusion

The development of the NDRI by institutions like the George Washington University Environmental and Energy Management Institute, in partnership with international bodies like the Korean National Institute of Green Technology and the UN's Climate Technology Center Network and the private sector (Chatmine Technologies), underscores the impact of public-private sector collaborative efforts to support developing countries. This initiative aims to facilitate the application of digital tools for transforming energy systems, promoting access to digital public goods, and designing policies that support climate risk assessments and resilience.

One of the most significant barriers to digitalization in the energy sector of developing countries is the lack of infrastructure, both physical and digital. Many areas lack reliable electricity and internet services, which are crucial for implementing digital technologies. Additionally, the high cost of setting up digital infrastructure and the low return on investment due to smaller market sizes and purchasing power deter investments (IEA).[21] There is also a significant gap in technical expertise required to manage and integrate digital technologies into the existing energy frameworks. Developing countries often face challenges in training and retaining skilled professionals in digital technologies, which hampers the adoption and effective utilization of these innovations.

In addition, policy and regulatory environments in many developing countries are not conducive to digital innovation. The lack of clear policies, regulatory frameworks, and government support for digital technologies can create uncertainty for investors and slow down the adoption of new technologies. This is particularly evident in the energy sectors of African countries, where regulatory hurdles compound the difficulty of transitioning to more efficient and modern energy systems (Nwaiwu, 2021).

Several strategies can be employed to enhance international cooperation and support digital transformation in the energy sectors of developing countries. International bodies and developed nations can partner with developing countries to share knowledge, technical expertise, and best practices. This can include capacity-building initiatives, joint ventures in technology development, and research collaborations. Providing financial assistance through grants, loans, and funding for pilot projects can help overcome economic barriers. Technical assistance, particularly in developing regulatory frameworks and building local capacities, is also crucial. Strengthening existing multilateral agreements or establishing new ones focused on technology transfer and digitalization in energy can facilitate smoother collaboration and support.

[21] https://www.iea.org/reports/digitalisation-and-energy

Moreover, several technologies are emerging as particularly promising for advancing the digitalization of energy infrastructure in developing countries:

1. Smart Grids and Advanced Metering Infrastructure (AMI): These technologies allow for better demand response, grid management, and energy distribution efficiency. They can help utilities in developing countries manage resources more effectively and integrate renewable energy sources (IEA).
2. Internet of Things (IoT) and Big Data Analytics: These can optimize energy use and predict maintenance needs, thus saving costs and improving service reliability. IoT devices can monitor and control grid operations remotely, a significant advantage for rural and underserved areas (IEA).
3. Blockchain for Energy Transactions: Blockchain technology can facilitate secure and transparent energy transactions, enable peer-to-peer energy trading, and support the integration of renewable energy sources into the grid by providing reliable data management and transaction mechanisms (IEA).

The accompanying handbook, “Digitalization Options Handbook for the Energy Sector,” provides more information on introduced technology options.

Using the NDRI results, the research team temporarily reviewed cases in the Republic of Korea and briefly analyzed the applicability of digitalization technologies in Thailand. Moreover, a small survey was conducted targeting Korean field experts to identify how they feel about digitalization in the energy sector, what is recognized as success factors, and what challenges there are to promote and complete digitalization. This analysis does not provide a conclusion on what Thailand needs to do to digitalize its energy sector. Rather than focusing on the recommendation, it attempts to show how to use the index for digitalizing the energy sector in developing countries and share some lessons based on the NDRI.

Through the review of digital transformation in Korea, we have identified various digitalization technologies for the energy sector. Before selecting what technology to apply, the first step we have derived is to objectively observe the energy sector's status. The second is to identify and select a country with a similar energy structure that is benchmarkable. Last, we consider the fundamental components for digitalizing the energy sector, such as establishing a system for collecting and organizing relative data.

In conclusion, the developed index, NDRI, is regarded as a starting point for digitalizing the developing country’s energy sector. The index will contribute to identifying the status in terms of digitalization and showing the country's energy sector's strengths, weaknesses, and potential. Further application and case studies are required to make the assessment results more accurate.

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Appendix A – VOSViewer Visualization

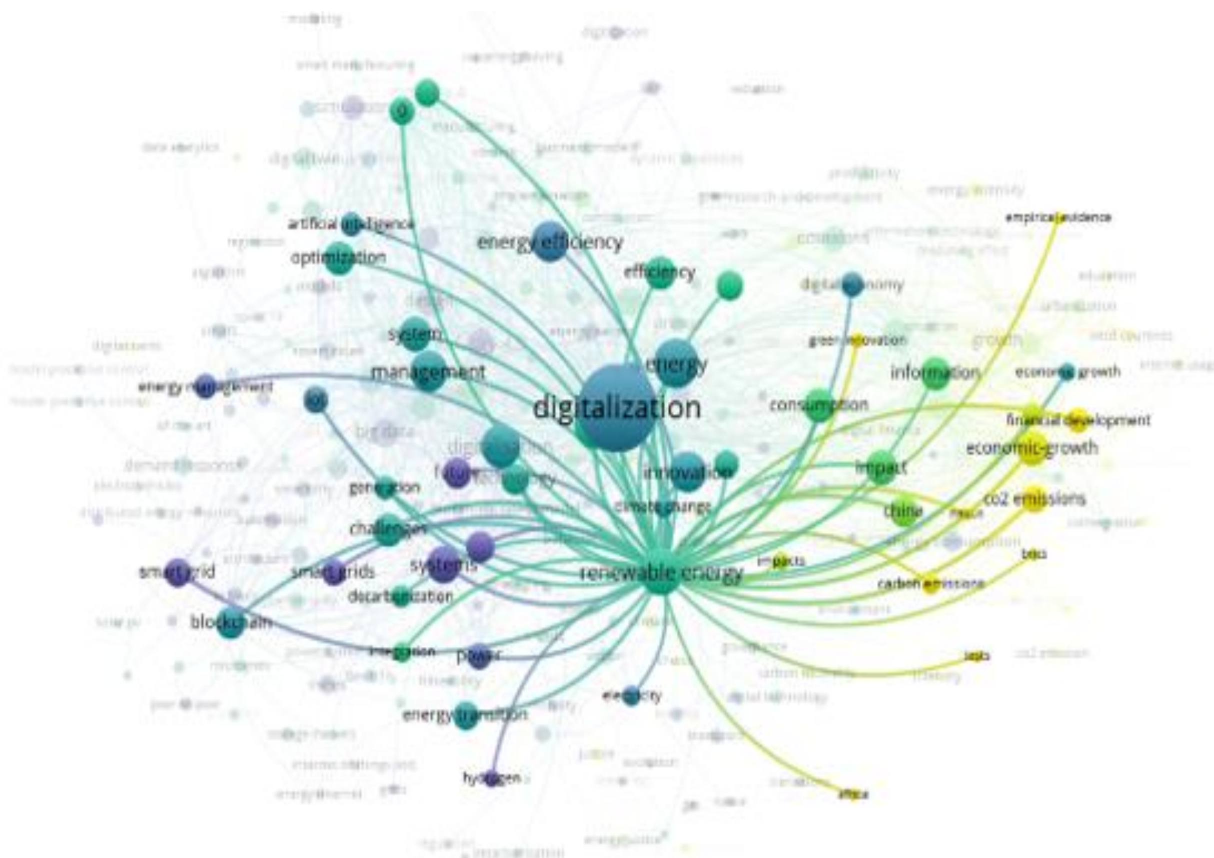

FIGURE A1: VOSVIEWER VISUALIZATION OF THE TERM DIGITALIZATION AND RELATED CONCEPTS. COLORS INDICATE SEGMENTS OF CLUSTER. WE WILL DETAIL THIS EXPLORATORY ANALYSIS IN AN ARTICLE IN 2024.

Appendix B – Data Variables used in the Analysis.

Code – ISO code for every country.

Country or Entity – Name of the country

M49 Code -

Region 1 – Geographical Classification such as Eastern Asia, Northern Africa, F

Region 2_UN classification such as Sub-Saharan Africa

Continent – Asia, Africa and Latin America.

Details on Twenty-Six Data Variables

We explain each data variable in detail.

GDP per Capita, PPP (constant 2017 international $): GDP per capita is a strong indicator of economic development, which correlates with investments in energy infrastructure and digital technologies. Higher economic capacity often enables more extensive deployment of smart energy solutions. In countries like Brazil and Malaysia, economic growth has facilitated investments in smart grid technologies and renewable energy sources, integrated through digital platforms. In Africa, countries with higher GDP per capita like Mauritius and Seychelles have greater financial resources to invest in digitalization and renewable energy projects. In South America, countries like Argentina and Uruguay with relatively higher GDP per capita have been able to implement advanced energy management systems and promote renewable energy adoption. In Asia, countries like Singapore and Japan, with high GDP per capita, have pioneered digitalization efforts in the energy sector, including smart grid technologies and renewable energy integration.

Annual CO2 equivalent emissions (per capita): This factor reflects the carbon footprint of a region's energy consumption, indicating the environmental impact and sustainability of energy systems. It also indicates the country's industrial growth[22]. In Africa, countries like South Africa have relatively high CO2 emissions per capita due to heavy reliance on coal for electricity generation. In South America, Brazil's emissions are notable due to its large-scale deforestation and reliance on fossil fuels. In Asia, China and India are significant contributors to global CO2 emissions due to their rapid industrialization and dependence on coal.

[22] Khatun, F., & Auda, A. A. S. A. (2018). Carbon dioxide emissions, energy consumption, economic growth, and financial development in GCC countries: Dynamic simultaneous equation models. Journal of Cleaner Production, 189, 708-723.

Population: Population size[23] influences energy demand, infrastructure requirements, and resource allocation, shaping energy policies and strategies. In Africa, Nigeria has one of the largest populations, driving the need for extensive energy infrastructure development to meet growing demand. In South America, countries like Brazil and Colombia face challenges in providing energy access to remote and growing populations in the Amazon region. In Asia, India and China's large populations necessitate significant energy investments to support economic development and improve living standards.

Urban Population: developing countries are also being rapidly urbanized. Urban populations often have better access to infrastructure, which can facilitate the implementation of digital energy solutions, such as smart grids and automated energy management systems. Urbanization drives energy demand growth and necessitates efficient energy management solutions, including digital technologies for grid optimization and demand-side management. These advancements are crucial for optimizing energy consumption and reducing wastage. Major cities[24] in South America, such as São Paulo and Bogotá, are exploring smart city initiatives that integrate digital technologies into their energy systems to cope with growing urban energy demands. In South America, countries like Colombia are implementing smart grid projects in urban centers to improve energy efficiency and reliability. In Asia, urbanization in countries like China and India has led to the deployment of smart meters and advanced grid infrastructure to manage energy consumption and reduce losses.

Literacy Rate All Genders: Literacy rates[25] influence the adoption and utilization of digital technologies for energy management, including smart meters, energy monitoring systems, and digital platforms for energy services. Educated populations are more likely to utilize and support innovations in digital energy management. In Kenya, educational programs aiming to boost literacy have been coupled with initiatives to introduce digital skills necessary for managing the country's evolving digital energy infrastructure. Improving literacy rates in Africa, South America, and Asia enhances the effectiveness of digitalization efforts in the energy sector by enabling broader participation and understanding of digital technologies among the population.

Learning-Adjusted Years of School: Education level is directly linked to the capacity of the workforce to adopt and innovate with new technologies[26], including those in the energy sector. In Singapore and South Korea, high education standards have facilitated the development and deployment of sophisticated energy management systems.

Literacy Rate Female: Female literacy rates influence socioeconomic development, workforce participation, and the adoption of technological innovations, including digital energy solutions[27]. In

[23] United Nations, Department of Economic and Social Affairs, Population Division. (2019). World Population Prospects 2019: Highlights (ST/ESA/SER.A/423).

[24] https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf; https://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2018_data_booklet.pdf.

[25] https://uis.unesco.org/en/topic/literacy

[26] https://shorturl.at/muDJV

[27] https://uis.unesco.org/en/topic/literacy

Africa, improving female literacy rates in countries like Rwanda has contributed to broader access to education and opportunities for women to participate in decision-making processes, including energy-related initiatives. In South America, countries like Uruguay have achieved high levels of female literacy, fostering gender-inclusive policies and programs for sustainable development, including in the energy sector. In Asia, initiatives in countries like Bangladesh aim to enhance female literacy rates to empower women and promote their involvement in the energy workforce and community-level projects.

Literacy Rate Male: Male literacy rates, like female literacy rates, influence socioeconomic development and the adoption of digital energy solutions, contributing to overall progress and inclusivity. Similar to female literacy, improving male literacy rates in Africa, South America, and Asia enhances access to education, promotes innovation, and facilitates the adoption of digital technologies in the energy sector.

Gender Development Index: The Gender Development Index (GDI) assesses gender disparities in education, health, and living standards, highlighting areas for gender-responsive policy interventions, including in the energy sector[28]. Improving the Gender Development Index in Africa, South America, and Asia involves addressing gender inequalities in access to education, healthcare, and economic opportunities, including in the energy sector. Initiatives such as promoting women's participation in STEM (science, technology, engineering, and mathematics) fields and leadership roles in energy-related industries and policymaking can contribute to more inclusive and sustainable energy transitions.

Fixed Broadband Subscriptions (per 100 people): Fixed broadband subscriptions are crucial for enabling advanced digital technologies that improve productivity and welfare in developing economies, such as the deployment of smart grid technologies, facilitates energy management systems, and supports the integration of renewable energy sources into the grid. These technologies can significantly enhance energy sector efficiency through better grid management and energy distribution optimizations (Siope Vakataki 'Ofa, 2018; ITU[29]). In Asia, countries like Singapore have leveraged broadband connectivity to support smart nation initiatives, significantly enhancing public and private sector efficiencies. In Africa, countries like Kenya have made significant strides in expanding fixed broadband infrastructure, supporting initiatives such as off-grid solar systems and smart metering. In South America, Brazil has been investing in broadband infrastructure to enhance energy efficiency and promote digitalization in the energy sector. In Asia, countries like South Korea have advanced broadband networks, enabling innovative energy management solutions and promoting renewable energy integration.

Mobile Cellular Subscriptions (per 100 People): Mobile connectivity is vital for real-time data exchange and remote control of distributed energy resources, supporting the deployment of mobile-based energy management systems and digital services for energy access and efficiency. In Kenya, mobile applications like M-KOPA enable pay-as-you-go solar electricity, enhancing access to energy in rural areas. Similarly in other countries in Africa, mobile-based payment systems and energy monitoring apps are being used to improve energy access and efficiency in off-grid areas. In South America, mobile-enabled energy services are helping to expand access to electricity in remote regions of countries like Brazil and Peru. In

[28] https://hdr.undp.org/

[29] https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2020.pdf

Asia, mobile applications for energy management and payment systems are increasingly being adopted to enhance energy access and efficiency in both urban and rural areas.

