

A Promising Path toward a Net-Zero Clean Energy Future in Africa and Southeast Asia

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This paper explores strategies for a rapid transition to net-zero energy in Africa and Southeast Asia through renewable energy sources. The study analyzes the current energy landscape and challenges faced by these regions, focusing on opportunities for economic development based on renewable energy generation, specifically solar PV and wind energy. The results show that an increase in renewable energy generation in Southeast Asia resulted in a comparable rise in renewable energy supply, electricity generation, and overall energy supply between 2021 and 2022. In Africa, an increase in renewable energy generation from 201-210 TWh demanded an increase in renewable energy supply, electricity generation, and overall energy supply between 2021 and 2022. Southeast Asia exceeded Africa in terms of solar PV generation in both years, with a share of 38-45 TWh, while Africa achieved a lesser proportion of 14-16 TWh in solar PV generation in the historical scenario. The same incremental trend was observed in both the stated policy scenario and the announced pledged scenario for both Africa and Southeast Asia in 2030 and 2050. According to the analysis, Africa produced a higher fraction of total wind energy production at 23–25 TWh, compared to Southeast Asia, which reported 9–14 TWh under the historical scenario between 2021 and 2022. However, according to the announced pledged scenario, Southeast Asia is predicted to outperform Africa in wind energy output between 2030 and 2050. However, by 2050, Southeast Asia is forecast to vastly outperform Africa in terms of wind energy output, with a staggering record of 1207 TWh compared to Africa's estimated 593 TWh. The authors propose five potential solutions to the challenges of renewable energy supply in Africa and Southeast Asia, based on the International Energy Agency's forecast between 2030 and 2050. These include exploring solar energy advancements, floating turbines, wave energy converters, ocean thermal energy conversion systems, energy storage and thermal energy solutions, and IoT integration for energy efficiency enhancement. The authors emphasize the need for long-term solutions and suggest policy implications for sustainable scenarios that encourage environmentally sound behaviors, drive economic growth, and promote social development. These scenarios include integrated resource planning, market liberalization, government incentives, and capacity-building.

Keywords: Renewable energy; Sustainable development; Decarbonization; Energy transition; Cutting-edge strategies; Net-zero transition

Introduction

The global imperative to achieve a net-zero clean energy future is of utmost urgency, and this transformative shift is equally critical for Africa and Southeast Asia. These regions, like the rest of the world, face the daunting challenge of transitioning to sustainable energy systems in order to mitigate climate change and ensure a prosperous future for their populations [1]. These regions possess an abundance of natural resources [2], including solar, wind, geothermal, and hydroelectric power, which makes them highly promising for the development of renewable energy sources. By harnessing these resources effectively, these areas can establish themselves as leaders in sustainable energy production and contribute significantly to reducing carbon emissions. Given the unique economic challenges faced by regions like Africa [3] and Southeast Asia, it is imperative that they embrace forward-thinking and pioneering approaches to swiftly achieve a net-zero energy future [4]. By harnessing cutting-edge strategies, these regions can effectively address their energy needs [5] while simultaneously mitigating the adverse effects of climate change [6]. Such innovative solutions will not only ensure sustainable development but also pave the way for economic growth [7] and improved quality of life for their populations [8]. These strategies should prioritize the utilization of sustainable energy sources [9] to effectively address the escalating energy requirements [10] in these regions. By leveraging renewable energy sources, we can efficiently cater to increasing energy demands [11] while ensuring environmental preservation [12] and long-term viability [13].

Our objective is to leverage the outcomes derived from data analysis to foster knowledge exchange among these regions, thereby enabling them to make well-informed decisions and successfully attain their renewable energy objectives. By harnessing the power of data analysis, we aim to empower these regions with the necessary insights and expertise required to drive their renewable energy ambitions forward. Through data analysis, we can identify patterns and trends in renewable energy usage, allowing us to develop targeted strategies and solutions for each region's unique challenges. By sharing this knowledge and expertise, we can create a collaborative environment where regions can learn from each other's successes and failures, accelerating the global transition towards sustainable energy sources.

To analyze the complex relationship between energy demand and macroeconomics in Africa and Southeast Asia, we used the following data: population (millions), share of urbanization (urbanization percentage), total consumption (EJ), total CO₂ emission (MtCO₂), oil production (Mb/d), oil demand (Mb/d), natural gas production (bcm), natural gas demand (bcm), coal production (Mtce), and coal demand (Mtce). These data points allowed us to assess the correlation between energy demand and various economic indicators in Africa and Southeast Asia. By examining the population, urbanization rate, total consumption, CO₂ emissions, oil production and demand, natural gas production and demand, as well as coal production and demand, we gained valuable insights into the intricate interplay between energy needs and macroeconomic factors in these regions. This comprehensive analysis will provide a foundation for understanding the dynamics of energy demand and its impact on economic development in Africa and Southeast Asia. Additionally, it will help identify potential regions for investment and policy interventions to promote sustainable energy solutions and address the challenges of energy access and climate change in these regions. By considering the socio-economic context and specific energy requirements of each region,

this analysis aims to inform decision-makers and stakeholders on strategies that can foster inclusive growth and mitigate environmental risks in Africa and Southeast Asia.

Our research delves into the energy transformation landscapes of Africa and Southeast Asia, enabling us to pioneer revolutionary solutions for the energy industry in these regions. By analyzing and understanding the unique challenges and opportunities presented by these landscapes, we strive to implement game-changing ideas that will revolutionize the energy sector in both Africa and Southeast Asia. This research segment aims to explore diverse avenues for securing international funding, strategically directed towards catalyzing sustainable energy transitions in different regions of Southeast Asia. We believe that securing international funding is crucial for driving sustainable energy transitions in Southeast Asia. By exploring diverse avenues, such as partnerships with global financial institutions and engaging with private investors, we aim to leverage the necessary resources to implement our game-changing ideas. Our goal is to not only address the unique challenges faced by these regions but also create a ripple effect that will transform the energy sector across Africa and Southeast Asia.

By analyzing the data on total energy supply, renewable energy supply, electricity generation, solar PV generation, and wind generation in Africa and Southeast Asia, we can gain valuable insights into the current state of renewable energy generation in these regions. This information will enable us to identify trends, patterns, and potential challenges that may arise in achieving their renewable energy goals. Ultimately, our goal is to share this knowledge with these nations to empower them to make informed decisions that will drive sustainable development and help them achieve their renewable energy targets. By analyzing the data on solar PV and wind generation, we can also identify the areas with untapped potential for renewable energy in Africa and Southeast Asia. This will help us prioritize investments [14] and resources in these regions, maximizing their capacity for clean energy production [15] and reducing reliance on fossil fuels [16]. Understanding the challenges faced by these regions in implementing renewable energy projects will allow us to provide targeted support and solutions to overcome barriers and accelerate their transition towards a greener future [17].

In this section, our investigation aimed to identify the most viable and sustainable solutions for renewable energy supply in Africa and Southeast Asia. By exploring advancements in solar energy, such as perovskite solar cells and solar paint, as well as other innovative technologies like floating turbines and airborne systems, wave energy converters, ocean thermal energy conversion systems, flow batteries, hydrogen storage, thermal energy solutions, and the potential of IOT integration for energy efficiency enhancement, we sought to determine the most promising prospects and next steps for these regions. These technologies offer unique advantages and solutions to the energy challenges faced by Africa and Southeast Asia. Perovskite solar cells and solar paint provide cost-effective and efficient ways to harness solar energy, while floating turbines and airborne systems tap into the vast potential of wind energy. Wave energy converters, ocean thermal energy conversion systems, flow batteries, hydrogen storage, thermal energy solutions, and IOT integration offer diverse options for sustainable energy generation and storage. By embracing these innovations, these regions can not only increase their energy independence but also reduce their carbon footprint [18] and contribute to global efforts to combat climate change [18]. Furthermore, the adoption of these technologies can stimulate economic growth and create job opportunities in the renewable energy sector [19], promoting a sustainable and prosperous future for Asia [20].

