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Accelerating Solar Energy Transition Towards Green Industrial Revolution in Kenya

Yabesh Kongo and Yegon Cheruiyot Wilbon

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THE KENYA INSTITUTE FOR PUBLIC POLICY RESEARCH AND ANALYSIS (KIPPRA)

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Accelerating Solar Energy Transition Towards Green Industrial Revolution in Kenya

Yabesh Kongo and Yegon Cheruiyot Wilbon

Kenya Institute for Public Policy
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This paper is produced under the KIPPRA Young Professionals (YPs) programme. The programme targets young scholars from the public and private sector, who undertake an intensive one-year course on public policy research and analysis, and during which they write a research paper on a selected public policy issue, with supervision from senior researchers at the Institute.

KIPPRA acknowledges generous training on futures foresight methodology by EDHEC Business School, France; and the UNESCO Futures Literacy Laboratory Chair at Dedan Kimathi University of Technology (DeKUT), Kenya. The course on "Building Strategic Foresight Capabilities" by EDHEC Business School was beneficial for building capacity of Young Professionals on futures foresight.

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Abstract

Solar energy intake in Kenya is still low as compared to other renewable sources, however, its potential is growing as evidenced by increased installed and effective capacity. Kenya plans to attain 100 per cent renewable energy by the year 2030 and achieve net zero emissions by the year 2050. The study explores the current state of solar energy use in Kenya, factors that will accelerate solar energy adoption by the year 2050, and the potential role of Internet of Things (IoT) technologies in optimizing solar energy utilization. A mix of literature review and futures methodology was applied. The scenarios considered political, environmental, social, technological, economic, and legal (PESTEL) factors through consultations with energy sector experts.

The findings show that by 2050 solar energy can manifest in four scenarios: delayed transition, successful transition, sustainability, and business-as-usual. The delayed transition scenario represents slow progress in solar adoption due to limited energy storage technologies, slow rural uptake, low environmental accountability, and limited technical progress. The successful transition scenario depicts a rapid increase in solar energy uptake driven by policy incentives and reforms. The sustainability scenario envisions a robust solar energy sector supported by substantial financing through public-private partnerships and a clear, transparent policy framework. The business-as-usual scenario represents maintaining current practices and policies, leading to modest progress without significant advancements. The systematic literature review showed that integrating IoT technologies can potentially enhance efficiency across the solar value chain.

To achieve sustainable solar energy use by the year 2050, there is a need to lower the cost of solar energy investment by 2030 Green energy financing guided by clear and transparent policy and regulatory frameworks while capitalizing on public-private partnerships on solar energy. Additionally, investment in Internet of Things infrastructure offers significant potential to enhance efficiency and reliability in the solar energy sector by investing in IoT infrastructure. This paves the way for a sustainable energy future.

Abbreviations and Acronyms

4IR	Fourth Industrial Revolution
AfDB	African Development Bank
AI	Artificial Intelligence
COP28	28th Convention of Parties
DOI	Diffusion of Innovations Theory
EPRA	Energy and Petroleum Regulatory Authority
ESS	Energy Storage Systems
ETIP	Energy Transition and Investment Plan
GW	Gigawatts
GWh	Gigawatts per hour
IEA	International Energy Agency
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRENA	International Renewable Energy Agency
KIPPRA	Kenya Institute for Public Policy and Research Analysis
KNBS	Kenya National Bureau of Statistics
KOSAP	Kenya Off Grid Solar Access Project
MEA	Middle East and Africa
MICMAC	Matrice d'impacts croisés multiplication appliquée á un classment
PESTEL	Political, Economical, Social, Technological, Environmental, and Legal
PV	Photovoltaics
SDG	Sustainable Development Goals
SREP	Scaling Up Renewable Energy in Low-Income Countries
TIS	Technological Innovation Systems
TOE	Technology-Organization-Environment
TWh	Terawatts per hour
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
UNIDO	United Nations Industrial Development Organization

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1. Introduction

Solar energy is pivotal in the global transition to renewable energy sources, driven by the need to address climate change. The reliance on fossil fuels for economic growth has accelerated global warming, necessitating a shift towards cleaner alternatives (Chipangamate and Nwaila, 2024).