Access to Electricity (% of population): Universal access to electricity is foundational for any digital advancement in the energy sector. It allows for the deployment of digital infrastructure, including data centers and communication networks essential for modern energy systems. Programs in rural India and parts of Africa (Ethiopia) focus on expanding electricity access through decentralized solar power systems, which are increasingly coupled with digital monitoring and control technologies. In South America, countries like Peru have implemented electrification programs to reach remote and underserved communities in the Amazon region. In Asia, countries like Bangladesh have achieved notable improvements in electricity access through initiatives like the Rural Electrification Program, which utilizes solar home systems to provide electricity to off-grid areas.

Proportion of population with primary reliance on clean fuels and technologies for cooking (%): Access to clean cooking fuels and technologies is crucial for public health, environmental sustainability, and reducing indoor air pollution-related health risks[30]. In Africa, a significant portion of the population relies on traditional biomass for cooking, leading to health issues and environmental degradation. Efforts in countries like Kenya to promote clean cooking solutions such as biogas and improved cookstoves are underway. In South America, initiatives in Peru aim to reduce reliance on traditional biomass by promoting LPG (liquefied petroleum gas) for cooking. In Asia, countries like Bangladesh are implementing programs to increase access to clean cooking fuels such as natural gas and biogas.

Primary Energy Consumption per Capita (kWh/person): This metric indicates the energy efficiency and the impact of energy consumption on the economy and the environment[31]. In Morocco, efforts to reduce primary energy consumption include enhancing energy efficiency in the building and industrial sectors. Higher primary energy consumption per capita in Africa, South America, and Asia underscores the need for energy efficiency measures and investments in renewable energy to meet growing demand sustainably.

Per Capita Electricity – kWh: The consumption of electricity per capita is indicative of the level of industrialization and urbanization, which are closely tied to the availability and use of digital technologies in the energy sector[32]. In Africa, countries like South Africa have relatively higher per capita electricity consumption compared to their neighbors, highlighting disparities in energy access and infrastructure development. In South America, countries like Chile have higher per capita electricity consumption rates due to industrialization and urbanization. In Asia, countries like Japan and South Korea have high per capita electricity consumption levels, driven by industrial activities and technological advancement.

Low-Carbon Electricity (% of Electricity): Transitioning to low-carbon electricity sources such as renewables and nuclear power is crucial for reducing CO2 emissions and aligning with global climate

[30] Bonjour, S., et al. (2013). Solid fuel use for household cooking: country and regional estimates for 1980–2010. Environmental Health Perspectives, 121(7), 784-790.

[31] https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances

[32] https://datacatalog.worldbank.org/search/dataset/0037712

goals[33]. Developing low-carbon technologies within the electricity sector plays a significant role in this transition, especially in nations where electricity is a major emission source (Xia Qing, 2009). n Africa, countries like Kenya and Morocco are investing in renewable energy projects such as wind and solar to increase the share of low-carbon electricity in their energy mix. In South America, countries like Costa Rica and Uruguay have achieved high proportions of low-carbon electricity through hydropower and wind energy. In Asia, countries like China and India are scaling up renewable energy deployment to reduce carbon emissions and enhance energy security.

Renewables (% of Electricity): Increasing the share of renewables in the electricity mix is essential for sustainable development, reducing environmental impact, and improving resilience against fossil fuel price volatility. In Africa, countries like Ethiopia and South Africa are expanding their renewable energy capacity through wind, solar, and hydroelectric projects to enhance energy access and promote economic growth. In South America, countries like Uruguay and Costa Rica have achieved high proportions of renewable electricity through investments in wind, solar, and hydropower. In Asia, countries like Indonesia and Vietnam are ramping up renewable energy deployment to meet growing electricity demand and address environmental challenges.

Hydro (% of Electricity): Hydroelectric power is a renewable energy source that can contribute to a sustainable energy mix, reducing dependence on fossil fuels and mitigating greenhouse gas emissions. In Africa, Ethiopia has significant hydroelectric potential, with projects like the Grand Ethiopian Renaissance Dam aiming to increase electricity generation. In South America, Brazil's Itaipu Dam is one of the world's largest hydroelectric plants, providing a substantial portion of the country's electricity. In Asia, countries like Nepal and Bhutan rely heavily on hydroelectricity for their energy needs. SE Asia has seen vast expansion of hydroelectricity, part of China’s Belt and Road Initiative[34].

Solar (% of Electricity): Solar power is pivotal for reducing dependence on fossil fuels, especially in regions with high solar irradiance, contributing to energy security and sustainability. Solar energy is abundant in regions with high solar irradiance, offering a sustainable and decentralized energy source for electrification and digitalization in remote and off-grid areas. India’s solar projects in Gujarat and Rajasthan have dramatically increased solar’s share in the electricity mix, supporting rural electrification and reducing carbon emissions[35]. In Africa, countries like Kenya and Rwanda are leveraging solar energy to increase electricity access and support digitalization efforts through off-grid solar solutions and utility-scale solar projects.

Wind (% of Electricity): Wind energy is a critical component of the renewable energy portfolio, providing a significant reduction in carbon emissions.[36] In Africa, countries like Egypt and Morocco are investing in wind energy projects to diversify their energy mix and increase renewable energy capacity. In South

[33] https://www.iea.org/reports/world-energy-outlook-2020

[34] Wang, J., et al. (2014). Review on research and development of hydropower in China. Renewable and Sustainable Energy Reviews, 37, 583-597.

[35] https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023

[36] https://gwec.net/global-offshore-wind-report-2020/

America, countries like Argentina and Brazil are harnessing their wind resources to expand their renewable energy portfolio and reduce carbon emissions. In Asia, countries like China and India are leading the deployment of wind energy through onshore and offshore wind projects to meet growing electricity demand and address environmental concerns.

Coal (% of Electricity): Reducing coal's share in energy production is crucial for lowering greenhouse gas emissions and health-related impacts from air pollution. In Africa[37], countries like South Africa are facing challenges in reducing their dependence on coal due to existing infrastructure and economic considerations. In South America, countries like Colombia are seeking to diversify their energy mix away from coal by increasing investments in renewable energy. In Asia, countries like Indonesia and Vietnam are still heavily reliant on coal for electricity generation, but efforts are underway to shift towards cleaner alternatives such as natural gas and renewables. China's aggressive policy to reduce the share of coal in its energy mix has led to substantial growth in renewable energy investments.

Carbon Intensity of Electricity (gCO2/kWh): Lowering the carbon intensity of electricity generation is vital for meeting international climate commitments and improving public health. China and India should decommission their coal-fired power plants and increase their share of renewables in their climate action plans. As described before, in Africa, South America, and Asia, reducing the carbon intensity of electricity generation requires investments in renewable energy, energy efficiency measures, and policy incentives to transition away from fossil fuels and towards low-carbon technologies.

Fossil fuels - % electricity: The share of fossil fuels in electricity generation impacts energy security, environmental sustainability, and vulnerability to price fluctuations in global energy markets[38]. In Africa, countries like South Africa heavily depend on coal for electricity generation, leading to environmental concerns and efforts to diversify the energy mix. In South America[39], Venezuela relies extensively on oil for power generation, while countries like Argentina are shifting towards renewable energy sources to reduce fossil fuel dependence. In Asia, coal remains a dominant energy source for electricity generation in countries like China and India, despite efforts to increase renewable energy deployment.

Gas - % electricity: Natural gas is a relatively cleaner fossil fuel compared to coal and oil, providing flexibility in electricity generation and serving as a transition fuel towards low-carbon energy systems[40]. In Africa, countries like Nigeria are expanding their natural gas infrastructure to increase electricity generation capacity and reduce reliance on more polluting fuels. In South America, countries like Argentina are increasing natural gas utilization in power generation to diversify their energy mix and reduce emissions. In Asia, countries like Indonesia are investing in natural gas-fired power plants to meet growing electricity demand and reduce emissions from coal-based generation.

[37] https://www.iea.org/reports/coal-information-overview/consumption
[38] https://www.iea.org/reports/world-energy-outlook-2020/overview-and-key-findings
[39] https://www.iea.org/reports/world-energy-outlook-2020/overview-and-key-findings
[40] https://igu.org/resources/2020-world-lng-report/

PRISMA Analysis Related to Each Data Variable

Population (2020 or estimate). Total population of each country in 2020

Source: Hannah Ritchie, Lucas Rodés-Guirao, Edouard Mathieu, Marcel Gerber, Esteban Ortiz-Ospina, Joe Hasell and Max Roser (2023) - "Population Growth". Published online at OurWorldInData.org. : 'https://ourworldindata.org/population-growth' [Online Resource]

GDP per capita, PPP [41] (constant 2017 international $): This GDP per capita indicator provides information on economic growth and income levels from 1990. This data is adjusted for inflation and for differences in the cost of living between countries. This data is expressed in international-$ at 2017 prices.

Source: Our World in Data

Per capita electricity – kWh: Total electricity generation per person measure in kilowatt-hours per person.

Source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023); Population based on various sources (2023) – with major processing by Our World in Data

Primary energy consumption per capita (kWh/person): Primary energy consumption per capita measured in kilowatt-hours per person.

Source: U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2023); Population based on various sources (2023) – with major processing by Our World in Data

Carbon intensity of electricity - gCO2/kWh: Carbon intensity of electricity generation measured in grams of CO_2 equivalents per kilowatt-hour.

Source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023) – with major processing by Our World in Data

Annual CO_2emissions (per capita): Per capita emissions represent the emissions of an average person in a country or region - they are calculated as the total emissions divided by population. This data is based on territorial emissions, which do not account for emissions embedded in traded goods. Emissions from international aviation and shipping are not included in any country or region's emissions. They are only included in the global total emissions.

Source:
Data source: Global Carbon Budget (2023); Population based on various sources (2023)

Mobile cellular subscriptions (per 100 people): Mobile phone subscriptions per 100 people, 2021. This number can get over 100 when the average person has more than one subscription to a mobile service.

[41] https://ourworldindata.org/grapher/gdp-per-capita-worldbank?time=2021

Data Source: International Telecommunication Union (via World Bank) – Learn more about this data OurWorldInData.org/technological-change

Proportion of population with primary reliance on clean fuels and technologies for cooking (%) - proportion of population with primary reliance on clean fuels and technologies for cooking (%) (SDG 7.1.2)

Source: https://platform.who.int/data/maternal-newborn-child-adolescent-ageing/indicator-explorer-new/MCA/proportion-of-population-with-primary-reliance-on-clean-fuels-and-technologies-for-cooking-(-)-(sdg-7.1.2)

Access to electricity (% of population): percent population with access to electricity Source: https://data.worldbank.org/indicator/

Fixed broadband subscriptions (per 100 people). Source: https://data.worldbank.org/indicator/IT.NET.BBND

Low-carbon electricity - % electricity: Electricity generation form low-carbon sources. Measured in terawatt-hours.

Source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023) – with major processing by Our World in Data

Renewables - % electricity: Share of electricity production from renewables, 2020. Renewables include electricity production from hydropower, solar, wind, biomass & waste, geothermal, wave, and tidal sources.

Solar - % electricity: Share of electricity production from solar

Wind - % electricity: Share of electricity production from wind

Coal - % electricity: Share of electricity production from coal

Fossil fuels - % electricity: Share of electricity production from fossil fuels

Gas - % electricity: Share of electricity production from natural gas

Hydro - % electricity: Share of electricity production from hydro

Source: Data source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute -Statistical Review of World Energy (2023) – https://ourworldindata.org/renewable-energy

Learning-Adjusted Years of School: New measure called Learning-Adjusted Years of Schooling (LAYS) : Defining A New Macro Measure of Education. The standard summary metric of education-based human capital used in macro analyses—the average number of years of schooling in a population—is based only on quantity. But ignoring schooling quality turns out to be a major omission. As recent research shows, students in different countries who have completed the same number of years of school often have vastly different learning outcomes. This paper therefore proposes a new summary measure, Learning-Adjusted Years of Schooling (LAYS)[42], that combines quantity and quality of schooling into a single easy-to-understand metric of progress. The cross-country comparisons produced by this measure are robust to different ways of adjusting for learning (for example, by using different international assessments or different summary learning indicators), and the assumptions and implications of LAYS are consistent with other evidence, including other approaches to quality adjustment; Source: World Bank:[43]

Urban Population: Urban population as percent of the total population; Source: World Bank:[44]

Gender Development Index: Defined by UNDP - GDI measures gender inequalities in achievement in three basic dimensions of human development: health, measured by female and male life expectancy at birth; education, measured by female and male expected years of schooling for children and female and male mean years of schooling for adults ages 25 years and older; and command over economic resources, measured by female and male estimated earned income; Source: UNDP[45]

Literacy Rate All Genders: Literacy rate, adult total (% of people ages 15 and above); Source: UNESCO[46] Institute for Statistics (UIS).

Literacy Rate Female: Literacy rate, females adult total (% of people ages 15 and above); Source: UNESCO[47] Institute for Statistics (UIS).

Literacy Rate Male: Literacy rate, male adult total (% of people ages 15 and above); Source: UNESCO[48] Institute for Statistics (UIS).

Governance (World Bank 2022[49]): World Governance Index 2022 The World Governance Index (WGI) is a research project that measures the quality of governance in over 200 countries and territories, as reported by the World Bank. The index covers six dimensions of governance: voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption.

Global Innovation Index (WIPO, 2022)[50]: The 2022 edition of the Global Innovation Index (GII) reveals the most innovative economies in the world, based on investment in science and innovation,

[42] Filmer, D., Rogers, H., Angrist, N., & Sabarwal, S. (2020). Learning-adjusted years of schooling (LAYS): Defining a new macro measure of education. Economics of Education Review, 77, 101971.
[43] https://documents.worldbank.org/en/publication/documents-reports/documentdetail/243261538075151093/learning-adjusted-years-of-schooling-lays-defining-a-new-macro-measure-of-education
[44] https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS
[45] https://hdr.undp.org/gender-development-index#/indicies/GDI
[46] https://data.worldbank.org/indicator/SE.ADT.LITR.ZS
[47] https://data.worldbank.org/indicator/SE.ADT.LITR.ZS
[48] https://data.worldbank.org/indicator/SE.ADT.LITR.ZS
[49] https://databank.worldbank.org/source/worldwide-governance-indicators
[50] https://www.wipo.int/publications/en/details.jsp?id=4679&plang=EN

technological progress, technology adoption, and socioeconomic impact. This report uses the overall score of each country.