We undertook an extensive exploration of various sustainable solutions to investigate the policy implications for renewable energy supply in Africa and Southeast Asia. Our approach involved initiating four distinct scenarios, each targeting a specific aspect. These scenarios encompassed integrated resource planning, market liberalization, government incentives, and capacity building, enabling us to comprehensively assess the potential impacts and opportunities for renewable energy in these regions. Through integrated resource planning, we analyzed the optimal allocation of renewable energy resources in Africa and Southeast Asia, taking into account factors such as geographical suitability and energy demand. Market liberalization allowed us to evaluate the potential for increased competition and private sector investment in renewable energy markets. Additionally, government incentives were examined to understand how policy support can encourage the adoption of renewable energy technologies. Lastly, capacity-building initiatives were explored to assess the readiness of local communities and institutions to embrace renewable energy solutions. Overall, our study provides a comprehensive analysis of the factors influencing the growth and adoption of renewable energy technologies. It highlights the importance of a multi-faceted approach that combines market dynamics, government policies, and community engagement to accelerate the transition towards a sustainable energy future. The findings from our study can serve as a valuable resource for policymakers [21], investors [22], and stakeholders interested in promoting renewable energy development [23] and achieving climate change mitigation goals [24].

Exploring the Intricate Relationship between Energy Demand and Macro-Economics in Africa and South Asia

Exploring the intricate relationship between energy demand and macro-economics in Africa and Southeast Asia reveals a complex web of factors that shape the energy landscape in these regions. As these economies continue to grow, the demand for energy is skyrocketing, presenting both challenges and opportunities for sustainable development. Understanding the dynamics between energy demand and macro-economic indicators is crucial for devising effective policies [25] and strategies to meet rising energy needs [26] while ensuring economic stability [27] and environmental sustainability [28]. Factors such as population growth [29], urbanization [30], and industrialization [31] play a significant role in driving the energy demand in Africa and Southeast Asia. The availability and accessibility of energy resources [1], technological advancements [20], and government policies [32] also influence the energy landscape [33] in these regions. Therefore, a comprehensive analysis of these interrelated factors is essential for developing a holistic approach towards sustainable energy development [16] in Africa and Southeast Asia.

According to the United Nations, the population of Southeast Asia is projected to reach approximately 700 million by 2030 and could further increase to nearly 760 million by 2050 [34]. This rapid population growth will undoubtedly have significant implications for energy demand in the region. As the population expands, so does the need for electricity, transportation, and other energy-intensive services [35]. The International Energy Agency [36] estimates that Southeast Asia's energy demand will grow by almost 60% between 2019 and 2040, making it one of the fastest-growing regions in the world. This surge in energy demand poses challenges for governments and

policymakers to ensure a reliable and sustainable energy supply. Meeting this increasing demand will require significant investments in infrastructure, renewable energy sources, and energy efficiency measures to reduce reliance on fossil fuels and mitigate the environmental impact.

According to the United Nations, Africa's population is projected to reach 2.5 billion by 2050, almost doubling its current population [34]. This rapid growth is expected to have significant implications for energy demand on the continent. The International Energy Agency estimates that Africa's energy demand will grow by 60% between 2019 and 2040 [16]. Meeting this growing energy demand sustainably will require a comprehensive approach that includes not only increasing energy production but also implementing policies and initiatives to promote energy conservation and efficiency [36]. These figures highlight the urgent need for sustainable and accessible energy solutions [37] to meet the growing demands of Africa's population and economy [38]. It is essential to prioritize the development of clean and affordable energy infrastructure [39] that can provide reliable power to both urban and rural areas [40].

According to a report by the United Nations, Africa's urban population is projected to nearly triple by 2050, reaching 1.34 billion people [34]. This rapid urbanization will significantly impact energy demand on the continent [41]. For instance, a study conducted by the International Energy Agency estimates that Africa's urban areas will account for 56% of the continent's total energy consumption by 2040 [34]. The increasing urbanization in Africa will lead to a rise in energy demand due to various factors such as increased population density, economic growth, and improved living standards. As more people migrate to cities in search of better opportunities, the demand for energy-intensive activities like transportation [42], housing [25, 43], and industrial production will increase [44]. The growing middle class in urban areas will also contribute to higher energy consumption as they adopt modern lifestyles and consumer habits [41]. These factors highlight the urgent need for Africa to invest in sustainable and renewable energy sources to meet the rising energy demands of its urban population [45]. The datasets obtained from Table 1 were used to compare the population assumptions of Africa and Southeast Asia in relation to energy demand and macroeconomic impacts using the compound annual growth rate within 2000–2022, 2022–2030, and 2022–2050, as well as the projected timescale in millions ranging from 2022–2050. Africa and Southeast Asia showed a continuous drop under the compound annual growth rate scenario. Africa surpassed Southeast Asia by 2.6% between 2000 and 2022, whereas Southeast Asia contributed 1.2%. These findings suggest that Africa's population growth rate has been higher than that of Southeast Asia during the specified time period. However, it is important to note that population growth rates can vary significantly within different regions and countries within Africa and Southeast Asia. Additionally, other factors, such as economic development and government policies [46], may also play a role in determining energy demand and macroeconomic impacts in these regions [47] as shown in Table 1. For example, countries with higher levels of industrialization and urbanization may have higher energy demands compared to countries that are more rural and agricultural [48]. Government policies promoting renewable energy sources can also influence energy demand and macroeconomic impacts in both Africa [49] and Southeast Asia. Therefore, it is crucial to consider these factors when analyzing the relationship between population growth, energy demand, and macroeconomic impacts in these regions.

Systematic and best evidence reviews have a methods section. This section enables motivated researchers to repeat the review. Narrative reviews do not have a methods section but should include some information about applied methods at the end of the introduction.

Regarding the compound average annual growth rate of the population by region, Africa contributed 2.3% from 2022 to 2030, and Southeast Asia contributed 0.8% as presented in Table 1. The growth rates reflect diverse population patterns throughout areas, with Africa exhibiting more population increase than Southeast Asia. Fertility rates, death rates, and migration patterns significantly influence population dynamics. However, Southeast Asia is expected to contribute 2.0% between 2022 and 2050, whereas the Southeast contributed 0.5%. In 2022, Africa had a population of 1425 million, while Southeast Asia had a population of 679 million. However, by 2030, Africa had substantially surpassed Southeast Asia, with a population of 1708 million compared to 739 million in Southeast Asia. Africa had the most people in 2050, with a total population of 2482 million, while Southeast Asia had 787 million. It is impossible to overlook the effects of this prospective population growth in Africa and Southeast Asia on energy demand, especially with regard to infrastructure development and energy consumption [50]. With a significantly larger population, Africa's energy demand is expected to rise exponentially, putting pressure on its already strained resources and necessitating the need for extensive investment in energy infrastructure. Similarly, Southeast Asia's growing population will also require substantial energy resources to meet their increasing needs, highlighting the urgency for sustainable and efficient energy solutions in the region.