Energy demand grows as the population expands and technology advances. Solar, with other renewable sources, is freely available. Solar energy can be the best option for future energy demand as it is available, cost-effective, accessible, and efficient in relation to other renewable energy sources (Kannan and Vakeesan). International Energy Agency shows that in 2050 solar will supply around 45 per cent of energy demand in the world. Solar use runs from food, non-metallic textile, building, and chemical industries. Furthermore, solar electricity is widely applied in agriculture, water desalination, telecommunication, operating lights, pumps, engines, fans, refrigerators, and water heaters (Mekhilef et al.,2011). The growth of industrial production has been primarily fueled by the use of fossil fuels, hydroelectric power, and solar energy on a limited scale. Solar power has been employed for illuminating light industries. This study sought to investigate the potential incorporation of solar energy into industrial production as part of Kenya's energy transition.

International agreements such as the Paris Agreement underscore the importance of reducing greenhouse gas emissions to limit global temperature increases. Nations are increasingly turning to renewable energy to meet their energy needs and reduce reliance on non-renewable resources, to achieve net-zero emissions by 2050 (International Energy Agency [IEA], 2023). To accomplish this goal, certain compromises must be made as the process requires the extraction of substantial quantities of clean energy transition minerals to sustain various technologies, including solar photovoltaics (PV), wind turbines, storage facilities, and others (Valero et al., 2021).

Solar photovoltaic technology plays a crucial role in this transition by making a substantial contribution to the global generation of renewable energy (International Renewable Energy Agency [IRENA], 2021). Renewable energy accounted for 26.2 per cent of the overall worldwide electricity generation in 2020. The use of solar energy played a substantial part in contributing to this proportion (IRENA, 2021). Solar photovoltaic (PV) has been widely acknowledged as a technology that can improve energy self-sufficiency and reduce greenhouse gas emissions in industrialized and developing nations (Hondo and Moriizumi, 2017).

Embracing the Fourth Industrial Revolution (4IR) can further enhance the utilization of solar energy, enabling countries like Kenya to maximize their renewable resources, promote sustainable development, and achieve clean energy goals (Boobalan et al., 2023). This research has the potential to greatly influence policy development and provide practical insights to improve Industry 4.0 strategies such as IoT in the field of solar energy. The study aims to significantly contribute to shaping an equitable and sustainable energy landscape, both in Kenya and as a model for global clean energy efforts, by integrating these crucial aspects.

The study sought to answer the following research questions: i) What is the current landscape of solar energy in Kenya's industrial sector? ii) What are the future drivers of change associated with accelerating the solar energy transition in Kenya by 2050? iii) How can IoT technologies be applied to optimize and enhance the efficiency and reliability of solar energy in Kenya?

The rest of the document provides further discussions on the renewable sector, it begins by providing an overview of renewable energy in the global, regional, and local context. It is then followed by a review of the current solar landscape. The next sections provide a literature review of solar energy and gap identification, methodology, results, and finally conclusion and recommendations.

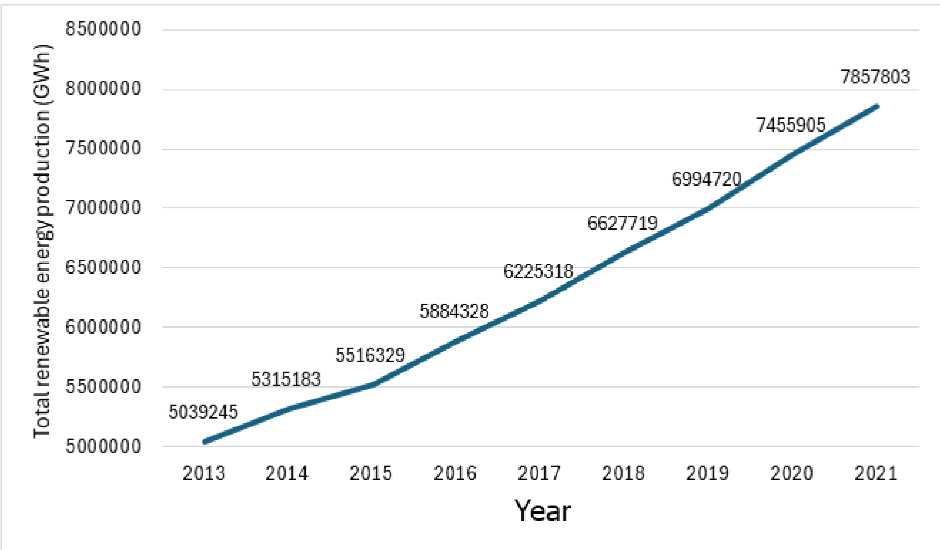
2. Overview of the Renewable Energy Sector