Appendix C – List of Countries

Country or Area	Comp. Normalized Score	Comp. Standard. Z-Score	Country or Area	Comp. Normalized Score	Comp. Standard. Z-Score	Country or Area	Comp. Normalized Score	Comp. Standard. Z-Score
Singapore	0.996	3.261	Cyprus	0.633	1.530	Viet Nam	0.386	0.377
Republic of Korea	0.779	2.162	China	0.591	1.284	Jamaica	0.378	0.323
Japan	0.761	2.071	Malaysia	0.543	1.091	Indonesia	0.368	0.292
United Arab Emirates	0.751	2.115	Saudi Arabia	0.536	1.120	Kazakhstan	0.367	0.341
Qatar	0.739	2.134	Bahrain	0.520	1.061	Costa Rica	0.367	0.324
Israel	0.696	1.796	Mauritius	0.481	0.803	Botswana	0.353	0.230
			Chile	0.465	0.748	Colombia	0.340	0.192
			Kuwait	0.463	0.817	Philippines	0.340	0.169
			Uruguay	0.454	0.688	Panama	0.337	0.220
			Thailand	0.409	0.499	Jordan	0.334	0.145
			India	0.401	0.427	Mexico	0.331	0.180
			Georgia	0.400	0.432	South Africa	0.323	0.120
			Oman	0.395	0.491	Argentina	0.317	0.122

Country or Area	Comp. Normalized Score	Comp. Standard. Z-Score	Country or Area	Comp. Normalized Score	Comp. Standard. Z-Score	Country or Area	Comp. Normalized Score	Comp. Standard. Z-Score
Morocco	0.293	-0.024	El Salvador	0.202	-0.415	Angola	0.060	-1.012
Dominican Republic	0.292	-0.005	Cambodia	0.185	-0.497	Myanmar	0.048	-1.061
Brazil	0.285	-0.022	Pakistan	0.179	-0.512	Iraq	0.043	-1.075
Azerbaijan	0.276	-0.086	Benin	0.170	-0.576	Mali	0.042	-1.102
Tunisia	0.276	-0.087	Algeria	0.166	-0.556	Guinea	0.040	-1.115
Armenia	0.270	-0.100	Bangladesh	0.136	-0.694			
Namibia	0.268	-0.141	Kyrgyzstan	0.124	-0.740			
Peru	0.267	-0.116	Tajikistan	0.124	-0.752			
Mongolia	0.259	-0.148	Uganda	0.123	-0.768			
Rwanda	0.251	-0.244	Zambia	0.116	-0.795			
Sri Lanka	0.240	-0.228	Guatemala	0.109	-0.797			
Ghana	0.239	-0.273	Togo	0.108	-0.831			
Uzbekistan	0.236	-0.267	Niger	0.103	-0.856			
Senegal	0.234	-0.303	Honduras	0.103	-0.835			
Ecuador	0.217	-0.343	Ethiopia	0.103	-0.851			
Kenya	0.217	-0.362	Mozambique	0.093	-0.897			
Egypt	0.216	-0.335	Mauritania	0.090	-0.897			
Paraguay	0.208	-0.360	Nicaragua	0.089	-0.887			
			Nepal	0.089	-0.896			
			Burkina Faso	0.085	-0.926			
			Madagascar	0.083	-0.928			
			Nigeria	0.081	-0.925			
			Cameroon	0.081	-0.937			
			Zimbabwe	0.068	-0.988			

Appendix D – Energy sector characteristics of Korea and Thailand

Republic of KOREA

<u>(Energy source and consumption at the national level)</u>

The total energy consumption of Korea was recovering quickly from a 4.4% decline in the second half of 2020, when the economy slowed sharply due to the spread of COVID-19, though it fell again by 4.0% in the first half of 2023. The domestic and international economic slowdown that began in the second half of 2020 and the subsequent decline of production activities in the industrial sector intensified, accelerating the decline in energy consumption. By energy source, oil, coal, and natural gas declined rapidly, while nuclear power was stagnant and renewables and other energy sources slightly increased.

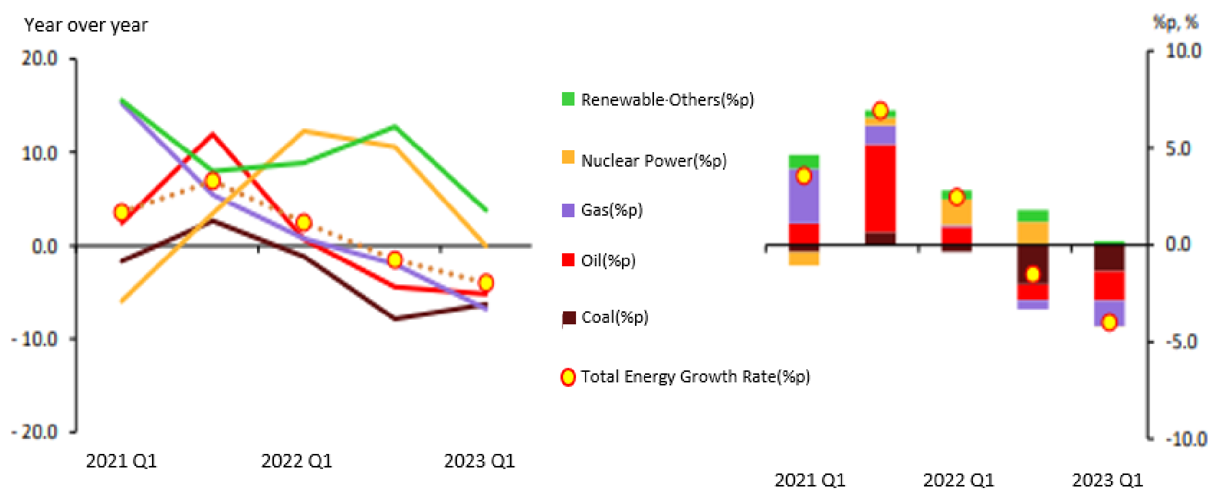

FIGURE D1: ENERGY CONSUMPTION OF KOREA BY SOURCE[51].

Oil consumption in Korea decreased by 5.2%. There was a slight increase in consumption in the transport sector, though it declined rapidly in the industry sector due to a sharp drop in petrochemical production activities. In detail, an 18.3% decline in the industry sector was shown due to the decrease in petrochemical production. This led to a 6.6% and 27.6% decline in lead and LPG, resulting in a 9.1 decline in overall oil consumption. On the contrary, oil consumption in the transportation sector increased by 1.0% due to the lower gasoline and diesel prices compared to the same period a year earlier, when international oil prices spiked due to the Ukraine-Russia war. For the building sector, oil consumption

[51] Korea Energy Economics Institute. (2023). 2024 Korea energy demand outlook: 2023 Second half. Ulsan: Korea Energy Economics Institute.

decreased by 5.3% due to the decrease in heating days and other energy sources continue to be substituted.

Coal consumption in Korea decreased by 6.3% year-on-year due to a rapid decline in power generation and industry sectors. In power generation, substitutes such as nuclear and renewable power continue to expand as they have an advantage over conventional coal power generation. Moreover, the lack of transmission networks to connect to the capital energy consumption sites results in a 2.5% decrease in coal power generation and a 7.7% decrease in consuming coal for power generation. In the industry sector, coal consumption decreased by 2.0%, 3.4%, and 21.3% in steel, petrochemicals, and other industries, respectively, affected by the decline in manufacturing activity.

For natural gas, consumption decreased by 6.8% year-on-year, with declines in both the power generation and final consumption sectors. In the power generation sector, total power generation decreased by 1.8% while other generation sources such as nuclear, coal, renewables, and others decreased by only 0.5%. This resulted in a 5.2% decrease in gas inputs for power generation. Gas consumption in the industry sector and urban consumption decreased by 4.5% due to increased gas tariffs. Consumption in the building sector also decreased by 8.6% due to higher tariffs and fewer days for heating.

Nuclear power generation increased by 6.0% due to the application of large-capacity generators, but the capacity utilization rate dropped by 5.0%, resulting in stagnant power generation compared to last year. As the 1.4GW unit was newly commissioned in December 2022, the installed capacity of nuclear power increased by 6.0% by the end of the first half of 2023. However, the capacity utilization rate decreased to the low 70% as some nuclear power plants entered planned preventive maintenance.

Renewable and other energy consumption increased by 3.8%, led by the power generation sector, but the growth rate slowed significantly. In the final consumption sector, renewable and other energy consumption decreased by 3.4% year-on-year, but renewable and other electricity generation increased by 4.4%. By source, solar, bio, fuel cell, and hydropower generation grew by 7.4%, 18.1%, 6.5%, and 5.1%, respectively, while wind and IGCC (integrated gasification combined cycle) power generation grew by 3.5% and 94.4%, respectively. Although the power generation sector led the growth of renewable and other energy consumption, the growth of renewable and other power generation slowed down significantly, which was caused by the slowdown in the growth of solar power facilities due to high-interest rates resulting in dampened investment sentiment and strengthening of related regulations.

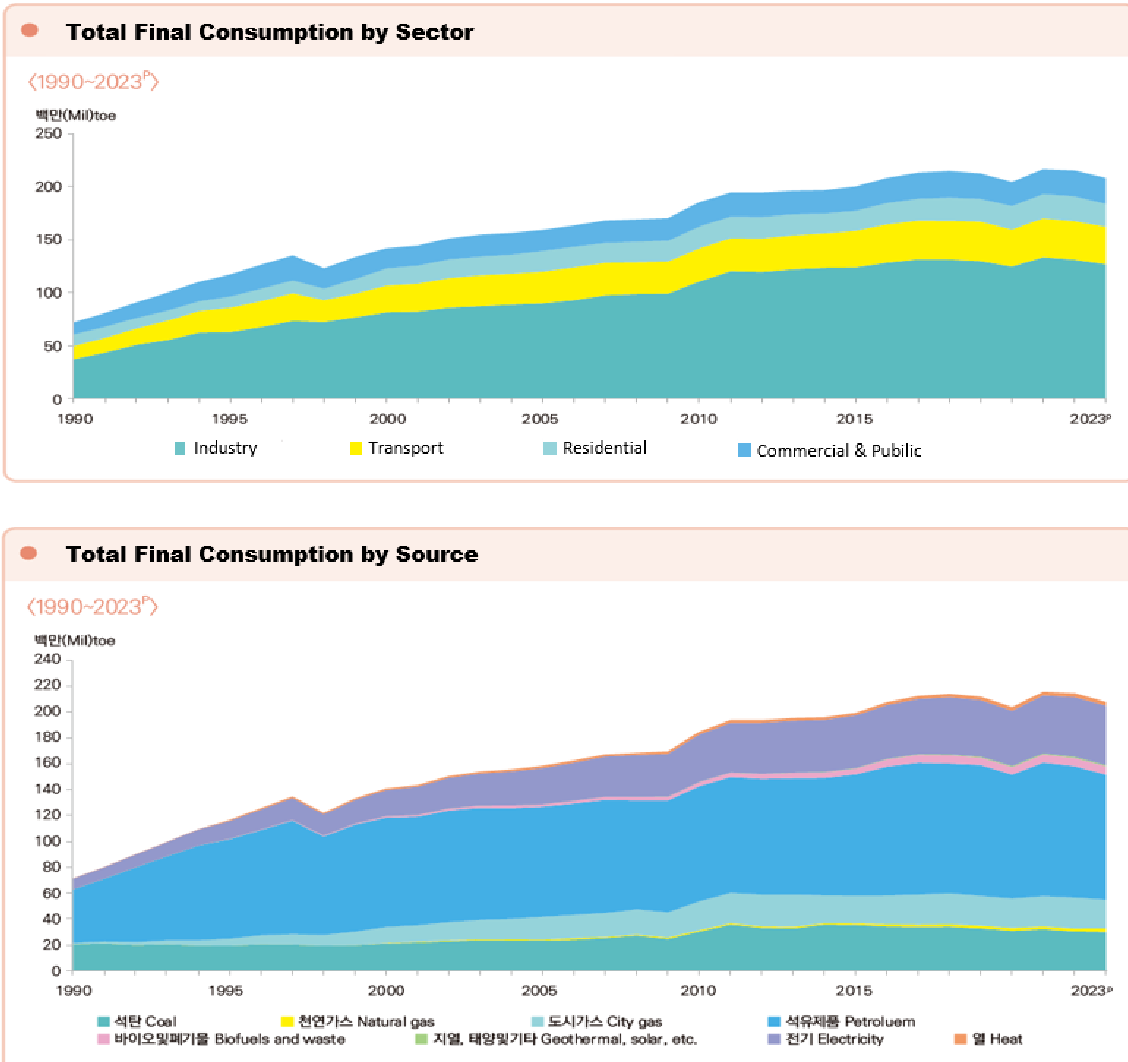

FIGURE D2: ENERGY CONSUMPTION TREND BY SECTOR AND SOURCE IN KOREA.[52]

<u>(Energy management and operation system at the national level)</u>

Other energy sources, such as oil, coal, and gas, are managed similarly to other countries. However, Korea has a unique management and operation structure for electricity. Electricity is a good that is produced and consumed simultaneously, which is not easy to store. Therefore, it is essential to secure adequate reserve facilities to ensure a stable power supply. The Korean power industry is characterized by having a high dependence on foreign energy sources (approximately 97%). This requires stable energy security, and the geopolitical isolation of the power system makes it impossible to import and export energy from neighboring countries. Since electricity generation is concentrated in the southern region

[52] Korea Energy Economics Institute. (2023). 2024 Korea energy demand outlook: 2023 Second half. Ulsan: Korea Energy Economics Institute.

while consumption is concentrated in metropolitan areas, long-distance transmission is essential, and it is difficult to control the demand through market functions. Therefore, large-scale investment in power facility construction is necessary to secure supply capacity.

In the structure of the Korean electricity system, power generation is done by 6 power plant companies, smaller private companies, and district electricity companies. The generated power is managed by the Korea Electricity Power Corporation (KEPCO), which purchases and distributes electricity to consumers through its transmission and distribution network.