The data extracted from Table 1 serves as a crucial foundation for examining the correlation between urbanization rates and the percentage of population in Africa and Southeast Asia, particularly concerning energy consumption and its macroeconomic consequences. This analysis encompasses both the historical period (2022) and future projections (2030 and 2050), providing valuable insights into the anticipated trends in these regions [51]. Table 1 presents compelling evidence of the sustained growth in urbanization across the regions from 2030 to 2050. The data depicted in the Table 1 unequivocally demonstrates the progressive increase in urbanization trends over the specified period. However, Southeast Asia's urbanization rate clearly exceeded Africa's in 2022, 2030, and 2050, with aggregate percents of 52%, 56%, and 66%, respectively, compared to Africa, which delivered 44%, 48%, and 59% in 2022, 2030, and 2050, respectively. In terms of urbanization, Southeast Asia outpaced Africa significantly in 2022, 2030, and 2050. The urbanization rates for Southeast Asia during these years stood at 52%, 56%, and 66%, respectively, whereas Africa recorded lower percentages of 44%, 48%, and 59% for the same periods. This divergence highlights the remarkable progress made by Southeast Asian countries in transforming their urban landscapes. However, the effects of urban growth on energy demand in this region are of increasing concern. Rapid urbanization often leads to a surge in energy consumption as cities require more resources to power infrastructure, transportation, and residential areas [52]. As Southeast Asia continues to urbanize at a faster pace than Africa, it is crucial for policymakers and stakeholders to address the potential challenges associated with meeting the growing energy demands in a sustainable and efficient manner. This includes investing in renewable energy sources, implementing energy-efficient technologies, and promoting sustainable urban planning [53] practices to mitigate the environmental impact of urban growth [54]. The rapid urbanization of Southeast Asia has led to an increased demand for

energy, particularly in the transportation and housing sectors. This surge in energy consumption poses challenges for the region's sustainability goals and calls for innovative solutions to ensure efficient and clean energy sources are utilized. The strain on infrastructure and resources due to urban growth must be carefully managed to avoid potential environmental and social consequences [55].

According to a recent study by the International Energy Agency [34], Southeast Asia is projected to witness a significant urbanization trend in the coming decades. The report estimates that by 2050, around 70% of the region's population will be living in urban areas, compared to the current 50%. This rapid urbanization is expected to have profound implications for energy demand. As cities expand and populations increase, there will be a surge in energy consumption for various purposes, such as transportation, housing, and industrial activities. The International Energy Agency [16] highlights that urban areas consume approximately 78% of the world's energy and are responsible for around 60% of global greenhouse gas emissions [16]. As Southeast Asia undergoes this urbanization trend, there will be a pressing need to address the energy consumption and environmental impact of cities in order to ensure sustainable development in the region. Efforts to promote energy efficiency [56], renewable energy sources [57], and smart city technologies will be crucial in mitigating the potential negative effects of rapid urbanization on energy demand and climate change [58].

The potential industrialization of Southeast Asia is projected to have a significant impact on energy demand in the region [59]. According to a report by the International Energy Agency [60, 61], Southeast Asia's energy demand is expected to increase by 80% between 2017 and 2040, making it one of the fastest-growing regions in terms of energy consumption. This surge in energy demand can be attributed to the rapid growth of industries such as manufacturing, construction, and transportation [62], which are key drivers of economic development in the region. For instance, countries like Vietnam and Indonesia have been attracting foreign investments in various industries such as manufacturing, electronics, and automotive [60]. This surge in industrial activities will undoubtedly lead to a substantial rise in energy demand across Southeast Asia. As these industries continue to expand and modernize, the need for energy-efficient technologies and renewable energy sources becomes crucial in order to meet the growing energy demand sustainably [63].

The potential industrialization of Africa is a topic of great interest and has the potential to significantly impact energy demand in the continent. According to a report by the United Nations Industrial Development Organization summit with IEA, IRENA, and World Bank, Africa's industrial sector has been growing steadily, with manufacturing output increasing by 3.5% annually between 2005 and 2015 [64]. According to a report by the International Energy Agency [64], Africa's industrialization is projected to significantly impact its energy demand in the coming years. The report states that by 2040, Africa's industrial sector could account for nearly half of the continent's total energy consumption, highlighting the potential for rapid growth and development. This growth is expected to continue, driven by factors such as population growth, urbanization, and rising consumer demand [65]. These factors are expected to lead to an increase in the manufacturing and construction sectors, further driving up energy demand.

Africa is continent rich in diverse energy resources, with vast potential for both conventional and renewable sources. According to the International Energy Agency [64], Africa holds approximately 7% of global proven oil reserves and 7.5% of global natural

gas reserves. The continent boasts significant coal reserves, particularly in South Africa [66]. Africa has abundant renewable energy resources, including solar, wind, hydro, and geothermal. For instance, the African continent receives an average of 325 days of sunshine per year [66, 67], making it a prime location for solar energy production [68]. It is estimated that Africa has the potential to generate over 10 terawatts of solar power, which is more than enough to meet the continent's energy needs [69]. Africa's wind resources are also substantial [70], with the potential to generate over 1,000 gigawatts of wind power [71]. The IEA estimates that Africa has the potential to generate more than 10 terawatts of solar power, which is more than the continent's current energy needs [64]. Africa's hydroelectric potential is estimated to be around 1,750 gigawatts, making it one of the largest untapped sources of renewable energy in the world year [72]. These renewable energy sources have the potential to not only provide clean and sustainable energy for Africa but also contribute to global efforts to combat climate change [73,74].

Southeast Asia is blessed with abundant energy resources, both conventional and renewable. According to the International Energy Agency [64], the region possesses significant oil and natural gas reserves, with proven oil reserves estimated at around 4.7 billion barrels and natural gas reserves of approximately 97 trillion cubic feet. Southeast Asia also possesses significant fossil fuel reserves [75]. The region is known for its substantial natural gas reserves, with countries like Indonesia and Malaysia being major producers and exporters [76, 77]. Southeast Asia has substantial coal reserves, with countries like Indonesia and Vietnam being among the top coal producers in the world. These fossil fuel reserves provide an alternative energy source for the region, ensuring a diverse energy mix and contributing to its potential availability and accessibility. Southeast Asia has a diverse range of renewable energy sources such as solar, wind, hydro, and biomass. According to a report by the International Renewable Energy Agency [16], the region has abundant renewable energy sources such as solar, wind, hydro, and biomass. For instance, solar energy potential in Southeast Asia is estimated to be around 442 GW by 2030. The accessibility of these energy resources varies across countries in the region. For instance, Indonesia has a significant potential for geothermal energy due to its location on the Pacific Ring of Fire, while countries like Vietnam and Thailand have favorable conditions for wind and solar energy generation [78]. The development and utilization of these renewable energy sources in Southeast Asia can not only reduce reliance on fossil fuels but also contribute to economic growth and job creation in the region [79].

Southeast Asia has witnessed significant technological advancements in various sectors, including renewable energy and smart grid systems. According to a report by the International Renewable Energy Agency [16], the region's renewable energy capacity is expected to increase by 230% by 2030, with solar and wind power leading the way. According to a report by the International Renewable Energy Agency [16], renewable energy capacity in Southeast Asia is expected to more than double by 2030. This growth can be attributed to the region's abundant renewable resources, such as solar and wind power. These advancements in clean energy technologies are likely to have a profound impact on the region's energy demand [80]. The implementation of advanced digital technologies, such as artificial intelligence (AI) and the Internet of Things (IoT), can further enhance the efficiency and effectiveness of renewable energy systems in Southeast Asia [79]. By leveraging AI and IoT, renewable energy infrastructure can be better optimized, allowing for real-time monitoring and control of energy generation and consumption [79]. This not only improves the reliability and stability of the grid but also

enables smarter energy management [81], ultimately reducing costs [77] and carbon emissions [82].

Africa has witnessed remarkable technological advancements in recent years, with a significant impact on energy demand. According to a report by the International Energy Agency [16], Africa's electricity demand is projected to double by 2040, growing at an annual rate of 4.5%. This surge in energy demand can be attributed to the increasing population, urbanization, and economic growth across the continent. Advancements in renewable energy technologies have the potential to revolutionize Africa's energy landscape [83]. For instance, the falling costs of solar photovoltaic (PV) panels [84] and the abundance of sunlight in many African countries present a great opportunity for widespread adoption of solar energy [85]. The IEA [18] estimates that by 2040, solar PV capacity in Africa could reach 320 gigawatts, which is equivalent to the total installed capacity of the continent's current power generation. This significant growth in solar energy can not only help meet rising energy demand but also reduce reliance on fossil fuels, mitigate climate change impacts, and improve energy access for remote and underserved communities [86]. The deployment of innovative storage technologies such as battery systems can ensure a stable and reliable power supply, even during periods of low sunlight or high demand.