2.1 Global Context of the Renewable Energy Sector

The Sustainable Development Goals (SDGs), which were endorsed by the United Nations General Assembly (UNGA) in 2015, offer a robust framework for global collaboration to attain a sustainable future for the planet. The 17 Sustainable Development Goals (SDGs) and their 169 targets, which are central to the Agenda 2030, establish a roadmap for eradicating extreme poverty, addressing inequality and injustice, and safeguarding the Earth's environment. Agenda 2030 relies heavily on sustainable energy for its success. The global objective of SDG 7 is to achieve three main targets: to guarantee affordable, dependable, and widespread access to modern energy services; to significantly raise the proportion of renewable energy in the global energy combination; and to double the global rate of enhancement in energy efficiency (McCollum et al., 2017).

The world's total renewable energy production has steadily increased from 5,039,245 GWh in 2013 to 7,857,803 GWh in 2021, representing a significant 56 per cent growth over the period as illustrated in Figure 2.1 (IRENA, 2023).

Figure 2.1: Global total renewable energy production (GWh) (2013-2021)

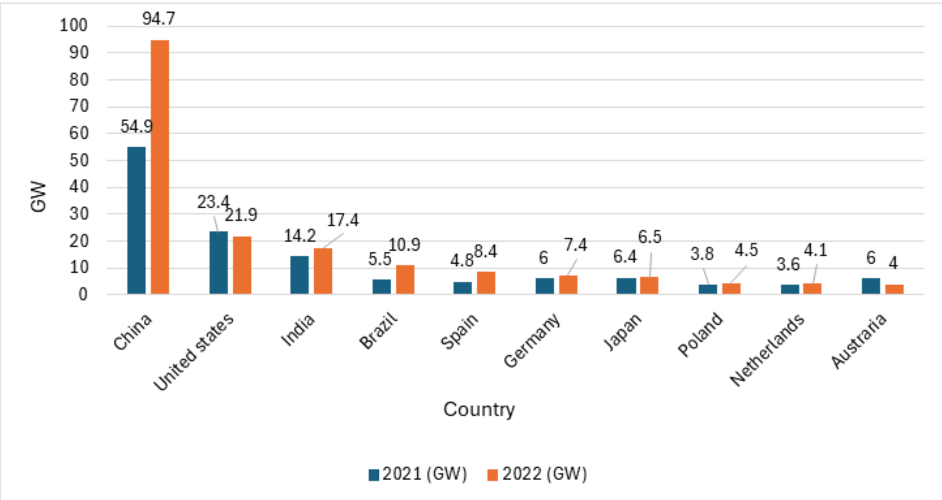


Source: IRENA, 2023

The significant market potential of solar energy and its cost advantage suggest that it will continue to dominate the power generation sector and play a leading role in the global shift towards renewable energy sources. In 2022, solar power, which is leading the transition to renewable energy sources, produced 1,289 TWh, marking a 24 per cent increase from the 1,040 TWh it created in 2021 (Solar Power Europe, 2023).

The rise of solar energy is evident as witnessed by top solar PV markets. According to Solar Power Europe, 2023, China dominates the scene with nearly 95 GW of installed solar photovoltaic capacity by 2022, more than double what they had in 2021. The United States has also seen a remarkable increase, reaching over 55 GW in 2022 from 24 GW the previous year. This trend of growth is not unique to these superpowers. India, Brazil, and Poland are equally undergoing substantial growth in their solar photovoltaic (PV) capacity. Largely, the data provides a distinct representation: solar energy is experiencing a significant increase worldwide, with China taking the lead.