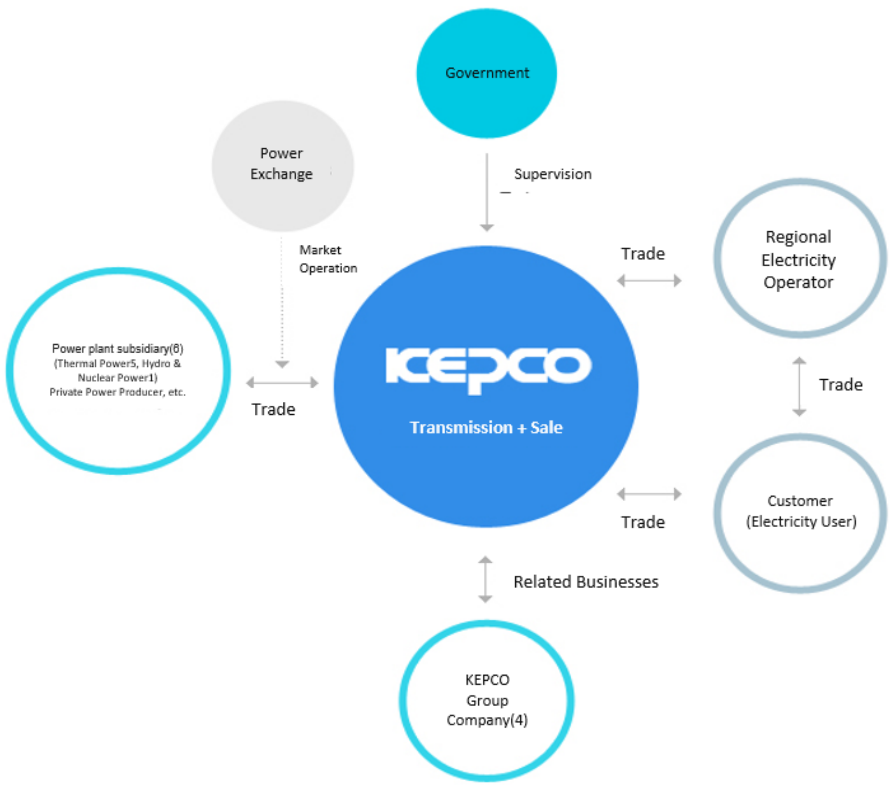

FIGURE D3: ENERGY (ELECTRICITY) MANAGEMENT FRAMEWORK IN KOREA.[53]

KEPCO manages the transmission and distribution network, including maintenance and expansion of related facilities. In particular, the construction of facilities such as transmission pylons and substations is carried out by preparing environmental impact assessments, holding public briefings, and earning agreements from local councils and residents. The Ministry of Environment and 11 other central administrative agencies approve the final approval.

Korea's demand management can be categorized into load management and efficiency improvement. Load management is implemented to reduce the difference between peak and minimum loads by suppressing peaks and increasing late-night demand, thereby promoting load leveling and improving the

[53] https://home.kepco.co.kr/kepco/KO/C/htmlView/KOCCHP001.do?menuCd=FN05030301

utilization efficiency of power supply facilities. Efficiency improvement aims to save energy resources and preserve the environment by reducing electricity demand through improving the efficiency of electricity utilization. To this end, KEPCO promotes developing and distributing high-efficiency devices to improve the efficiency of devices, diagnosing customers' electricity facilities, and providing power-saving information.

The term demand side management (DSM) originated in the United States in the 1970s and gradually spread to other countries. Despite its theoretical economics and high potential for contribution, it has not received much attention due to the supply-side-oriented power supply planning of electricity power generation companies. However, supply-oriented power generation faces difficulties in securing power plant construction sites and financing large investments for construction which recently emphasizes the importance of demand management along with the concept of integrated resources planning, which seeks the optimal combination of supply-side and demand-side alternatives as part of least cost planning, and considers demand management as an essential consideration in power supply planning.

(Business model of the Energy industry)

Electricity market system and price characteristics: Korea's business model, particularly for electricity, is a market-based system. The electricity market is a system for coordinating and managing the overall production and distribution of electricity, referred to as a "POOL" because the electricity generated by power plants is centrally collected and sold without discrimination. The electricity market in Korea is centered on the 'Korea Electricity Exchange.' Korea's market is divided into two: the wholesale market and the retail market.

First, the wholesale electricity market trades electricity, capacity, and electricity reserve. Trade is made between all stakeholders including electric operators and other customers who are allowed to trade wholesale electricity. There are 3 types of wholesale electricity markets: (1) Centralized Pool (or Gross Pool) where power is traded only between power generators and operators (sellers) in the wholesale power market, (2) Contract-driven market (Decentralized Pool, Net Pool, or Bilateral contracts) where transactions are done by direct contractors between power generators and operators, and (3) a Hybrid market which is a mixture of the former two markets. Regardless of type, the key goal of the market is to balance supply and demand in real time, which requires a market and an ancillary service market. Second, the retail electricity market is responsible for trading electricity between distributors and end consumers, and the electricity price traded in this market is the electricity tariff. There are various pricing schemes for electricity such as fixed-rate pricing, time-of-use (TOU), real-time, and critical peak pricing (CPP).

Currently, the Korean domestic power wholesale market is based on Article 43 of the Electricity Business Act, and 3 power generation companies (6 affiliated companies of KEPCO and private power generation companies) generate electricity using nuclear power, coal, LNG, renewable energy, etc. The wholesale price paid by KEPCO is named the System Marginal Price (SMP), which is a price that only compensates for variable costs such as fuel cost (CBP power market), and a separate Capacity Payment (CP) exists to compensate for fixed costs such as power plant construction and operation costs. KEPCO purchases power from the wholesale power market and sells it to the end consumer based on transmission, distribution, and contract type rates.

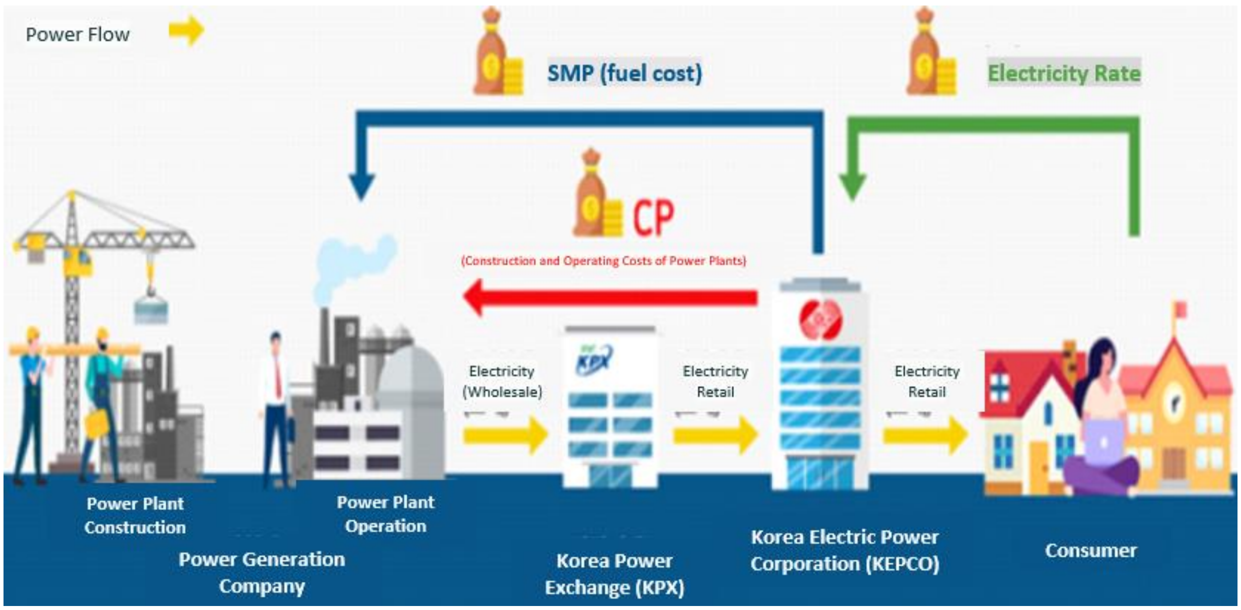

FIGURE D4: ELECTRICITY VALUE CHAIN IN KOREA (SOURCE: SK E&S MEDIA ROOM HOMEPAGE).[54]

Korean wholesale electricity market mechanism and settlement principles: Korea conducts one-day forecasting for electricity demand before trading and predicts electricity demand by time slots using past demand and weather data. Based on the forecast, bidding from power generation companies is submitted by 10 AM on the trading date, and the available capacity of each generator for each time slot is presented. On the power generation side, a price-determining generation plan is established to meet the demand of the power system at the lowest generation cost based on the forecasted demand, cost data for each generator, and bidding data (available capacity, etc.) by 15:00 the day before the transaction, and the SMP for each time slot is determined in this process. Based on the previously established operation plan, real-time supply and demand operations reflecting the real-time grid situation are carried out on the trading day. The power generation of each generator operated according to the results of the grid operation is measured every 5 minutes and the transaction price is settled by applying the power market price for each time period according to the measured value.

[54] Cho Heung-Jong (2023). Issues and Challenges of Electricity Market System and Electricity Pricing System. Korean Society of Resource Economics

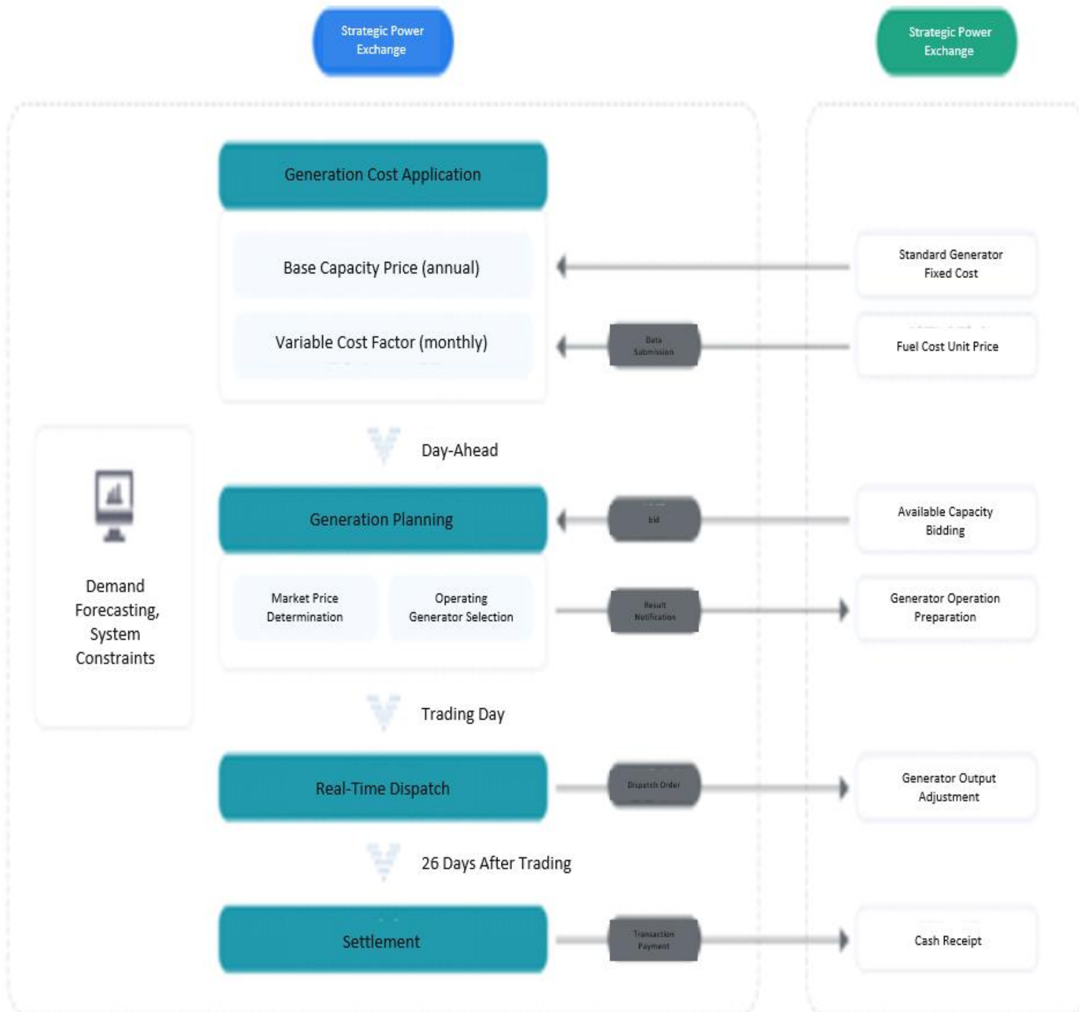

FIGURE D5: PROCEDURE AND STAKEHOLDERS OF POWER PURCHASE IN KOREA (SOURCE: KOREA POWER EXCHANGE HOMEPAGE).[55]

Settlement charges in the domestic wholesale electricity market (System Limit Price (SMP) and Settlement adjustment factor): The SMP is a wholesale electricity price that is intended to compensate for variable costs, including fuel costs. Since it is difficult to identify the variable costs of generators in real time accurately, the cost evaluation committee evaluates the variable cost factors of each generator in advance and applies the data that has been finalized. When each generator bids, the SMP is determined at the point where the supply curve is constructed by listing the generators in order of fuel cost and matches the forecast demand by time. It should be noted that the unit cost of power generation varies by source, with nuclear, coal, and LNG generation generally having the lowest unit cost. Within each source, the unit cost varies slightly depending on the performance and efficiency of the generator. Because electricity demand varies by time slots of day, the SMP is higher during periods of high demand and relatively lower during periods of low demand. Typically, the highest unit cost by source is nuclear, coal, and LNG where SMP is usually determined by power generation using LNG. In 2021, the SMP of

[55] Cho Heung-Jong (2023). Issues and Challenges of Electricity Market System and Electricity Pricing System. Korean Society of Resource Economics

LNG power generation was 7,904 hours (90%) out of a total of 8,760 hours; in 2022, the SMP of LNG power generation was 87%. Accordingly, considering the SMP on a monthly average, the SMP and the unit price of LNG show similar movements, resulting in the SMP rising if the cost of domestic LNG introduction rises.

Settlement fee in the domestic wholesale electricity market (Capacity charge (CP)): In Korea's domestic power generation market, companies within a certain volume (20MW) or more are required to bid for the power market unconditionally, and if they do not receive SMP because they do not receive feed-in tariffs, they will not be able to pay their fixed costs. To compensate for this issue, if the power plant operations are constantly disrupted, CP exists in the power market to recover the fixed costs of power plants, such as investment and operation and maintenance (O&M). The capacity charge of each generator is determined by reflecting construction investment, transmission connection cost, operation and maintenance cost, water supply cost, utilization rate of each generator, and environmental contribution cost. The reference capacity price, which is the basis of the capacity charge, is determined by the compensation price per unit time and unit performance to allow the reference generation to recover the corresponding fixed cost under basic operating conditions. The price is determined based on the fixed cost of a gas turbine generator, which is the peak generator among others participating in the electricity market. From July 2023, the capacity payment is comprised of 4 factors: Reference Capacity Payment (RCP), Regional Capacity Factor (RCF), Time of the day Capacity Factor (TCF), and Performance Capacity Factor (PCF).