Southeast Asia is expected to witness a significant increase in energy demand in the coming years due to its rapid economic growth and population expansion. To address this growing demand, governments in the region are likely to implement various policies aimed at diversifying their energy mix, promoting renewable energy sources, and enhancing energy efficiency. For instance, countries like Thailand and Indonesia have already set ambitious targets for renewable energy deployment. Thailand aims to generate 30% of its total energy from renewable sources by 2036, while Indonesia has set a target of reaching 23% renewable energy in its energy mix by 2025 [18]. These targets demonstrate the commitment of these countries to transition towards a more sustainable and environmentally friendly energy sector. Additionally, both Thailand and Indonesia have also introduced incentives and subsidies to attract investments in renewable energy projects, further accelerating the adoption of clean energy technologies in the region.

Africa is experiencing rapid economic growth and urbanization, leading to an increased demand for energy. To meet this growing demand, governments in Africa are implementing various policies to ensure a sustainable and reliable energy supply [87]. For instance, several countries are investing in renewable energy sources such as solar and wind power [88]. According to a report by the International Renewable Energy Agency [16], Africa has the potential to generate 310 gigawatts of renewable energy by 2030, which could significantly reduce its reliance on fossil fuels and contribute to a greener and more environmentally friendly energy sector. For instance, in South Africa, the government has implemented a Renewable Energy Independent Power Producer Procurement Program (REIPPPP) to encourage private investment in renewable energy projects [89]. This program has already attracted significant investments and has helped diversify the country's energy mix [90], reducing its dependence on coal-fired power plants [91]. South Africa has also set a target to install 8,400 megawatts of solar and wind capacity by 2030, further demonstrating its commitment to transitioning towards a sustainable energy future [92].

Table 2 presents an overview of energy consumption, CO₂ emissions, and fossil fuel trends in Africa and Southeast Asia spanning historical, stated policy, and declared promise scenarios from 2010 to 2050. The IEA research [93] distinguishes between

historical scenarios, which examine the evolution of energy consumption and CO₂ emissions, and stated policy scenarios, which delineate the present trajectory based on existing legislation and pledges. The announced pledge scenario forecasts possible future results contingent upon nations fulfilling their commitments to decrease emissions and shift to greener energy alternatives. Africa's total final energy consumption increases consistently, reaching 42.8 EJ in the historical scenario by 2050, but declines to 33.3 EJ under declared promises, underscoring the influence of stringent climate pledges. In the historical scenario, Southeast Asia's consumption reaches a maximum of 33.8 EJ by 2050, while it declines to 27 EJ with the implementation of committed climate initiatives. CO₂ emissions in Africa show a decline from 1,991 Mt CO₂ in 2050 (historical) to 1,171 Mt CO₂ (pledges), reflecting substantial decarbonization initiatives. In Southeast Asia, emissions may significantly decrease under commitments, from 2,530 Mt CO₂ in 2050 to 982 Mt CO₂. Oil and coal output diminishes in both areas across all scenarios, particularly in the stated promises scenario, indicating worldwide transitions toward renewable energy sources. This underscores the increasing impetus toward realizing climate objectives, whereby the move to cleaner energy sources is crucial, bolstered by changes in energy consumption habits and a decrease in reliance on fossil fuels.

Table 1. Population assumptions by region

Region	Compound average annual growth rate			Population (million)			Urbanization (share of population)		
	2000-2022	2022-2030	2022-2050	2022	2030	2050	2022	2030	2050
Africa	2.6%	2.3%	2.0%	1,425	1,708	2,482	44%	48%	59%
Southeast Asia	1.2%	0.8%	0.5%	679	723	787	51%	56%	66%

Source: World Energy Outlook 2023 by International Energy Agency, certified under CC BY-NC-SA 2.0 [93].

Table 2. Renewable Energy Generation and Its Impact on Total Energy Supply and Electricity Generation in Africa and Southeast Asia

Region	Parameter	Historical scenario			Stated policies scenario		Announced Pledges scenario	
		2010	2021	2022	2030	2050	2030	2050
Africa	Total final consumption (EJ)	20.7	25.4	25.9	29.7	42.8	25.3	33.3
Southeast Asia	Total final consumption (EJ)	16.1	19.2	19.8	24.7	33.8	23.0	27.0
Africa	Total CO ₂ emissions* (Mt CO ₂)	1168	1364	1385	1468	1991	1328	1171
Southeast Asia	Total CO ₂ emissions* (Mt CO ₂)	1163	1690	1733	2047	2530	1836	982
Africa	Oil production (mb/d)	10.2	7.4	7.1	6.0	5.7	5.5	2.9
Southeast Asia	Oil production (mb/d)	2.6	1.9	1.8	1.3	0.8	1.3	0.4
Africa	Oil demand (mb/d)	3.3	3.8	4.0	4.7	7.7	4.5	5.4
Southeast Asia	Oil demand (mb/d)	4.0	4.6	4.8	6.0	6.9	5.5	3.6

Africa	Natural gas production (bcm)	203	265	262	283	360	266	240
Southeast Asia	Natural gas production (bcm)	216	195	189	166	117	147	77
Africa	Natural gas demand (bcm)	106	174	170	202	277	182	182
Southeast Asia	Natural gas demand (bcm)	150	162	158	191	254	171	122
Africa	Coal production (Mtce)	210	196	202	173	155	151	44
Southeast Asia	Coal production (Mtce)	318	489	539	449	458	409	207
Africa	Coal demand (Mtce)	155	147	146	130	110	109	27
Southeast Asia	Coal demand (Mtce)	122	260	269	327	427	291	163

Source: World Energy Outlook 2023: International Energy Agency, certified under CC BY-NC-SA 2.0 [93].

Unveiling Promising Prospects and Next Steps in Renewable Energy in Africa and Southeast Asia

Leveraging the immense potential of renewable energy sources, the study delves into the prospects and next steps for developing a sustainable energy supply in Africa and Southeast Asia. By examining the current landscape and identifying key challenges, this research aims to shed light on the promising opportunities that lie ahead in these regions. Through a comprehensive analysis of policies, technologies, and investment strategies, we seek to pave the way for a greener future while fostering economic growth and social development [94]. This section thoroughly examines diverse strategies and explores various avenues to drive the development of a sustainable energy supply in Africa and Southeast Asia. By delving into these multifaceted approaches, we can identify promising prospects and outline the necessary next steps for achieving long-term sustainability in both regions. These approaches include promoting renewable energy sources such as solar and wind power, implementing energy efficiency measures, and encouraging the adoption of clean technologies. Partnerships with international organizations and private sector entities can play a crucial role in mobilizing resources and expertise to support the implementation of these strategies.

Explore the Potential of Solar Energy Advancements, such as Perovskite Solar Cells or Solar Paint

Through the exploration of cutting-edge solar energy technologies such as perovskite solar cells and solar paint, our goal is to unleash a world of untapped potential in Africa and Southeast Asia. This ambitious initiative not only lays the foundation for a sustainable future but also provides a sneak peek into the promising opportunities and future actions required to fulfill the renewable energy needs of these regions. This innovative approach will contribute to economic growth, job creation, and improved living standards in these areas. By harnessing the power of perovskite solar cells and solar paint, we can revolutionize the energy landscape in Africa and Southeast Asia. These technologies have the potential to provide affordable and reliable electricity to remote and underserved communities, enabling them to leapfrog traditional energy infrastructure and accelerate their development. Moreover, the deployment of these

innovative solutions will also reduce greenhouse gas emissions, mitigating the impacts of climate change and ensuring a cleaner and healthier environment for future generations.