Figure2.2: Top 10 Solar PV Markets, 2021 and 2022



Source: Solar power Europe, 2023

The BP Energy Outlook 2023 examines three scenarios (Accelerated, Net Zero, and New Momentum) for the global energy sector to achieve its objectives by 2050. Peak oil consumption is expected around 2029 in the Rapid and Net Zero scenarios, followed by a decline, while the New Momentum scenario projects peak demand around 2030. Renewables are forecasted to account for nearly 80 per cent of global electricity production by 2050 in the Accelerated and Net Zero scenarios, highlighting their importance. Even in the less aggressive New Momentum scenario, renewables are expected to make up over 50 per cent of power generation. Solar Photovoltaics (PV) are expected to experience significant growth, becoming the fastest-expanding power source, with an estimated annual output exceeding 18,000 TWh by 2050 according to BP's projections (BP, 2023).

Current investment levels in clean energy technologies are insufficient to achieve global net zero emissions by mid-century. To align with the Net Zero Scenario, which is consistent with the Paris Agreement, investment in energy transition would need to average $4.8 trillion per year from 2024 to 2030, nearly three times the total investment observed in 2023 (BloombergNEF, 2023). Global investment in low-carbon energy reached $1.1 trillion in 2022, a 31 per cent increase from the previous year, with renewable energy attracting the most investment at $495 billion, up 17 percent. Electrified transport also saw significant growth, rising 54 per cent to $466 billion. China received the most energy transformation investment, followed by the US.

Despite the increase, the Net Zero Scenario requires substantially more investment. Climate-tech companies raised $119 billion in 2022, indicating market interest, but further investment is needed to meet global climate goals. This underscores the importance of accelerating the adoption of renewable energy sources to address pressing environmental concerns (Grigoroudis et al., 2021; Tanaka et al., 2022).

2.2 Regional Context of the Renewable Energy Sector

Africa possesses the greatest capacity for solar energy systems globally, encompassing 60 per cent of the world's most exceptional solar resources. However, its installed solar energy capacity is now approximately 1.0 per cent of its potential. The absence of energy access is widely seen as the foremost obstacle to economic progress in Africa. Nevertheless, solar photovoltaic (PV) technology currently stands as the most cost-effective energy source in numerous regions across Africa. Furthermore, projections for 2030 indicate that solar PV is expected to surpass all other energy sources in terms of competitiveness (IEA, 2022).

In 2022, the Middle East and Africa (MEA) area experienced significant expansion in solar energy, with an additional 8.3 GW installed. This is a 77 per cent increase compared to the previous year. This achievement is a significant milestone for the area, surpassing the previous highest level of advancement in the Middle East and Africa (MEA) which was 6.7GW in 2019, a year that saw the completion of several large-scale projects. While no countries in the Middle East and Africa (MEA) region hit the GW level in 2021, two markets successfully surpassed this threshold in 2022. Israel has become the dominant solar market in the Middle East, surpassing the gigawatt (GW) threshold for the first time. It achieved this milestone by installing slightly over one (1) GW of new solar power, up from 935 MW in 2021. South Africa maintained its dominant position on the African continent by installing 1.3 GW of solar capacity, successfully reaching the predicted GW scale (Solar Power Europe, 2023).

By 2023, South Africa had a remarkable 79 per cent share of the total solar panel capacity deployed in Africa. This represented a substantial rise compared to the previous record year, 2022, when the installed capacity was 3.1 megawatts peak (MWp). In 2023, the capacity of solar power in Africa had increased to 3.7 MWp, demonstrating the significant growth of this renewable energy source in the region. South Africa contributed an additional 3 MWp to the overall solar PV capacity, highlighting its crucial role in promoting the adoption of solar energy in Africa. Africa's progress in shifting towards renewable energy sources, particularly solar power, is evident in its total growth in this sector (Soly, 2023). Its renewable energy production has increased, at a slower pace, from 127,704 GWh in 2013 to 194,361 GWh in 2021, marking a 52 per cent increase (IRENA, 2023).