Retail rates in the Korean electricity market: In the Korean electricity market, electricity is purchased from KEPCO through the electricity exchange, and KEPCO sells electricity to end users through different tariff plans. The retail electricity rate determination system is based on Article 16 of the Electricity Business Act and Article 4 of the Price Stabilization Act, and when KEPCO applies for a rate change to the Ministry of Trade, Industry, and Energy, the electricity commission of the Ministry of Trade, Industry, and Energy and the Ministry of Strategy and Finance finally approves the rate change after consultation.

Domestic electricity retail bills are composed of a basic rate, volume rate, climate and environment rate, and a fuel cost adjustment rate. The final consumer bill comprises electricity usage charges, value-added tax (10% of the total), and the electricity industry base fund (3.7% of the total). The fuel cost adjustment fee is a system that periodically reflects the price changes of imported fuels such as coal, natural gas, and oil in the price of electricity to alleviate the burden of temporary adjustments and to induce rational electricity consumption by providing consumers with information on price changes in advance. The fuel cost adjustment fee is adjusted every quarter, by multiplying the monthly usage with the difference between the recent one-year period average fuel cost and 2~4 months earlier average fuel cost. On the other hand, the upper and lower limits for fuel cost adjustment are set to alleviate the burden on consumers when the global fuel price fluctuates rapidly. In emergencies, the Minister of Trade, Industry, and Energy may temporarily suspend the change of fuel cost adjustment to stabilize people's lives.

THAILAND

(Energy source and consumption at the national level)

In late 2018, the Thai government announced the Power Development Plan 2018 (2018-2037) (PDP 2018), a revised version of the existing Power Development Plan (PDP 2015), which will cover the 20-year period from 2018 to 2037. The main feature of the PDP 2018 is that the share of natural gas has significantly increased from 37% to 53%, as opposed to the previous development plan, which aimed to reduce the share of imported natural gas to below 40% and increase coal-fired power generation capacity. The increase in the share of natural gas is analyzed as a major factor due to the expected decline in natural gas (LNG) import prices as new supply chains are secured in the global market, but critics point out that PDP 2018 is based on the assumption that LNG prices will be stable, which is highly uncertain in reality. The share of coal has been reduced by 11 percentage points, from 23% to 12%, while nuclear power has been excluded and the share of renewable energy has been kept at 20%.

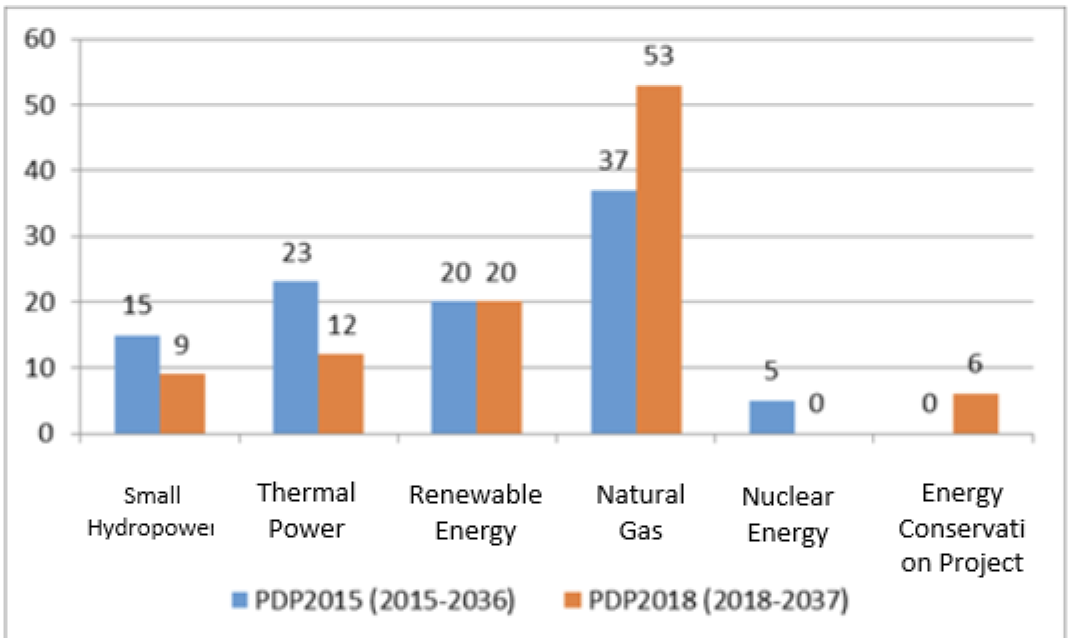

FIGURE D6: COMPARISON OF POWER GENERATION SHARES BY SOURCE IN THAILAND (UNIT: %)
(SOURCE: ENERGY POLICY PLANNING OFFICE).

The main difference from the previous plan is a significant decrease in the amount of self-generation, including renewables, cogeneration, and thermal power, and a significant increase in power purchases from neighboring countries. New hydropower and thermal power generation will decrease by 76.2% and 76.5%, respectively, compared to the previous plan, while imports will increase by 297.6%, from 1473 MW to 5857 MW.

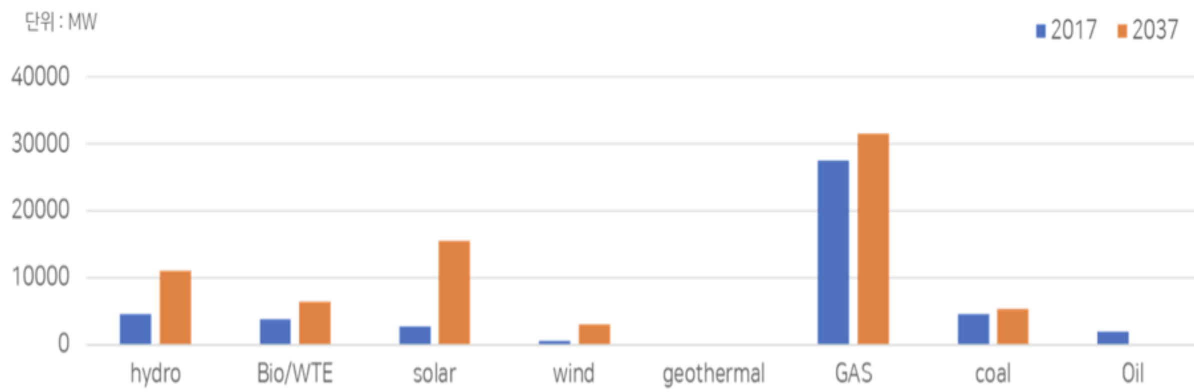

FIGURE D7: POWER CAPACITY PLANNING BY ENERGY SOURCE IN THAILAND (2017 VS. 2037) (SOURCE: KETEP (N.D.) B, BASED ON PDP 2018).

Country	Energy Source	Power Capacity(MV)		Power Mix by Energy Source(%)		CAGR	:Average Annual Increase
		2017	2037	2017	2037		
Thailand	Total(MW)	45,693.30	72,912.30	100.0%	100.0%	2.4%	1,360.95
	Hydro	4,541.00	10,993.00	9.9%	15.1%	4.5%	322.60
	Bio/WTE	3,824.00	6,446.00	8.4%	8.8%	2.6%	131.10
	Solar	2,700.00	15,464.00	5.9%	21.2%	9.1%	638.2
	Wind	628.00	2,989.00	1.4%	4.1%	8.1%	118.05
	Geothermal	0.30	0.30	0.0%	0.0%	0.0%	-
	GAS	27,550.00	31,572.00	60.3%	43.3%	0.7%	201.10
	Coal	4,528.00	5,383.00	9.9%	7.4%	0.9%	42.75
	Oil	1,922.00	65.00	4.2%	0.1%	-15.6%	-92.85

TABLE D1- POWER CAPACITY AND MIX IN THAILAND (SOURCE: THAILAND POWER DEVELOPMENT PLAN 2018).

Moreover, the Thai government instructed the Electricity Generating Authority of Thailand (EGAT) to study grid development and purchase more renewable energy to keep electricity prices affordable. Another notable change in the PDP 2018 was the reduction of the share of electricity generation through the Electricity Generating Authority of Thailand (EGAT) to 24% from 35% to encourage competition between private and public power generation.

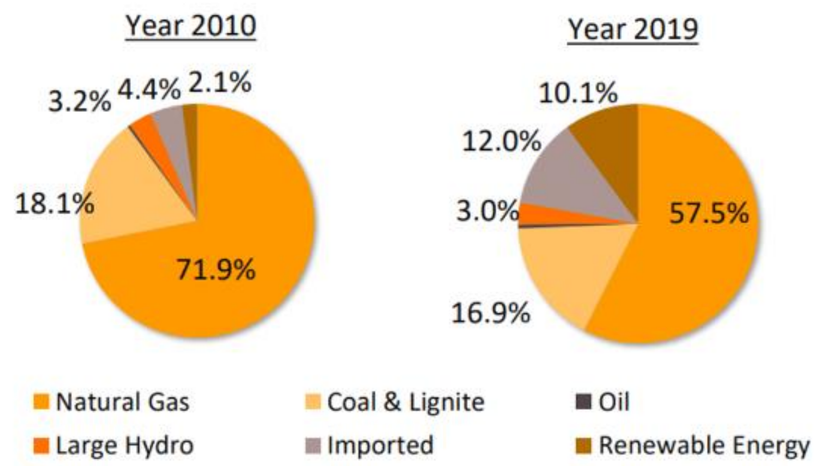

FIGURE D8: POWER GENERATION (GWH) BY FUEL IN THAILAND (SOURCE: EPPO, TUNPAIBOON(2021))

The figure above shows the share of each energy source in Thailand, and it can be seen that the share of natural gas is significantly lower in 2019 compared to 2010, and the share of renewable energy sources has nearly doubled. While South Korea's energy mix is composed of oil, coal, and gas; Thailand's is dominated by natural gas, and oil is the lowest, indicating that the two countries have different primary energy sources, but both are expanding renewable energy sources.

(Energy management and operation system at the national level)

Energy-related governance in Thailand is organized as follows: First, the Ministry of Energy (MOE) is responsible for setting measures, regulations, supervision, control decisions, and energy policy plans and actions for energy operations. In the case of the Ministry of Industry, it is not a government department directly related to energy, but rather a related support organization that operates and promotes environmentally friendly industries. The Energy Policy and Planning Office (EPPO) is responsible for promoting energy conservation and renewable energy, recommending energy policies, and presenting integrated management plans.

Energy policy is overseen by the National Energy Policy Council (NEPC) and the MOE, which is composed of four departments: EPPO, Department of Mineral Fuels (DMF), Department of Energy Business (DoEB), and Department of Alternative Energy Development and Efficiency (DEDE). The NEPC is responsible for reviewing the EPPO's policy proposals. There are 3 state-owned enterprises under the MOE: EGAT, Petroleum Authority of Thailand (PTT), and Bangchak Corporation Public Company Limited (BCP). In addition, there is also the Energy Regulatory Commission of Thailand (ERC), which is independent and monitors and overseas operations in the energy sector. The Thai Industrial Standards Institute (TISI) is responsible for setting standards of compliance with international guidelines, inspecting and certifying the standards of products, and promoting and developing national standards.

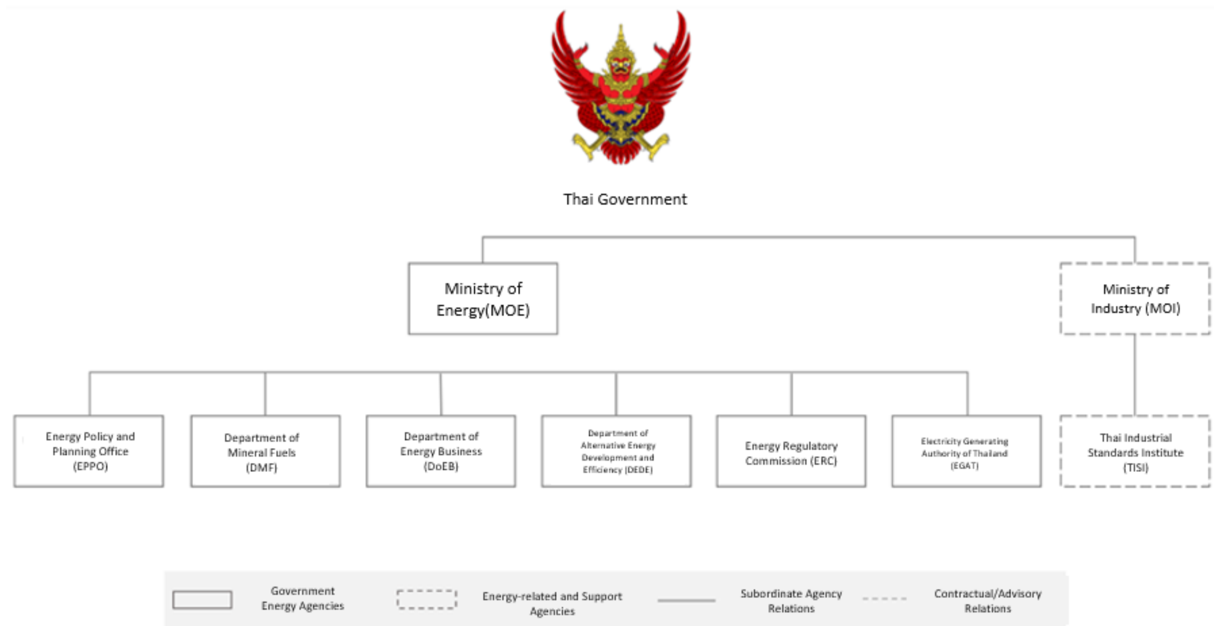

FIGURE D9: ENERGY (ELECTRICITY) MANAGEMENT FRAMEWORK IN THAILAND (SOURCE: KETEP (N.D.) B).

In addition, the Ministry of Energy has set a five-year review cycle for grid modernization, but it can be reviewed in the event of major issues affecting the power development plan. As shown in the figure below, the Thai government's main concern is to ensure grid flexibility and expand smart grid development. Therefore, it is necessary to place special emphasis on the smart grid in relation to the digitalization of Thailand's energy system.