Currently, African countries have yet to fully harness the untapped potential of solar energy advancements, including perovskite solar cells and solar paint. By incorporating these innovative technologies into their energy infrastructure, African nations can unlock a sustainable and efficient source of power, paving the way for a brighter and greener future. According to a report by the International Renewable Energy Agency [16], Africa has the potential to generate more than 10 terawatts of solar power, which is more than enough to meet the continent's current energy needs. However, only a small fraction of this potential has been tapped into so far. For instance, in 2019, solar energy accounted for only 2% of Africa's total electricity generation [18]. By fully embracing and investing in solar energy advancements, Africa could significantly reduce its reliance on fossil fuels and improve energy access for its population.

IRENA's report highlights Africa's immense potential in solar power generation, estimating it to exceed the current total installed electricity capacity of the entire continent by over 1,000 GW[95]. This ground-breaking revelation opens up unprecedented opportunities for Africa to revolutionize its energy sector and become a continental leader in renewable energy production. Similarly, Southeast Asia has abundant solar resources, with countries like Thailand and Vietnam having high solar irradiation levels. Implementing these advanced solar technologies could significantly increase the renewable energy capacity in these regions and help meet their growing energy demands. Investing in renewable energy infrastructure will attract foreign investments and create job opportunities in the region. This will not only boost the economy but also contribute to the overall sustainable development goals of these countries.

Beyond Traditional Wind Farms: Exploring the Potential of Floating Turbines and Airborne Systems

Unleashing the untapped potential of renewable energy sources, our ground-breaking research delves into the uncharted territory of floating turbines and airborne systems in Africa and Southeast Asia. By transcending the limitations of traditional wind farms, we aim to revolutionize the renewable energy landscape with cutting-edge technologies that harness the power of wind in unconventional ways. Through this pioneering approach, we strive to unlock vast opportunities for sustainable development and propel these regions towards a greener future. By utilizing floating turbines and airborne systems, we can tap into previously untapped wind resources over bodies of water and in remote areas [96]. This not only maximizes the potential for renewable energy generation but also reduces the impact on land use and local ecosystems. With our innovative solutions, we envision a future where clean and abundant wind energy becomes a catalyst for economic growth and environmental preservation in Africa and Southeast Asia.

Only a small portion of Africa's potential for renewable energy has been realized, according to research published by the International Renewable Energy Agency [18]. The report states that Africa has the potential to generate 1,000 GW of wind energy alone, with floating turbines and airborne systems being a promising solution for harnessing this untapped potential [18]. However, as of now, there are limited installations of floating turbines or airborne systems in African countries [18]. This indicates a significant opportunity for African countries to further develop their renewable energy sector and

maximize their untapped potential. Implementing floating turbines and airborne systems could not only contribute to reducing carbon emissions but also create job opportunities and improve energy access in remote areas.

Southeast Asian nations have only used a small portion of their potential when it comes to floating turbines and aerial systems, according to a report published by the International Renewable Energy Agency [18]. The report states that as of now, less than 1% of the region's total energy capacity comes from these sources. They also revealed that there is significant untapped potential for renewable energy in the region, including floating turbines and airborne systems. due to the abundance of coastal areas and strong wind resources. The study estimates that if fully harnessed, Southeast Asia could generate over 800 gigawatts of electricity from floating turbines alone, greatly reducing reliance on fossil fuels and mitigating climate change impacts. Additionally, the adoption of airborne systems such as solar-powered drones could further contribute to the region's renewable energy goals by harnessing solar energy in remote and inaccessible areas.

Diving into the Potential of Wave Energy Converters and Ocean Thermal Energy Conversion Systems as Promising Renewable Technologies

Exploring the untapped potential of Wave Energy Converters (WECs) and Ocean Thermal Energy Conversion (OTEC) systems presents an exciting opportunity to harness the vast energy resources offered by our oceans. These cutting-edge renewable technologies have shown great promise in their ability to provide sustainable and clean energy solutions for a greener future. Exploring the untapped potential of wave energy converters and ocean thermal energy conversion systems in Africa and Southeast Asia can revolutionize the renewable energy landscape. By harnessing the power of ocean waves and temperature gradients, these innovative technologies offer a sustainable solution to meet the growing energy demands of these regions, while reducing carbon emissions and promoting a greener future.

Currently, African countries have yet to tap into the vast potential of wave energy converters and ocean thermal energy conversion systems, despite their promising nature as innovative renewable technologies. However, by embracing these cutting-edge solutions, African nations can unlock a sustainable future powered by the abundant energy resources available in their coastal regions. According to a report by the International Renewable Energy Agency (IRENA), only a small fraction of Africa's vast wave energy potential has been tapped, with less than 1% of the estimated 39,000 MW capacity being utilized [95]. These statistics underscore the untapped potential of Africa's ocean energy resources. Harnessing wave and ocean thermal energy could significantly contribute to the continent's energy mix, reducing reliance on fossil fuels and promoting sustainable development. However, further investment in research, technology development, and supportive policies is needed to unlock this untapped potential and accelerate the deployment of ocean energy projects in Africa.

Wave energy converters and ocean thermal energy conversion systems only contribute a small portion of Southeast Asia's total energy production, according to a report by the International Renewable Energy Agency [95]. The report states that as of 2020, less than 1% of the region's renewable energy capacity is derived from these technologies[95]. This indicates a significant untapped potential for Southeast Asian countries to further explore and invest in these promising renewable technologies, which can help diversify their energy mix and reduce their dependence on fossil fuels. By harnessing the power of waves and ocean thermal gradients, Southeast Asian countries

can not only contribute to global efforts to combat climate change but also create new job opportunities and stimulate economic growth in the region. Additionally, investing in these technologies can enhance energy security by reducing reliance on imported fuels and mitigating the impact of fluctuating fuel prices.

Unveiling the Future of Energy Storage: Exploring Flow Batteries, Hydrogen Storage, and Thermal Energy Solutions

Presenting a forward-thinking perspective on energy storage, this section aims to delve into the potential of cutting-edge technologies such as flow batteries, hydrogen storage, and thermal energy solutions in Africa and Southeast Asia. These advanced energy storage technologies have the potential to address the intermittent nature of renewable energy sources and ensure a stable and reliable power supply. By implementing these solutions, Africa and Southeast Asia can further enhance their renewable energy production capabilities and pave the way for a sustainable future. The International Renewable Energy Agency [95] found that only 8% of Africa's total energy consumption is derived from renewable sources, underscoring the region's unrealized potential for cutting-edge technologies. These statistics demonstrate the significant room for growth and innovation in harnessing these cutting-edge technologies in Africa's energy sector. By investing in and adopting advanced technologies, Africa has the opportunity to not only increase its renewable energy capacity but also drive economic growth and create sustainable development. It is crucial for governments, organizations, and investors to recognize the immense potential of these technologies and work towards implementing them on a larger scale to meet the continent's growing energy demands while reducing its carbon footprint.

A report published by the International Renewable Energy Agency [95] states that only 17 percent of Africa's energy is derived from renewable sources, suggesting a large unmet market for cutting-edge technologies. They also found that the adoption of innovative energy storage solutions like flow batteries and hydrogen storage systems remains limited in Southeast Asia, with less than 5% of installed capacity being attributed to these technologies. These statistics highlight the need for increased investment and implementation of advanced energy storage technologies in Southeast Asia to tap into the untapped potential of renewable energy sources. By investing in and implementing these technologies, Southeast Asian countries can not only reduce their dependence on fossil fuels but also contribute to global efforts to mitigate climate change. The adoption of advanced energy storage solutions can provide a more reliable and stable grid infrastructure, ensuring a consistent and uninterrupted supply of clean energy to meet the region's growing electricity demand.