Solar energy therefore has become a crucial solution to the urgent energy challenges Africa is currently facing. Africa possesses significant potential for solar energy generation due to its plentiful year-round sunlight. Photovoltaic (PV) systems, which directly convert sunshine into power, are highly suitable for this situation. These systems provide a sustainable, renewable, and environmentally friendly energy source that can assist in alleviating energy poverty, which affects a substantial section of the population. Furthermore, photovoltaic (PV) systems can have a crucial impact on diminishing reliance on fossil fuels, decreasing emissions associated with energy production, and promoting energy security and resilience (Waheed et al., 2019; Abbassi et al., 2018).

Despite Africa's rich solar resources, 2 per cent of its current energy production is derived from renewable sources. Photovoltaics (PV) provides a sustainable and decentralized means of accessing electricity to fulfill development requirements (Santos et al., 2023).

2.3 Local Context of the Renewable Energy Sector

Kenya's renewable energy production has shown a consistent upward trend, rising from 6,349 GWh in 2013 to 9,663 GWh in 2021, indicating a 52 per cent growth (IRENA, 2023). Like other developing countries, Kenya is currently undergoing swift economic expansion and urbanization, resulting in a significant increase in the need for energy. Nevertheless, this expansion presents a noteworthy obstacle as it heavily depends on non-renewable energy sources, thereby exacerbating environmental deterioration and raising concerns about climate change (Khimulu, 2017). Therefore, Kenya faces a critical decision regarding how to meet its growing energy needs sustainably and securely. This necessitates a multifaceted approach, including diversifying the energy mix, exploring renewable energy sources, and promoting energy efficiency across all sectors.

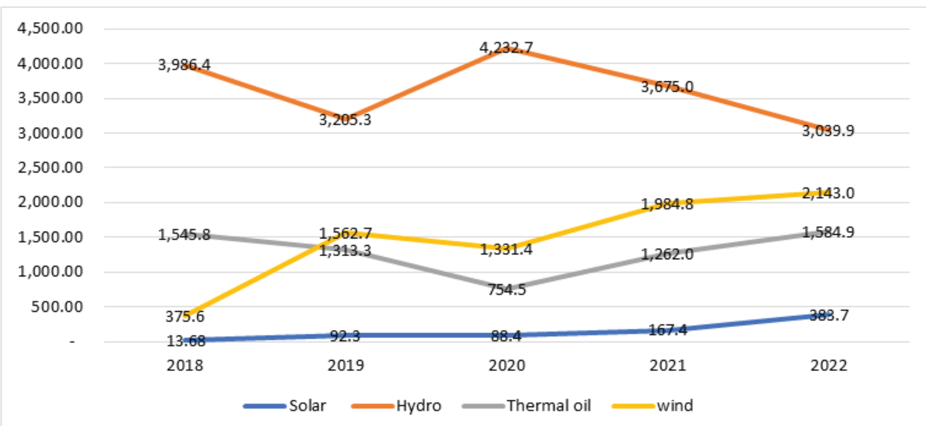
The Country has taken several steps to reduce carbon emissions and promote sustainability, according to the 2023 Kenya Economic Report by KIPPRA. The country has promoted electric mobility to reduce carbon emissions and improve public health and the environment. Kenya hopes to save money and time on air pollution-related illnesses by switching to electric vehicles (Briceno-Garmendia et al., 2022). The United Nations Framework Convention on Climate Change (UNFCCC) received Kenya's updated nationally determined contribution (NDC) in December 2020, demonstrating its commitment to fighting climate change. Kenya now aims to cut greenhouse gas emissions by 32 per cent by 2030 under this revised NDC. This ambitious goal shows Kenya's commitment to reducing carbon emissions significantly within a decade (International Energy Agency [IEA], 2022).