POP 2018 Overview		
1. Regional balance and stable supply of generation, transmission, and distribution systems.	2. Securing grid flexibility in response to energy demands.	3. Encouraging low-cost electricity production to reduce consumer burden.
4. Preparing a competitive generation system considering power production efficiency.	5. Minimizing environmental impact.	6. Promoting renewable energy electricity generation and expanding smart grid development.
Power Supply Plan	2017 year 46,090 MW -> 2037SUS 77,211 MW(including energy efficiency, Thailand-Malaysia transmission connection)	
2037 Power Mix (Capacity)	BIO/WTE : 8.8% HYDRO : 15.1% Gas : 4.3.3% Solar : 21.2% Geothermal : 0.0% Coal 7.4% Wind : 4.1% Oil:0.1%	

TABLE D2- MAJOR ISSUES AND FURTHER PLAN FOR THAILAND'S ENERGY SECTOR (SOURCE: KETEP (N.D.) B, BASED ON PDP 2018).

Thailand's electricity industry is divided into 3 state-owned organizations (EGAT, PEA, and MEA), 3 categories of private companies (IPP, SPP, and VSPP), and imports. The Electricity Generating Authority of Thailand (EGAT) is a state-owned utility that is directly responsible for power generation and transmission and holds a monopoly position. EGAT's subsidiaries, Metropolitan Electricity Authority

(MEA) and Provincial Electricity Authority (PEA) are in charge of distribution and sales in urban centers and rural areas, respectively, and have a split monopoly by region.

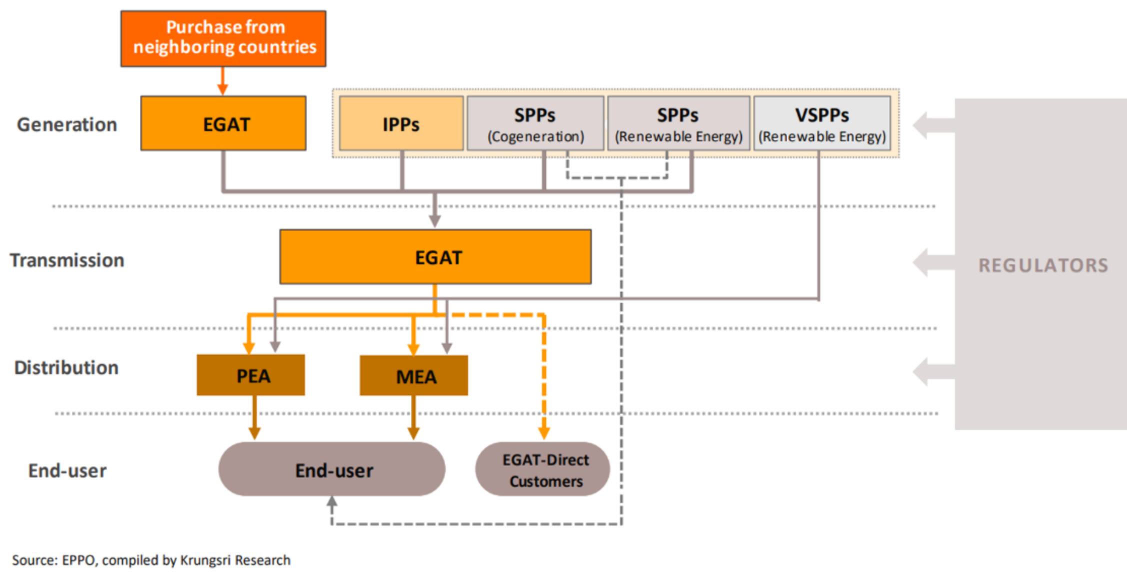

FIGURE D10. THAILAND'S ELECTRICITY SUPPLY CHAIN (SOURCE: EPPO, TUNPAIBOON (2021))

There are 3 categories of private organizations in Thailand's power generation sector: (1) Independent Power Producers (IPPs), (2) Small Power Producers (SPPs), and (3) Very Small Power Producers (VSPPs).

(1) Independent Power Producers (IPPs)

With a total installed capacity of over 90 MW, producers that fall under the category of IPPs primarily use natural gas or coal as fuel for their power plants. The most prominent IPPs include (i) Ratchaburi Electricity Generating Holdings, (ii) Gulf JP NS, (iii) Gulf JP UT, (iv) Gulf Power Generation, (v) Ratchaburi Power, (vi) BLCP Power, (vii) Electricity Generating, (viii) Glow IPP, (ix) Global Power Synergy, (x) Gheco-One, and (xi) Eastern Power & Electric. The revenues of the players in this group are exposed to a low level of risk as they have long-term (25-year) power supply contracts with EGAT. Revenues are derived from two sources (i) a guaranteed 'minimum demand' specified in their contracts with EGAT and (ii) direct power supply to the grid to meet demand. Their revenues are, therefore, dependent on national electricity consumption, although some players also derive revenues from investments in power generation facilities overseas, including Myanmar, Lao PDR, Indonesia, the Philippines, and Australia.

(2) Small Power Producers (SPPs)

The installed capacity required to qualify as an SPP is 10-90 MW. SPPs generate power primarily from natural gas, coal, oil, and renewable energy, and sell power primarily to EGAT. Some of their output is sold to industrial consumers adjacent to SPP power plants. SPPs are divided into (i) "firm" type SPPs and (ii) "non-firm" SPPs. "Firm" type SPPs have 20-25-year supply contracts with EGAT and operate primarily with natural gas or coal. 'Non-firm' SPPs have 5-year contracts (extendable in 5-year increments) and operate primarily with renewable energy such as solar, wind, waste, and biomass.

SPPs have two revenue streams (i) the revenue derived from the long-term contract with EGAT, which, like the IPP contract, comes with a minimum revenue guarantee. This means that SPP is only slightly exposed to the risk of weak revenues. (ii) Revenues derived from supplying electricity to industrial consumers located near the power plant. However, these revenues can fluctuate depending on the overall economic conditions and individual industry cycles. In addition to this, some players receive returns from investments in overseas power generation assets, including solar electricity production assets in Japan, China, and Taiwan, and wind assets in Vietnam.

(3) Very Small Power Producers (VSPPs)

The installed capacity required to qualify as a VSPP is less than 10 MW. VSPPs generate electricity primarily from renewable energy sources (including solar, wind, hydropower, biomass, biogas, and waste) for their own use and sell their excess output to the MEA or PEA over the life of the project under a feed-in tariff (FiT), depending on the generation technology and other circumstances. Most VSPPs that generate and sell electricity from renewable energy sources are involved in the supply, design, purchase, and construction or manufacturers of solar cells and related equipment. This is because these operators have the necessary expertise to install and maintain renewable electricity systems. The VSPP supplies electricity to the MEA or PEA under the terms and conditions set forth in the contract. They receive payment when the electricity is delivered to the grid. Players generating power from natural resources (solar, wind, or hydro) are likely to make losses in the first 1-2 years due to the high cost of construction and installation sites, but after this initial period, the situation will improve due to the revenue from electricity sales. However, players generating electricity from biomass, biogas, and waste may experience fluctuating revenues due to limited access to raw materials and fluctuations in raw material prices.

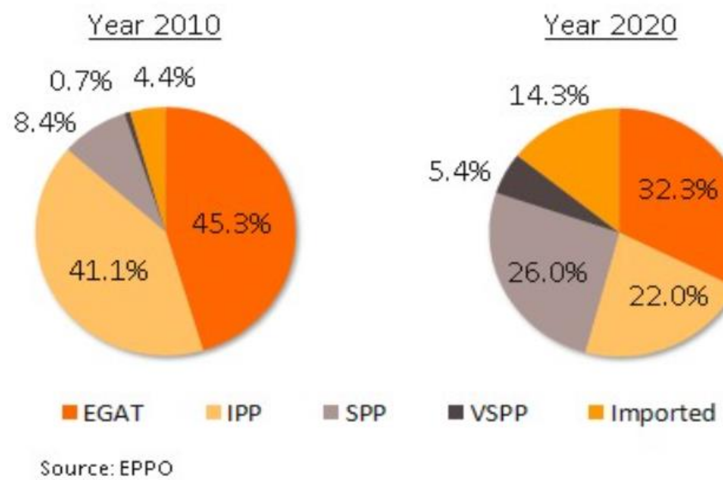

FIGURE D11: THAILAND'S POWER GENERATION (GWH) PORTION BY PRODUCER (SOURCE: EPPO, TUNPAIBOON(2021)).

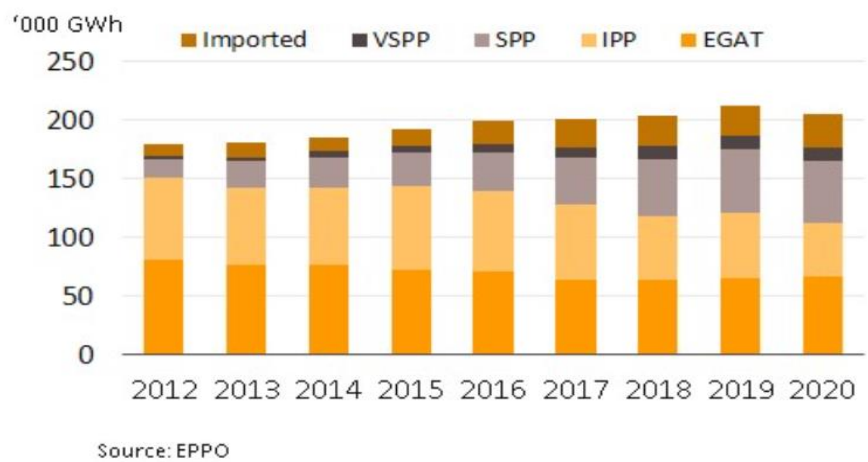

FIGURE D12: THAILAND'S POWER GENERATION BY PRODUCER IN TIME SERIES (SOURCE: EPPO, TUNPAIBOON (2021)).

As shown in the figures above, from 2010 to 2020, the share of electricity produced by SPPs and VSPPs skyrocketed due to government support for the AEDP and increased purchases from suppliers in these groups. By 2020, their contribution to the national energy mix jumped from 0.7% in 2010 to 5.4% of all electricity sold through the electricity grid.

<u>(Business model of the Energy industry)</u>

Electricity tariffs in Thailand are based on eight different categories. They are (1) residential, (2) small general service, (3) medium general service, (4) large general service, (5) certain business services, (6) non-profit organizations, (7) agricultural pumping, and (8) transient services. The pricing structure for electricity rates effective January 2023 is as follows (PEA)

Residential: Applicable to households and other dwelling places, monasteries, house of priest, and religious places of worship, including their compound, through a single Watt-hour meter.

Monthly Rate

1.1 Normal Rate					Energy Charge (Baht/kWh)	Service Charge (Baht/Month)
1.1.1 Consume up to 150 kWh. per Month						8.19
	First	15	kWh.	(0 – 15 th)	2.3488	
	Next	10	kWh.	(16 th – 25 th)	2.9882	
	Next	10	kWh.	(26 th – 35 th)	3.2405	
	Next	65	kWh.	(36 th – 100 th)	3.6237	
	Next	50	kWh.	(101 st – 150 th)	3.7171	
	Next	250	kWh.	(151 st – 400 th)	4.2218	
	Over	400	kWh.	(401 st and over)	4.4217	
1.1.2 Consume over 150 kWh. per Month						24.62
	First	150	kWh.	(0 – 150 th)	3.2484	
	Next	250	kWh.	(151 st – 400 th)	4.2218	
	Over	400	kWh.	(401 st and over)	4.4217	

1.2 Time of Use Rate (TOU)	Energy Charge (Baht/kWh)		Service Charge (Baht/Month)
	Peak	Off-Peak	
1.2.1 At voltage level 22 - 33 kV.	5.1135	2.6037	312.24
1.2.2 At voltage level lower than 22 kV.	5.7982	2.6369	24.62

(SOURCE: PROVINCIAL ELECTRICITY AUTHORITY (PEA). (N.D.))

Consumers in the residential category will fall into different subcategories based on the following conditions:

1. Customer, who has installed meter up to 5 Amp., 220 V., 1 Phase, 2 Wires, is classified under 1.1.1. If the customer consumes over 150 kWh for 3 consecutive months, he/she will be reclassified under 1.1.2 in the following month. When the customer does not consume over 150 kWh for 3 consecutive months, he/she will be reclassified under 1.1.1 in the following month.
2. Customer, who has installed meter over 5 Amp., 220 V., 1 Phase, 2 Wires, is classified under 1.1.2.
3. Customer, who has classified under 1.1.1 and does not consume over 50 kWh, will be received free electricity for that month until December 2015. From January 2016 onwards, the customer who classified under 1.1.1, and not be a juristic person, and does not consume over 50 kWh for 3 consecutive months (including the current month), will be received free electricity for that month.
4. As for tariff No. 1.2, if the customer installs a meter on a low voltage side of his/her transformer, another 2% of kWh will be added to the energy consumption to compensate for the losses in the transformer.
5. Tariff No. 1.2 is an optional rate, in order that the customer is obligated to pay for any additional cost specified by PEA.

6. After the minimum use of 12 months, the customer can require to be in tariff No. 1.1.

For small general service: Applicable to businesses, enterprises with residential facilities, industries, government agencies, local authorities, state-owned enterprises, embassies, foreign-related facilities, or international organizations, where the maximum average integrated energy demand per 15 minutes is less than 30 kW per single watt-hour meter.

Monthly Rate

2.1 Normal Rate				Energy Charge (Baht/kWh)	Service Charge (Baht/Month)
2.1.1 At voltage level 22 - 33 kV.				3.9086	312.24
2.1.2 At voltage level lower than 22 kV.					33.29
First	150	kWh.	(0 – 150 th)	3.2484	
Next	250	kWh.	(151 st – 400 th)	4.2218	
Over	400	kWh.	(401 st and over)	4.4217	

2.2 Time of Use Rate (TOU)	Energy Charge (Baht/kWh)		Service Charge (Baht/Month)
	Peak	Off-Peak	
2.2.1 At voltage level 22 - 33 kV.	5.1135	2.6037	312.24
2.2.2 At voltage level lower than 22 kV.	5.7982	2.6369	33.29

(SOURCE: PROVINCIAL ELECTRICITY AUTHORITY (PEA). (N.D.))

Customers who qualify as small general service customers are divided into subcategories based on the following criteria:

1. As for tariff No. 2.2, if the customer installs a meter on a low voltage side of his/her transformer, another 2% of kWh will be added to the energy consumption to compensate for the losses in the transformer.
2. Tariff No. 2.2 is an optional rate, in order that the customer is obligated to pay for any additional cost specified by PEA. After the minimum use of 12 months, the customer can require to be in tariff No. 2.1
3. If the maximum of an average integrated demand of energy in 15 minutes is equal to 30 kW. or over, the customer will be classified under the schedule 3 – 5 depend on the case.