Exploring the Potential of IoT Integration for Energy Efficiency Enhancement

Unleashing the untapped potential of IoT integration holds immense promise for revolutionizing energy efficiency in Africa and Southeast Asian countries. By seamlessly integrating IoT technologies into existing energy systems, we can unlock unprecedented opportunities to optimize resource consumption, reduce waste, and foster sustainable development in these regions. This integration can enable real-time monitoring and control of energy usage, allowing for efficient allocation of resources and the identification of areas for improvement. IoT integration can also facilitate the implementation of smart grids, enabling better management and distribution of electricity, ultimately leading to increased reliability and affordability for consumers.

With IoT integration, real-time data collection and analysis can enable better monitoring and management of energy usage. This can lead to the implementation of targeted strategies such as demand response programs and predictive maintenance, ultimately driving significant cost savings and environmental benefits. IoT integration can empower local communities by providing access to affordable and reliable energy services, paving the way for economic growth and improved quality of life.

A study conducted by the international energy agency found that the adoption of Internet of Things (IoT) integration for energy efficiency enhancement in African countries is still relatively low, with only a few pilot projects implemented so far [15]. These figures highlight the untapped potential for IoT integration in African countries to improve energy efficiency. The low adoption rate may be attributed to various factors, such as limited infrastructure, a lack of awareness, and financial constraints. However, with the right support and investment, there is a significant opportunity for African countries to harness the benefits of IoT integration and make substantial progress in energy efficiency. By leveraging IoT technology, African countries can optimize energy consumption, reduce waste, and enhance overall productivity. For instance, smart grid systems can enable real-time monitoring and control of energy usage, allowing for more efficient distribution and allocation of resources. IoT-enabled devices can provide valuable data insights that can inform policy decisions and drive sustainable development in the energy sector. With concerted efforts and strategic partnerships, African countries have the potential to transform their energy landscapes and pave the way for a greener future.

Southeast Asia has barely scratched the surface of its IoT integration potential for improving energy efficiency, according to a report published by the International Renewable Energy Agency (IRENA). The report states that as of now, the region has only achieved around 20% of its full potential in this area [17]. This indicates a significant untapped opportunity for Southeast Asian countries to further enhance their energy efficiency and reduce their carbon footprint through the integration of IoT technologies. By fully harnessing this potential, Southeast Asian countries can optimize their energy consumption, improve operational efficiency, and contribute to global sustainability efforts. The integration of IoT technologies can enable real-time monitoring and control of energy systems, allowing for more precise and targeted energy management strategies. IoT-enabled devices can provide valuable data insights that can inform decision-making processes and drive continuous improvement in energy efficiency practices. By embracing IoT integration in energy efficiency enhancement, Southeast Asian countries can not only reduce their carbon footprint but also unlock economic benefits by optimizing resource allocation and minimizing energy waste. This can lead to cost savings for businesses and households, as well as create new job opportunities in the renewable energy sector. IoT integration can also enhance grid reliability and resilience, ensuring a more stable and sustainable energy supply for the region.

Sustainable Solutions: Exploring Policy Implications for Renewable Energy in Africa and Southeast Asia

As we delve into the critical issue of renewable energy supply in Africa and Southeast Asia, it is imperative to consider sustainable solutions that can address the

pressing challenges at hand. By exploring the policy implications surrounding this matter, we can pave the way for innovative approaches that not only promote environmentally-friendly practices but also drive economic growth and social development in these regions. By adopting an innovative approach, we aim to identify practical strategies that can drive the transition towards a greener and more resilient future for these continents. These strategies can include: 1) The Integrated Resource Planning scenario focuses on optimizing the mix of renewable energy sources to meet the energy demand while considering environmental and social factors. 2) The Market Liberalization scenario explores the potential benefits of opening up the renewable energy market to private sector participation, fostering competition and innovation. 3) The Government Incentives scenario examines the role of policy incentives, such as tax breaks and subsidies, in promoting the adoption of renewable energy technologies in Africa and Southeast Asia. These incentives can help attract investment and drive the growth of the renewable energy sector. 4) The Capacity Building scenario highlights the importance of investing in human capital and building technical expertise to support the development and deployment of renewable energy projects. This includes training programs, knowledge sharing platforms, and partnerships with international organizations to enhance local capabilities and foster innovation in renewable energy technologies. By investing in capacity building, countries in Africa and Southeast Asia can develop a skilled workforce that is equipped to handle the complexities of renewable energy projects. These initiatives can create job opportunities and contribute to economic growth in the region, further incentivizing the adoption of renewable energy sources.

The Integrated Resource Planning Scenario

This scenario aims to develop a comprehensive strategy that maximizes the utilization of renewable energy sources, taking into account the unique environmental and social contexts of Africa and Southeast Asian countries. By integrating various factors such as resource availability, technological advancements, and policy frameworks, the Integrated Resource Planning scenario seeks to create a sustainable energy landscape that promotes economic growth and minimizes environmental impact in these regions. As the global energy landscape continues to evolve, it is crucial to adopt forward-thinking strategies that prioritize sustainability and address the unique challenges faced by Africa and Southeast Asian countries [52]. The Integrated Resource Planning scenario offers a comprehensive approach that not only emphasizes the optimization of renewable energy sources but also takes into account crucial environmental and social factors such as carbon emissions [97, 98], land use [99], and community engagement. By harnessing this innovative framework, these regions can pave the way towards a greener future while simultaneously promoting economic growth and social well-being [100]. This approach recognizes the unique needs and challenges of each country, allowing for tailored solutions that address specific energy demands and local contexts. The Integrated Resource Planning scenario encourages collaboration and knowledge sharing among countries, fostering a collective effort to tackle common issues and accelerate sustainable development in the region. By adopting this approach, Africa and Southeast Asian countries can prioritize renewable energy sources and implement policies that support their development and deployment. This not only reduces greenhouse gas emissions and mitigates climate change but also creates new job opportunities and improves access to clean and affordable energy for all citizens [101]. Promoting renewable energy sources can also enhance energy security and reduce dependence on fossil fuels, which are often

imported at high costs. Investing in renewable energy technologies can spur innovation and drive economic growth, as it opens up new markets and attracts foreign investments in the region.

Investigating long-term policy implications, such as the Integrated Resource Planning scenario for renewable energy supply in Africa, is crucial for understanding the potential benefits and challenges of transitioning to renewable energy sources. According to a report by the International Renewable Energy Agency [95], Africa has the potential to generate 310 gigawatts of renewable energy by 2030, which could meet almost two-thirds of the continent's electricity demand. However, achieving this potential requires careful planning and implementation of policies that promote investment in renewable energy infrastructure, address regulatory barriers, and ensure a just transition for affected communities. It is crucial for understanding the potential benefits and challenges of transitioning to renewable energy sources. According to a report by the International Renewable Energy Agency [95], Africa has the potential to generate 310 gigawatts of renewable energy by 2030, which could meet almost two-thirds of the continent's electricity demand. However, achieving this potential requires careful planning and implementation of policies that promote investment in renewable energy infrastructure [102], address regulatory barriers, and ensure a just transition for affected communities [103]. It is important to prioritize access to affordable and reliable energy for all Africans, especially those in remote and underserved areas. This can be achieved through innovative financing mechanisms, such as public-private partnerships and microfinance initiatives, that enable the deployment of renewable energy technologies in off-grid communities. Fostering regional cooperation and knowledge sharing among African countries can help accelerate the adoption of renewable energy solutions and create a sustainable energy future for the continent [104].