Further, the country has established ambitious objectives to shift towards a sustainable economy, with the aim of achieving 100 per cent renewable energy by 2030 and promoting green industries by 2040 (Fields et al., 2023). Kenya's unwavering commitment to a renewable energy future is evident through a multitude of initiatives and efforts. Spearheading the Accelerated Partnership for Renewables in Africa (APRA) alongside global partners, Kenya aims to unlock continent-wide green development. The ambitious Kenya Energy Transition and Investment Plan (ETIP) lays out a pathway to net-zero emissions by 2050, emphasizing massive renewable energy expansion, electrification across key sectors, and improved energy efficiency. Recognizing the current reliance on fossil fuels and projected emissions reaching 130 Mt CO2e, it outlines a multi-pronged strategy. By emphasizing energy efficiency improvements and exploring carbon capture, the plan aims to avoid 2.7Gt of CO2 emissions, create 500,000 jobs, and attract substantial investments (Kenya Ministry of Energy, 2023).

Kenya's active participation at COP28 further underscores this dedication; with leaders highlighting APRA's potential and advocating for increased financial support (IRENA, 2023). Beyond these overarching commitments, several concrete actions paint a clear picture of Kenya's progress. Established Feed-in Tariffs incentivize investments in solar and wind power, while the Green Mini-Grids Project brings clean energy solutions to rural areas (World Bank, 2021, 2023). The groundbreaking issuance of Africa's first green bond in 2019 demonstrates the government's proactive approach to mobilizing green finance (Climate Bonds Initiative, 2023). These initiatives, along with continuous exploration of new strategies, solidify Kenya's position as a leading force in Africa's renewable energy transition, paving the way for a sustainable and prosperous future.

Kenya's energy generation capacity has exhibited a consistent upward trend over the past five years, from 2018 to 2022 as illustrated in Figure 2.3. The total capacity has steadily increased from approximately 3,200 megawatts (MW) in 2018 to nearly 4,500 MW in 2022, reflecting a notable 40 per cent growth during this period. Solar energy has grown from 13.68 megawatts in 2018 to 383.7 in 2022 reflecting a 96.4 per cent growth (KNBS, 2023).

Figure 2.3: Solar energy generation in Kenya (Megawatts) (2018-2022)



Data source: KNBS, 2023

Hydropower has traditionally been the predominant source of energy generation in the country, consistently accounting for over half of the total generation capacity. However, its share has experienced a slight decline, decreasing from around 3986.4 MW in 2018 to 3039.9 MW in 2022. Conversely, solar energy has emerged as a significant player, witnessing remarkable growth over the years. Starting with merely 13.68 MW energy generation capacity in 2018, solar energy's contribution surged to almost 383.7MW by 2022, representing a nearly fourfold increase. This substantial growth underscores the increasing importance and potential of solar energy in Kenya's energy mix. While hydropower and solar energy have experienced notable shifts, thermal oil generation has remained relatively stable, fluctuating between 2.0 per cent and 4.0 per cent of the total energy mix. Similarly, wind energy, although still a minor contributor, has demonstrated some growth during the period under review (KNBS, 2023).

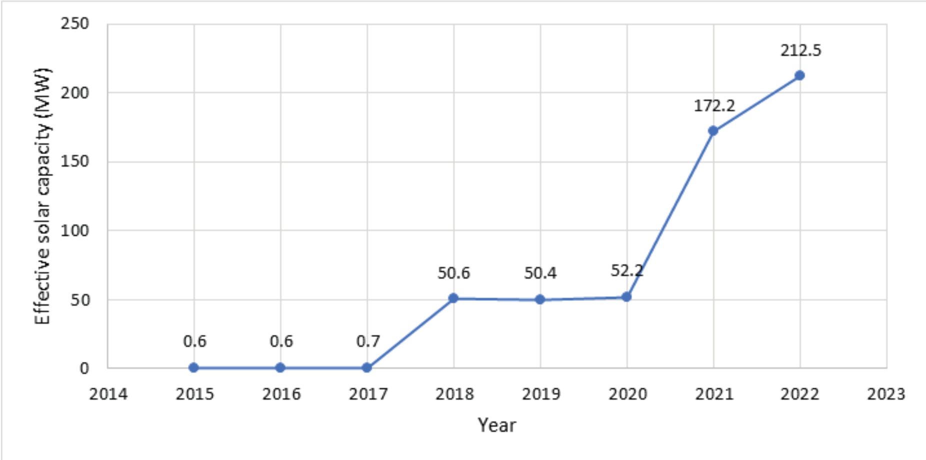
Given these observations, there is a compelling need to explore the opportunities presented by solar energy in Kenya's energy landscape. The substantial growth of solar energy underscores its potential to diversify the energy mix, reduce reliance on traditional sources, and contribute to energy security and sustainability. Moreover, the declining costs and technological advancements in solar energy make it an increasingly attractive option for meeting Kenya's growing energy demands while mitigating environmental impacts (Takase et al., 2021). Therefore, further exploration and investment in solar energy infrastructure and technologies are warranted to capitalize on its potential and accelerate Kenya's transition towards a more sustainable and resilient energy future.