For medium-sized general services: Applicable to businesses, enterprises with residential facilities, industrial enterprises, government agencies, local authorities, state-owned enterprises, embassies, foreign-related facilities, or international organizations, where the maximum average integrated energy demand per 15 minutes is between 30 kW and 1,000 kW on a single watt-hour meter, and the average energy consumption for the last three consecutive months does not exceed 250,000 kWh per month.

Monthly Rate

3.1 Normal Rate	Demand Charge (Baht/kW)	Energy Charge (Baht/kWh)		Service Charge (Baht/Month)
3.1.1 At voltage level 69 kV. and over	175.70	3.1097		312.24
3.1.2 At voltage level 22 - 33 kV.	196.26	3.1471		312.24
3.1.3 At voltage level lower than 22 kV.	221.50	3.1751		312.24
3.2 Time of Use Rate (TOU)	**Demand Charge** (Baht/kW)	**Energy Charge** (Baht/kWh)		**Service Charge** (Baht/Month)
	Peak	Peak	Off-Peak	
3.2.1 At voltage level 69 kV. and over	74.14	4.1025	2.5849	312.24
3.2.2 At voltage level 22 - 33 kV.	132.93	4.1839	2.6037	312.24
3.2.3 At voltage level lower than 22 kV.	210.00	4.3297	2.6369	312.24

(Source: Provincial Electricity Authority (PEA). (n.d.))

※ Minimum Charge: The minimum charge cannot be lower than 70% of the peak demand charge for the previous 12 months (ending in the current month).

Customers who qualify for medium-sized general service are further categorized according to the following conditions:

1. If the customer installs a meter on a low voltage side of his/her transformer, another 2% of kW and kWh will be added to the energy consumption to compensate for the losses in the transformer.
2. Tariff No. 3.1 is for customer who classified under tariff No. 3.1 before November 2015. The customer may switch to tariff No. 3.2 by paying for any additional cost specified by PEA, and cannot be able to switch back to tariff No. 3.1.
3. The maximum 15 minutes integrated demand is lower than 30 kW., this rate will still be applied. If the demand drops to lower than 30 kW. for 12 consecutive months and still be lower than 30 kW. in the 13th month, the customer will be reclassified under tariff No. 2.1 or No. 2.2 depend on the case. The customer who has classified under TOU rate, and has paid, will not have to pay an additional cost.

<u>For Large General Services</u>: Applicable to enterprises, businesses with residential facilities, industrial enterprises, government agencies, local authorities, state-owned enterprises, embassies, foreign-related facilities or international organizations, etc. whose maximum average integrated energy demand per 15 minutes is greater than or equal to 1,000 kW per single watt-hour meter, and whose average energy consumption in the last three consecutive months is greater than or equal to 250,000 kWh per month.

Monthly Rate

4.1 Time of Day Rate (TOD)	Demand Charge (Baht/kW)			Energy Charge (Baht/kWh)	Service Charge (Baht/Month)
	Peak	Partial	Off-Peak		
4.1.1 At voltage level 69 kV. and over	224.30	29.91	0	3.1097	312.24
4.1.2 At voltage level 22 - 33 kV.	285.05	58.88	0	3.1471	312.24
4.1.3 At voltage level lower than 22 kV.	332.71	68.22	0	3.1751	312.24

Peak : 06.30 p.m. – 09.30 p.m. everyday
Partial : 08.00 a.m. – 06.30 p.m. everyday (Demand charge is considered only the excess demand over peak period)
Off-Peak : 09.30 p.m. – 08.00 a.m. everyday

4.2 Time of Use Rate (TOU)	Demand Charge (Baht/kW)	Energy Charge (Baht/kWh)		Service Charge (Baht/Month)
	Peak	Peak	Off-Peak	
4.2.1 At voltage level 69 kV. and over	74.14	4.1025	2.5849	312.24
4.2.2 At voltage level 22 - 33 kV.	132.93	4.1839	2.6037	312.24
4.2.3 At voltage level less than 22 kV.	210.00	4.3297	2.6369	312.24

(SOURCE: PROVINCIAL ELECTRICITY AUTHORITY (PEA). (N.D.))

※ Minimum Charge: The minimum charge cannot be lower than 70% of the maximum demand charge for the last 12 months (ending the current month).

Customers who qualify as large general-purpose customers are divided into subcategories based on the following criteria:

1. Tariff No. 4.1 is for customer who classified under tariff No. 4.1 before November 2015. The customer may switch to tariff No. 4.2 by paying for any additional cost specified by PEA, and cannot be able to switch back to tariff No. 4.1.
2. The maximum 15 minutes integrated demand is lower than 1,000 kW., or the monthly energy consumption is not over 250,000 kWh., this rate will still be applied. If the demand drops to lower than 30 kW. for 12 consecutive months and still be lower than 30 kW. in the 13th month, the customer will be reclassified under tariff No. 2.1 or No. 2.2 depend on the case. The customer who has classified under TOU rate, and has paid, will not have to pay an additional cost.

<u>For Specified Business Services</u>: Applicable to hotels, guesthouses, or lodging establishments (including their buildings) where the maximum average integrated energy demand per 15 minutes is 30 kW or more on a single watt-hour meter.

Monthly Rate

5.1 Time of Use Rate (TOU)	Demand Charge (Baht/kW)	Energy Charge (Baht/kWh)		Service Charge (Baht/Month)
	Peak	Peak	Off-Peak	
5.1.1 At voltage level 69 kV. and over	74.14	4.1025	2.5849	312.24
5.1.2 At voltage level 22 - 33 kV.	132.93	4.1839	2.6037	312.24
5.1.3 At voltage level lower than 22 kV.	210.00	4.3297	2.6369	312.24

5.2 Whom does not installed with TOU meter	Demand Charge (Baht/kW)	Energy Charge (Baht/kWh)	Service Charge (Baht/Month)
5.2.1 At voltage level 69 kV. and over	220.56	3.1097	312.24
5.2.2 At voltage level 22 - 33 kV.	256.07	3.1471	312.24
5.2.3 At voltage level lower than 22 kV.	276.64	3.1751	312.24

(SOURCE: PROVINCIAL ELECTRICITY AUTHORITY (PEA). (N.D.))

※ Minimum Charge: The minimum charge cannot be lower than 70% of the peak demand charge for the previous 12 months (ending in the current month).

Customers eligible for certain Business Services are divided into subcategories based on the following conditions:

1. If the customer installs a meter on a low voltage side of his/her transformer, another 2% of kW and kWh will be added to the energy consumption to compensate for the losses in the transformer.
2. Tariff No. 5.1 must be applied to all customers who are first qualified under schedule 5. While the customer who has not yet installed a TOU meter, the tariff No. 5.2 is temporarily used.
3. The maximum 15 minutes integrated demand is lower than 30 kW., or the monthly energy consumption is not over 250,000 kWh., this rate will still be applied. If the demand drops to lower than 30 kW. for 12 consecutive months and still be lower than 30 kW. in the 13th month, the customer will be reclassified under tariff No. 2.1 or No. 2.2 depend on the case. The customer who has classified under TOU rate, and has paid, will not have to pay an additional cost.

<u>For nonprofit organizations</u>: Applies to non-governmental organizations that provide free services through a single demand metric. This does not include government agencies, local authorities, state-owned enterprises, embassies, foreign-related establishments, and international organizations.

Monthly Rate

6.1 Normal Rate					Energy Charge (Baht/kWh)	Service Charge (Baht/Month)
6.1.1 At voltage level 69 kV. and over					3.4149	312.24
6.1.2 At voltage level 22 - 33 kV.					3.5849	312.24
6.1.3 At voltage level lower than 22 kV.						20.00
	First	10	kWh.	(0 – 10 th)	2.8013	
	Over	10	kWh.	(11 th and onwards)	3.8919	

6.2 Time of Use Rate (TOU)	Demand Charge (Baht/kW)	Energy Charge (Baht/kWh)		Service Charge (Baht/Month)
	Peak	Peak	Off-Peak	
6.2.1 At voltage level 69 kV. and over	74.14	4.1025	2.5849	312.24
6.2.2 At voltage level 22 - 33 kV.	132.93	4.1839	2.6037	312.24
6.2.3 At voltage level lower than 22 kV.	210.00	4.3297	2.6369	312.24

(SOURCE: PROVINCIAL ELECTRICITY AUTHORITY (PEA). (N.D.))

※ Minimum Charge: For rates subject to 6.2, the minimum charge cannot be lower than 70% of the maximum demand charge for the previous 12 months (ending in the current month).

Customers who qualify as Nonprofit are further categorized based on the following conditions:

1. If the customer installs a meter on a low voltage side of his/her transformer, another 2% of kW and kWh will be added to the energy consumption to compensate for the losses in the transformer.
2. Tariff No. 6.2 is an optional rate, in order that the customer is obligated to pay for any additional cost specified by PEA. After the minimum use of 12 months, the customer can require to be in tariff No. 6.1

<u>For agricultural pumping</u>: One electricity meter can be applied to the electricity use of agricultural water pumping by the government, agricultural cooperatives, registered farmers' organizations, and farmers' organizations legalized by the government.

Monthly Rate

7.1 Normal Rate					Energy Charge (Baht/kWh)	Service Charge (Baht/Month)
						115.16
	First	100	kWh.	(0 – 100 th)	2.0889	
	Over	100	kWh.	(101 st and onwards)	3.2405	

7.2 Time of Use Rate (TOU)	Demand Charge (Baht/kW)	Energy Charge (Baht/kWh)		Service Charge (Baht/Month)
	Peak	Peak	Off-Peak	
6.2.2 At voltage level 22 - 33 kV.	132.93	4.1839	2.6037	204.07
6.2.3 At voltage level lower than 22 kV.	210.00	4.3297	2.6369	204.07

(Source: Provincial Electricity Authority (PEA). (n.d.))

※ Minimum Charge: For tariffs falling under 7.2, the minimum charge cannot be lower than 70% of the maximum demand charge for the last 12 months (ending in the current month).

Customers who qualify for agricultural pumping are divided into subcategories based on the following criteria.

1. If the customer installs a meter on a low voltage side of his/her transformer or PEA's transformer (only in the case of the CT is installed on the lower Voltage meter), another 2% of kW and kWh will be added to the energy consumption to compensate for the losses in the transformer.
2. Tariff No. 7.2 is an optional rate, in order that the customer is obligated to pay for any additional cost specified by PEA. After the minimum use of 12 months, the customer can require to be in tariff No. 7.1

If a customer classified under this scheme wishes to be classified under another permanent scheme, or if the PEA detects that their electricity consumption has changed to a different status, the customer may request permanent consumption from the PEA in their region. The customer will also be required to install electrical wiring or install internal equipment in accordance with PEA standards, pay additional fees in accordance with PEA regulations, and be reclassified under Schemes 1 through 7 above.

Thailand's energy policy is largely informed by its Power Development Plan (PDP) and Alternative Energy Development Plan (ADP), which set out the total desired generation capacity by plant type. In Thailand, the country used to calculate payments using the Adder system, which sets the price of renewable energy and is now used to determine feed-in tariffs (FiTs). The cost of electricity production from renewable energy is higher than conventional electricity production, making it less economically attractive to investors. Therefore, the Thai government announced a policy in 2007 to promote private sector investment in renewable electricity production, known as the "Adder". The Adder cost, which is the additional cost from each renewable electricity generation, is added to the cost of national electricity production, increasing the cost of production.

To alleviate the limitations of the existing Adder, the feed-in tariff (FIT) policy announced by the National Energy Commission in 2013 replaced the Adder policy. While the Adder is paid in addition to the retail electricity price, the FIT is a fixed wholesale price. Of course, both policies subsidize the high costs of higher electricity prices and thus increase the level of the fuel adjustment charge in the retail electricity price, but the above differences exist (Pita, Tia, Suksuntornsiri, Limpitipanich, Limmeechockchai, 2015). In addition, the government plans to expand the electricity distribution network to increase generation capacity to support the increase in electricity generation, especially from renewable sources.

Recently, Thailand is about to introduce a Green Utility Tariff (GUT). This will be the first ASEAN country to offer industrial green power that encompasses production, procurement, and certification, and is expected to help attract foreign investment in the energy sector. GUT refers to a power pricing system that incentivizes green power generation by purchasing renewable energy power at a higher price than conventional power. Thailand's green power tariff is divided into GUT1 and GUT2, with GUT1 being the purchase price for existing renewable power plants, which includes the six hydropower plants of the Electricity Generating Authority of Thailand (EGAT). GUT2 is the purchase price for new renewable energy plants and includes a wider range of power plants than GUT1, including solar, wind, and biogas. The price is expected to be slightly higher than GUT1's existing tariff of 4.2 baht per unit (kWh), while GUT2 is expected to be between 4.55 and 4.56 baht per unit.

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Appendix E – Data collection case studies in Korean

Data collection through open data portals

The 'Open Government Data' in Korea is a system that provides public data to the private sector to create new businesses and jobs and improve public benefits through private utilization. The Open Government Data Portal (https://www.data.go.kr) is an integrated public data provision system operated by the Ministry of the Interior and Safety, which aims to open up various public data held by the Korean government and make it convenient and easy for anyone to utilize. It provides national priority data provided through the National Priority Data Project, a national data map where you can find open government data through associations, and the status of open government data by classification system, provider organization, and type. It is available through file download or Open API (Open API).

Using the Open Government Data Portal to search for data related to digitalization in the Energy sector, data from various public organizations such as the Korea Electric Power Corporation (KEPCO), Korea Power Exchange (KRX), Korea Energy Agency (KEA), Korea Environment Corporation (KECO), and the Ministry of Environment are identified. These data are updated annually; some are updated once or automatically.

<u>Korea Electric Power Corporation (KEPCO)</u>

KEPCO is a market-type public corporation under the Ministry of Trade, Industry and Energy established to supply electricity. KEPCO has a total of 245 public data, of which we identified about 18 representative data related to the digitalization of energy. These data are managed by the Digital Solution Center and are mainly related to electric vehicles, such as "charger capacity information by charging station," "electric vehicle status information by region," "latitude and longitude of electric vehicle charging stations," "monthly usage of electric vehicle charging power and sales unit price," etc. The information elements include the status of electric vehicle charging stations and chargers, charging load, sales volume, etc. and are updated annually or from time to time. For data in the field of information and communication, items such as "Information and Communication Equipment Status" and "Information and Communication Equipment Trends" were identified, and they are collected on an annual basis, including information and communication facilities, transmission facilities, computer facilities, power operation and control facilities, and communication lines. Regarding electricity transmission and distribution, there is "e-distribution information line information" data, which is managed by the ICT Infrastructure Department, and the following information elements are collected on an annual basis: primary business office code, primary business office name, secondary business office code, secondary business office name, contracted power, main product, industrial classification code, and industrial classification.Regarding R&D, there are data such as "Intellectual Property Information (KEPCO) Knowledge Status" and "Digitization of Data Information and Integrated Information System". The information elements include country of publication, publication classification, SCI classification, paper title, lead author, journal name, publicationdate, and payment status. Additional data on electric vehicles can also be obtained through KEPCO's Energy Marketplace (https://edsm.kepco.co.kr), a portal for power data service providers.