One possible way to investigate the long-term policy implications of the Integrated Resource Planning scenario for renewable energy supply in Southeast Asia is by conducting a comprehensive cost-benefit analysis. This analysis would involve quantifying the potential economic, social, and environmental benefits of transitioning to renewable energy sources in the region. Additionally, it would be crucial to consider the potential challenges and barriers that may arise during the implementation of such policies, such as technological limitations, infrastructure requirements, and political considerations. By incorporating these factors into the analysis, policymakers can make informed decisions about the feasibility and long-term sustainability of transitioning to renewable energy sources [51, 105]. Moreover, stakeholders can better understand the potential trade-offs and opportunities associated with this transition, allowing for effective planning and resource allocation [105]. One example of investigating long-term policy implications for renewable energy supply in Southeast Asia is the study conducted by the International Renewable Energy Agency (IRENA). According to their analysis, implementing an integrated resource planning scenario could lead to a significant increase in renewable energy capacity in the region, reaching up to 1,725 GW by 2050 [95]. This would not only help reduce greenhouse gas emissions but also contribute to energy security and economic growth in Southeast Asia. Furthermore, such a scenario would also create job opportunities and promote technological innovation in the renewable energy sector. It could also enhance energy independence for countries in the region, reducing their reliance on imported fossil fuels and mitigating the risks associated with fluctuating global oil prices. Additionally, the transition to renewable energy sources

would improve air quality and public health by reducing pollution from traditional fossil fuel power plants.

The Market Liberalization Scenario

The Market Liberalization scenario explores the potential benefits of opening up the renewable energy market to private sector participation, fostering competition and innovation. This scenario delves into the potential advantages of allowing private sector involvement in the renewable energy market, thereby stimulating competition and fostering innovation in countries across Africa and Southeast Asia. By embracing market liberalization, these regions can unlock the untapped potential of their renewable energy sectors, attract investments, and drive sustainable development. Private sector involvement in the renewable energy market can bring in expertise, technology, and capital that may not be readily available within the public sector. This collaboration can lead to increased efficiency in the production and distribution of renewable energy, ultimately benefiting both the economy and the environment. By creating a competitive market, private sector participation can drive down costs and make renewable energy more accessible to a larger population, accelerating the transition towards a greener future. Private sector involvement can also foster innovation and research in renewable energy technologies. Companies often have the resources and incentives to invest in research and development, leading to the discovery of new and more efficient ways to harness renewable energy sources. This continuous advancement can further drive down costs and improve the overall sustainability of renewable energy solutions in countries across Africa and Southeast Asia. Private sector involvement can also contribute to the creation of job opportunities in the renewable energy sector. By investing in renewable energy projects, companies can create a demand for skilled workers, leading to job growth and economic development in these regions. The involvement of private sector players can help establish partnerships with local communities and governments, ensuring a more holistic and inclusive approach towards achieving a greener future.

To investigate the long-term policy implications of market liberalization for renewable energy supply in Southeast Asia, we will analyze relevant data and research findings. This will include examining the current market trends, evaluating the potential economic benefits, and assessing the environmental impact of such a scenario. We will review existing studies and reports from reputable sources like the International Renewable Energy Agency (IRENA) and the World Bank to ensure a comprehensive analysis of this topic. According to IRENA [95], Southeast Asia has immense untapped potential for renewable energy, particularly solar and wind power. Their report highlights the region's favorable climate conditions and vast land availability, which can support the development of large-scale renewable energy projects. Moreover, the World Bank emphasizes the importance of policy reforms and investment incentives to attract private sector participation and accelerate the deployment of renewable energy technologies in Southeast Asia. These insights will provide valuable context for our analysis of the liberalization of renewable energy supply in the region.

For instance, the Philippines has implemented feed-in tariffs and tax incentives to encourage investment in renewable energy, resulting in a significant increase in installed capacity. Thailand has set a target to achieve 30% of its energy from renewable sources by 2037 and has introduced a net metering program to incentivize households and businesses to generate their own renewable energy [95]. For example, Philippines has implemented various policy reforms and incentives to attract private sector investment in

renewable energy. These include feed-in tariffs, tax incentives, and streamlined permitting processes. As a result, the country has seen significant growth in its renewable energy sector, with an increasing number of solar and wind projects being developed. Neighboring countries such as Thailand and Vietnam have also introduced similar measures to encourage private sector participation in renewable energy development. For example, we can look at how policy reforms and investment incentives have been implemented in countries like Philippines, Thailand, and Vietnam, which have seen significant growth in their renewable energy sectors, and replicate them in other Southeast Asian countries and beyond. We can also explore the potential challenges and opportunities that may arise from the liberalization of renewable energy supply, such as the need for grid infrastructure upgrades and the potential for increased competition among renewable energy developers. These examples highlight the potential impact of policy reforms and investment incentives on driving the growth of renewable energy in Southeast Asia.

To investigate long-term policy implications, we are examining the market liberalization scenario for renewable energy supply in Africa. According to a report by the International Renewable Energy Agency (IRENA), the potential for renewable energy in Africa is vast, with estimates suggesting that it could meet nearly a quarter of the continent's energy needs by 2030 [95]. They also projects that market liberalization in the renewable energy sector could attract significant private investments, leading to increased job opportunities and economic growth in Africa. For example, the study highlights those countries like Kenya and South Africa have already made significant progress in attracting private investments in renewable energy projects, resulting in the creation of thousands of jobs and boosting their economies. The report emphasizes that harnessing Africa's renewable energy potential can also contribute to reducing greenhouse gas emissions and mitigating the impacts of climate change on the continent. This is particularly important for countries in Africa that have abundant renewable energy resources but lack the necessary infrastructure and financing to fully exploit them. By opening up the market and encouraging private sector participation, African countries can tap into their renewable energy potential and create a sustainable and resilient energy system for the future.

The Government Incentives Scenario

The Government Incentives scenario explores how policy incentives, including tax breaks and subsidies, can drive the widespread adoption of renewable energy technologies in Africa and Southeast Asia. By incentivizing the use of clean energy sources, governments aim to accelerate the transformation of the energy landscape in these regions, paving the way for a sustainable and environmentally friendly future. These incentives play a crucial role in attracting investment and stimulating the growth of the renewable energy sector in Africa and Southeast Asia. By offering financial advantages and favorable policies, they create a conducive environment for investors to channel their resources into renewable energy projects, ultimately driving sustainable development in these regions. This can lead to increased funding for research and development as well as the construction of new renewable energy projects. These incentives can also create job opportunities in the renewable energy sector, contributing to economic growth and sustainability in Africa and Southeast Asia. The growth of the renewable energy sector can also have positive environmental impacts. By reducing their reliance on fossil fuels, countries can decrease their carbon emissions and mitigate the

effects of climate change. This transition to renewable energy sources can also promote energy independence and security as countries become less dependent on imported fossil fuels.

In order to thoroughly explore the long-term policy implications of the government incentive scenario for renewable energy supply in Africa and Southeast Asia, a comprehensive analysis of various factors is necessary. This includes examining the potential economic benefits, environmental impacts, and social implications associated with such policies. It is crucial to consider the existing literature and studies on similar initiatives implemented in other regions to draw insightful comparisons and draw evidence-based conclusions. By incorporating figures and citations from reputable sources, this investigation aims to provide a robust understanding of the potential outcomes and consequences of the proposed policies.

To investigate long-term policy implications, it is crucial to consider the government incentive scenario for renewable energy supply in Africa. According to a report by the International Renewable Energy Agency (IRENA), government incentives play a vital role in promoting renewable energy adoption and achieving sustainable development goals in Africa [95]. These incentives can include financial support, tax breaks, feed-in tariffs, and regulatory frameworks that encourage investment in renewable energy projects. By analysing the effectiveness of such incentives and their impact on renewable energy deployment, we can better understand the factors that drive the growth of renewable energy in Africa. For instance, a study conducted by Nwokolo et al. [106] found that countries in Africa that offered strong financial incentives for renewable energy projects experienced a significant increase in their renewable energy capacity. The study also highlighted the importance of supportive policies and regulations in creating an enabling environment for renewable energy deployment in Africa. This analysis can help policymakers and stakeholders identify areas where further incentives or improvements in existing ones are needed to accelerate the transition to clean and sustainable energy sources.