Korea Power Exchange (KPX)

The KPX is an organization dedicated to the operation of Korea's electricity market and power grid, and was established in 2001 when the KEPCO's power generation division was divided into a competitive structure to ensure fair and transparent operation of the electricity market and stable and efficient operation of the power grid. Representative energy digitization-related data collected by the KEPCO include "Status of Informationization Projects" and "Status of Open Government Data" implemented by the Ministry of Information Technology. These data are managed by the Ministry of Information Technology and are updated from time to time, including information elements such as business type, business name, business amount, contract date, department in charge, related business, and budget.

Other governmental and quasi-governmental organizations (Korea Energy Agency, Korea Environment Agency, Ministry of Environment)

The Korea Energy Agency (KEA) is a quasi-governmental agency under the Ministry of Trade, Industry and Energy that was established in July 1980 under Article 45 of the Energy Utilization Rationalization Act to reduce carbon dioxide emissions and contribute to the healthy development of the national economy by efficiently promoting energy utilization rationalization projects. The KEPCO provides data on "Electric Vehicle Quick Charging Station Installation Status by Region" under the supervision of the Statistical Analysis Office, and collects data on an annual basis, including metropolitan governments, cities and districts, and usage (kWh). The Korea Environment Corporation (KECO) is a quasi-governmental organization under the Ministry of Environment established to contribute to the development of an environmentally friendly country by efficiently promoting projects to prevent environmental pollution, improve the environment and promote resource circulation, and establish a circular resource management system. It provides data on "Status of Public Fast Chargers" and "Installation and Usage of EV Chargers," which is organized by the Ministry of Environment and Mobility's Automotive Environmental Planning Division. It is updated from time to time, including information elements such as region, charging location, charger ID, installation year, fast charging amount, charger type, and number of charging cycles. The Ministry of Environment (MoE) is the central administrative agency of the Republic of Korea responsible for the preservation of the natural environment, living environment, prevention of environmental pollution, conservation, utilization, and development of water resources, and rivers. Under the supervision of the Air Future Strategy Division, data on "Electric Vehicle Quick Charging Station Supply Status" is collected and updated from time to time, including information on the year and number of quick charging stations.

Other relative foundation corporations (Smart Grid Business Unit, Smart Grid Data Center)

The Korea Smart Grid Initiative (KSGI) is a foundation corporation established to systematically support the smart grid business, a key policy for low-carbon green growth, and foster it as a new growth engine through innovation in green energy technology to improve the quality of life of the people and contribute to national economic development. Under the leadership of the management support team, data on the "distribution status of smart grid core devices" is collected on an annual basis, including detailed data such as "energy storage system (ESS)" and "intelligent electricity metering system (AMI)". The Smart Grid Data Center, a platform created by the Korea Smart Grid Association (KSGA), provides domestic and overseas statistical information on smart grids, new energy industries, and overseas research information, and provides electricity, energy, power, energy information, energy data, data, overseas expansion, and overseas energy statistics. "Electricity New Business Registration Statistics" provides information such as the status of small-scale power brokerage business, electric vehicle charger installation and operation status (region, quick charging, slow charging, RFID tag), renewable energy electricity supply business status, and renewable energy electricity supply business type on an annual basis. "Intelligent Power Grid Operator Registration Statistics" provides information on the number of companies participating in the demand resource trading market of the electricity exchange, the year of the demand resource trading market, the reduction performance by year, the number of resources in the demand resource trading market business, and the number of acceptable types of demand resource trading market business on an annual basis.

Organization	Abbreviation	URL
Korea Electric Power Corporation	KEPCO	https://www.kepco.co.kr
Korea Power Exchange	KPX	https://www.kpx.or.kr
Korea Energy Agency	KEA	https://www.energy.or.kr
Korea Environment Corporation	KECO	https://www.keco.or.kr
Ministry of Environment	ME	https://www.me.go.kr
Korea Smart Grid Institute	KSGI	https://www.smartgrid.or.kr
Korea Smart Grid Association	KSGA	https://ksga.org

TABLE F1- DATA ON THE DIGITIZATION OF SOUTH KOREA'S ENERGY SECTOR COLLECTED FROM THE OPEN GOVERNMENT DATA PORTAL.

Data name	Source	Dept.	Information elements	Renewal cycle
eDistribution Information Line Information Statistics	KEPCO	ICT Infrastructure	Primary and secondary business office name, contracted power, main products, industry classification code, industry classification	Annual
EV Charging load by time		Digital	Date, charging method, time zone	Annual

of day		Solution		
Convergence data of power and weather for apartment buildings			Item name, domain classification, data type, maximum length, expression method, unit, information system name	Occasional (one-time)
Data center electricity supply status			Region name, number of customers, contract power (MW)	Occasional (one-time)
Charger status information by use			Usage, Year	Annual
Charging station status information by use			Usage, Year	Annual
Data Information Digitization and Integrated Information System			Output Digitization, distributed data	Occasional (one-time)
Sales of electric vehicle charging power			Date, region, charging rate, number of customers, sales volume, sales inco	Annual
EV charging station installation status			Region, installation site, number of quick chargers	Occasional (auto-renewal)
Electric vehicle charging power usage and sales unit price by month			Charging fee, optional fee, sales volume, unit cost of usage	Occasional (one-time)
EV fast charger installation status			Region, Year	Occasional (one-time)
EV charging station latitude and longitude			Charging station ID, address, latitude, longitude Yearly	Annual
Information and Communication Facilities			Information and communication facilities, transmission facilities, computer facilities, power operation and control facilities, communication lines	Annual
Information and communication equipment status			Type, Unit, Quantity	Annual
Intellectual Property Information (KEPCO)			Country of publication, publication category, SCI category, paper title, lead author, journal name, publication date, payment status	Occasional (one-time)
Electric vehicle charger status information by region			Region, Year	Annual
Status of electric vehicles by region			Region, total number of EVs	Annual
Charger capacity information by charging			Charging station/charger ID, charging capacity (kw)	Occasional (one-time)

station				
Informationization Project Status	KPX	Information Technology Office	Project type, project name, project amount, contract date, completion, department in charge	Occasional (one-time)
Open Government Data Project Status		Information Technology Division	Open data name, related projects, budget	Occasional (auto-renewal)
Installation Status of Electric Vehicle Quick Chargers by Region	KEA	Statistical Analysis Office	Metropolitan government, city, district, usage (kWh)	Annual
Electric Vehicle Quick Charging Station Supply Status	MoE	Atmospheric Future Strategy Division	Year, number of fast chargers, description	Occasional (one-time)
Smart grid core equipment distribution status	KSGI	Management Support Team	Energy storage device (ESS), intelligent electricity metering system (AMI) distribution status	Annual
Electricity New Business Registration Statistics	KSGA		Small-scale electricity brokerage business, installation and operation of electric vehicle charging stations (local, quick charging, slow charging, RFID tag), renewable energy electricity supply business, renewable energy electricity supply business type	Annual
Statistics on Intelligent Power Grid Business Registration			Companies participating in the demand resource trading market on the electricity exchange, year of demand resource trading market, reduction performance by year, number of resources in demand resource trading market business, number of acceptable types of demand resource trading market business	Annual

TABLE F2- DIGITALIZATION DATA IN THE ENERGY SECTOR COLLECTED FROM THE PUBLIC DATA PORTAL OF KOREA.

Appendix F – Survey questionnaire for Korea and Thailand experts

※ Note that due to the length and redundancy, the background and introduction of the NDRI project is neglected.

KOREA SURVEY FORM

Digitalization awareness

1. In your opinion, to what extent does your country have the technology and momentum to digitize the energy sector globally? (   )

① Very poor ② Overall unsatisfactory ③ Medium ④ Generally excellent ⑤ Very good

1-1) Please rate the level of success in your country's energy sector for the digitalization technologies listed below (if you consider them "excellent (4-5)" for question 1).

※ Please check one of the following boxes for each item

Digitization technologies	Not successful at all	Slightly successful	Fairly successful	Very successful
① Adoption of data and automation technologies: Impacting work efficiency through automation of real-time data monitoring, analytics, process control, maintenance, and inventory management.				
② Smart grid and renewable energy integration: The impact on energy management and usage efficiency of the introduction of smart grid technologies or the integration of renewable energy resources.				
③ Adoption of digital twins and cloud technologies: Digital replication of facilities and assets, or cloud-based data management, impacts operational efficiency and collaboration.				
④ Application of advanced technologies: The application of artificial intelligence (AI), machine learning, and cybersecurity technologies to impact work processes, predictive analytics, and cybersecurity responses.				
⑤ Digital communications and remote technologies: Increased use of mobile and remote technologies impacts fieldwork efficiency and customer service				
Other: ( )				

1-2) (If you consider your answer to question 1 to be "not enough (1-3)") Why do you consider it not enough?

Digitalization practices, successes, and obstacles

2. If you consider the digitalization of the Korean energy sector to be world-leading or ahead of the rest of the world, what specifically do you think is the reason for this?

※ Please prioritize the causes below.

Cause	Prioritization (1st~7th)
① Access to power (energy)	
② Internet accessibility (Broadband subscriptions)	
③ Internet quality (speed and reliability)	
④ Technology innovation	
⑤ Active government support	
⑥ Enable mobile internet	
⑦ Other (* If there are other factors you can think of, please feel free to write them down.): ( )	

3. Which of the following digital technologies do you think have been or are being successfully applied to digitize the energy sector in Korea?

※ Multiple selections are possible

: (   )

①Smart Grid Technology ② Automation and remote and real-time monitoring

③ Digital twin technology ④ Artificial intelligence and machine learning

⑤ Digitalization of customer interactions (web, mobile apps, etc.)

⑥ Virtual Power Plant (VPP)

⑦ Other ( )

3-1. Which of the above technologies do you think is still relatively underdeveloped in the digitalization of the Korean energy sector?

※ Multiple selections are possible

: ( )

3-2. In question 3-1, please provide a brief description of why the skills you selected are not sufficient.

4. What do you think are the current challenges or obstacles to digitization in the Korean energy sector?

5. What factors or improvements do you think are needed to overcome the challenges/obstacles you listed in question 4?

Key-priority factors in digitizing the energy sector in developing countries

6. In your opinion, what are the most important factors that developing countries should prioritize in their efforts to digitize their energy sectors?

※ We would appreciate it if you could provide 1-3 key factors and a brief rationale for your choice for the example developing countries or countries in similar circumstances.

Developing country example	Key-priority elements and Resons
Thailand : Middle income Good infrastructure (power, internet access), active government support	
Cambodia : Low income levels, poor infrastructure, poor government support	
Ghana : Low income levels, poor infrastructure, low government support	

6-1. Based on your country's experience in digitizing the energy sector, if you were to give advice to government officials in developing countries on digitizing the energy sector, what would you recommend as your top priorities and why?

※ Please write about 3 elements that you recommend.

Ranking	Recommendation factors	Reasons
1st		
2nd		
3rd		

Others

7. Finally, if you have any other key considerations for driving digitalization in the energy sector, please feel free to share.

THAILAND SURVEY FORM

Awareness of Digitalization

1. How much do you think Thailand's energy sector has currently achieved digitalization (compared to the global average)? (*please highlight your selection below*)

① Very insufficient
② Insufficient
③ Average
④ Generally excellent
⑤ Very excellent

1-1. (If you answered 'Generally excellent' or 'Very excellent' to the previous question, no. 1) Please rate the level of success of the detailed technologies that have contributed to digitalization in Thailand's energy sector. (*Please highlight your selection between ①~④ below*)

Digitalization technologies	Not at all successful	Slightly successful	Fairly successful	Very successful
(1) Adoption of automation and data technologies: impacting work efficiency through automation of real-time data monitoring, analytics, process control, maintenance, and inventory management.	①	②	③	④
(2) Smart grid and renewable energy integration: impacting energy management and usage efficiency through the adoption of smart grid technologies or the integration of renewable energy resources.	①	②	③	④
(3) Adoption of digital twins and cloud technologies: Digital replication of facilities and assets, or cloud-based data management, impacts operational efficiency and collaboration.	①	②	③	④
(4) Adoption of advanced technologies: the application of artificial intelligence (AI), machine learning, and cybersecurity technologies to impact work processes, predictive analysis, and cybersecurity response.	①	②	③	④
(5) Digital communications and remote technologies: Increased utilization of mobile and remote technologies impacts field work efficiency and customer service.	①	②	③	④
(6) Others: (*Please right other technologies if there are others to introduce*)	①	②	③	④

1-2. (If you answered, 'Very insufficient,' 'Insufficient,' or 'Average' to the previous question no. 1) What do you think is why Thailand's energy sector has not been digitalized enough?

(*Please write down freely the reason why it has not been digitalized*)

Digitalization practices and their successes & obstacles

2. What components do you think are the most significant in driving the digitalization of Thailand's energy sector? Please prioritize the given components below and describe the reasons for them.

Expected components	Prioritization (1st ~7th)	Reason
(1) Accessibility to electricity		
(2) Broadband subscription		
(3) Internet quality (speed and reliability)		
(4) Technology innovation		
(5) Government's support and willingness		
(6) Mobile internet activation		
(7) Others *(Please fill in any other components that you think are significant)*		

3. Which of the following digital technologies do you think is significant in accelerating the digitalization of Thailand's energy sector? (multiple choices are possible)

Please select technology(number)from the given options below:	
① Smart grid technology	② Automation, remote, and real-time monitoring technology
③ Digital twin technology	④ Artificial intelligence, machine learning technology

⑤ Digitalization of customer interactions (web, mobile apps, etc)	⑥ Virtual Power Plant (VPP)
⑦ Others (*Please fill in freely of other digital technologies you think*) :	

3-1. For the selected digital technologies, why do you think these are significant for digitalization in Thailand's energy sector?

Digital technology	Reason
Smart grid technology	
Automation, remote, and real-time monitoring technology	
Digital twin technology	
Artificial intelligence, machine learning technology	
Digitalization of customer interactions (web, mobile apps, etc)	
Virtual Power Plant (VPP)	
Others	

4. What do you think are the current challenges or obstacles to digitalization of the energy sector in Thailand? And what are its reasons?

Others

5. Finally, if you have any other key considerations for driving digitalization in the energy sector, please feel free to share.