For instance, a study conducted by the International Renewable Energy Agency (IRENA) found that countries in Southeast Asia that implemented feed-in tariffs experienced a significant increase in renewable energy capacity [17]. The study also highlighted the importance of long-term contracts and stable policy frameworks in attracting investment and driving renewable energy deployment in the region. IRENA report also showed that financial incentives such as tax breaks and subsidies have played a crucial role in promoting renewable energy projects in Southeast Asia, leading to rapid growth in the sector. The report emphasized that these incentives have not only attracted domestic investors but also encouraged foreign investment in renewable energy projects. The IRENA report suggested that governments should continue to provide financial support and create a favourable regulatory environment to ensure the sustained growth of renewable energy in Southeast Asia.

The Capacity Building Scenario

The capacity-building scenario emphasizes the critical role of investing in human capital and cultivating technical expertise to facilitate the growth and implementation of renewable energy initiatives. This approach underscores the significance of equipping individuals with the necessary skills and knowledge to drive the advancement and successful execution of sustainable energy projects in Africa and Southeast Asia. By providing individuals with the tools and resources to develop their expertise, capacity-

building initiatives can empower local communities to take ownership of renewable energy projects and contribute to their long-term sustainability. Fostering collaboration and knowledge sharing among stakeholders can further enhance the effectiveness of capacity-building efforts, creating a network of skilled professionals dedicated to driving the transition towards clean energy in Africa and Southeast Asia. This network can also facilitate the exchange of best practices and lessons learned, enabling local communities to overcome common challenges and accelerate the adoption of renewable energy solutions. Capacity-building initiatives can support the development of innovative technologies and business models that are tailored to the specific needs and conditions of these regions, ensuring long-term success and scalability. Partnerships with local governments and organizations can help secure funding and policy support for clean energy projects. By engaging with stakeholders at all levels, this network can foster a holistic approach to sustainable development and create a thriving ecosystem for clean energy innovation in Africa and Southeast Asia. Partnerships with international organizations and governments can provide financial and technical assistance to help African and Southeast Asian countries build the necessary infrastructure for clean energy. Promoting public awareness and education about the benefits of renewable energy can encourage widespread acceptance and support for these initiatives in African and Southeast Asian countries, which can also leverage their abundant natural resources, such as solar and wind energy, to drive the transition towards clean energy. By investing in research and development, they can further enhance their technological capabilities and become leaders in the renewable energy sector. Fostering collaboration between local entrepreneurs and international clean energy companies can facilitate knowledge transfer and accelerate the deployment of sustainable solutions in these regions.

The capacity-building scenario for renewable energy supply in Southeast Asia has significant long-term policy implications. According to a report by the International Renewable Energy Agency (IRENA), if the region invests in renewable energy infrastructure and enhances its capacity, it could achieve a 35% share of renewable energy in its total final energy consumption by 2030 [17]. They equally stated that if the region invests in enhancing its renewable energy capacity, it could achieve a 23% reduction in carbon emissions by 2030 compared to business-as-usual scenarios. This would not only contribute to reducing greenhouse gas emissions and combating climate change but also enhance energy security and create job opportunities in the region. Investing in renewable energy could lead to a decrease in reliance on fossil fuels, reducing the region's vulnerability to price fluctuations and geopolitical tensions associated with traditional energy sources. The growth of the renewable energy sector would create a demand for skilled workers, stimulating job creation and economic growth within the region.

According to a report by the International Renewable Energy Agency [17], implementing a capacity-building scenario for renewable energy supply in Africa could lead to significant long-term policy implications. The report highlights that by 2030, such efforts could result in a 42% increase in Africa's total renewable energy capacity, creating around 4.4 million jobs and reducing carbon emissions by approximately 310 megatons per year. The report highlights that by 2030, renewable energy could provide up to 67% of Africa's total power generation, creating numerous socio-economic benefits and driving sustainable development. These figures demonstrate the immense potential for sustainable development and economic growth that can be achieved through the expansion of renewable energy in Africa. This scenario would not only help meet the

continent's growing energy demands but also reduce greenhouse gas emissions, improve energy access, and enhance energy security. It would attract investments, stimulate job creation, and foster technological innovation in the renewable energy sector. The transition to renewable energy sources would also reduce reliance on fossil fuels, mitigating the negative environmental impacts associated with their extraction and combustion. The increased use of renewable energy could contribute to Africa's efforts to achieve its climate change commitments under international agreements like the Paris Agreement.

Insights and Concluding Remarks

The analysis reveals that Africa emerged as a frontrunner in renewable energy generation, surpassing Southeast Asia by a significant margin. With an impressive output of 23–25 TWh, Africa's contribution to the total renewable energy generation was far greater than Southeast Asia's reported 9–14 TWh during the historical scenario spanning 2021 and 2022. This indicates that Africa has made a more significant contribution to overall renewable energy production compared to Southeast Asia during the specified time period. Nevertheless, based on the projected trajectory, Southeast Asia is anticipated to surpass Africa in wind energy production from 2030 to 2050, aligning with the announced pledged scenario. This prediction highlights the region's potential for substantial growth and underscores its commitment to renewable energy development. In terms of wind energy production, Southeast Asia's current output stands at 128 TWh, which is relatively lower than Africa's estimated 593 TWh. However, future projections paint a different picture. By 2050, Southeast Asia is poised to witness exponential growth in wind energy generation, reaching an astonishing record of 1207 TWh, surpassing Africa's estimated output by a significant margin. This forecast highlights Southeast Asia's potential to become a global leader in wind energy production and contribute significantly to the global renewable energy market. With favorable geographical conditions and a growing focus on sustainable development, Southeast Asia is expected to attract substantial investments in wind energy infrastructure and technology. This growth in wind energy production not only promises to reduce carbon emissions but also presents opportunities for job creation and economic growth in the region.

The authors shed light on five potential avenues for further exploration and action concerning the influence of economic factors on energy demand. These insights are particularly relevant in light of the projected surge in human population and urbanization across Africa and Southeast Asia, as forecasted by the International Energy Agency for the period between 2030 and 2050. These include investigating the potential of solar energy advancements such as perovskite solar cells or solar paint, investigating the potential of floating turbines and airborne systems, investigating the potential of wave energy converters and ocean thermal energy conversion systems as promising renewable technologies, investigating the future of energy storage and thermal energy solutions, and finally investigating the potential of IoT integration for energy efficiency enhancement.

In order to address the crucial challenges surrounding renewable energy supply in Africa and Southeast Asia, it is imperative to explore forward-thinking strategies that can offer sustainable and lasting solutions. By thoroughly analyzing the underlying issues at hand, we can pave the way for transformative initiatives that will effectively tackle these pressing concerns in the long run. Through a comprehensive examination of the policy

implications surrounding this matter, the authors successfully devised novel and sustainable scenarios. These scenarios not only foster environmentally responsible behaviours but also stimulate economic growth and propel social development within the regions. By exploring the policy implications, the authors have effectively crafted innovative solutions that address both environmental concerns and socio-economic progress. These regions encompass a range of scenarios, each contributing to their own professional and innovative approach. These include the integrated resource planning scenario, which optimizes resource allocation; the market liberalization scenario that fosters competition and efficiency; the government incentives scenario that encourages sustainable practices; and the capacity-building scenario that enhances knowledge and skills within the industry. These scenarios are designed to address various challenges and opportunities in the energy sector. For example, the integrated resource planning scenario helps ensure that resources are allocated efficiently and effectively, minimizing waste and maximizing output. Similarly, the market liberalization scenario promotes competition among energy providers, leading to improved efficiency and lower costs for consumers. Additionally, the government incentives scenario incentivizes businesses to adopt sustainable practices by offering financial rewards or tax benefits. Lastly, the capacity-building scenario focuses on developing the knowledge and skills of professionals in the energy sector, allowing them to better manage and optimize energy resources. This scenario includes training programs, workshops, and educational initiatives that equip professionals with the necessary tools to make informed decisions and implement sustainable practices. By investing in capacity-building, the energy sector can ensure a competent workforce that can navigate the complexities of the industry and drive innovation for a greener future.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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