The utilization of solar photovoltaic (PV) technology is gaining recognition as a method to improve energy sustainability, reduce greenhouse gas emissions, and create employment prospects in both developed and developing countries (Hondo and Moriizumi, 2017). Kenya's industrial growth has recently been driven by renewable energy making up to 85 per cent of energy consumption. The major sources are hydropower, wind, thermal oil, and solar energy. Hydroelectric generation has been hampered by numerous challenges like siltation, drought, and flooding, often resulting in low power supply. Wind and thermal have also proved unreliable (Kanda et al., 2023).

2.4 Current Solar Energy Subsector Landscape in Kenya

Figure 2.4 summarizes the growth in effective solar capacity and percentage growth from 2015 to 2022. The effective solar capacity has grown from 0.6 MW in 2018 to 212.5 MW by the end of the end of 2022. The growth is a clear indicator of solar energy's potential to actively contribute to the power grid.

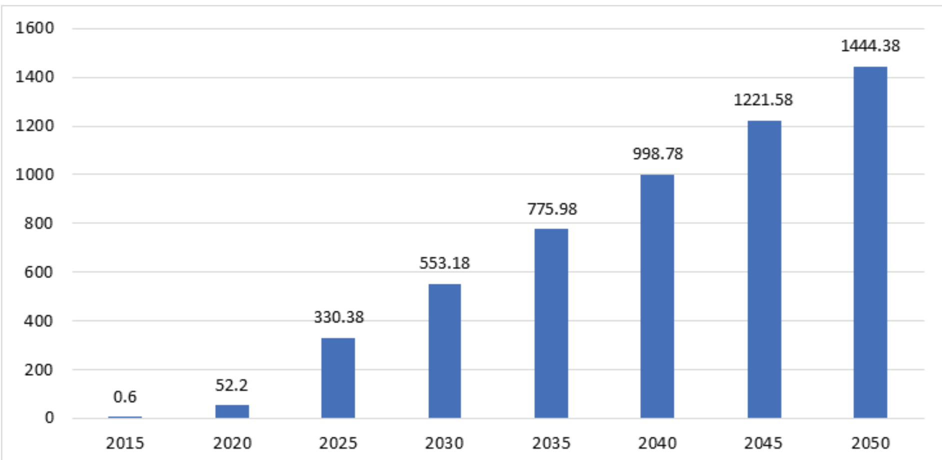
Figure 2.4: Effective solar capacity in megawatts (2014-2023)



Data source: KNBS,2023

The growth from the year 2015 to year 2022 (0.6MW to 212.5 MW) was used to predict solar energy growth by the year 2050. Figure 6 summarizes the potential growth. This shows solar energy growth from 0.6 Megawatts in year 2015 to 553.18 Megawatts in the year 2030 and reaching 1.44 gigawatts by year 2050.

Figure 2.5: Potential growth of solar effective capacity (2015-2050)



Source: Data Analysis Results, 2024

Energy and Petroleum Regulatory Authority (EPRA) is the authority in charge of licensing photovoltaic technicians. The technicians are classified into various categories, for example,T1, T2 and T3. The T1 category comprises technicians carrying out the light photovoltaic solar installation. The direct current systems installed are up to a maximum of 100 watts peak (wp). T2 technicians carry out medium solar photovoltaic system installation. This includes inverters.

T3 technicians are advanced technicians and can carry out advanced projects especially grid and hybrid systems. As shown by EPRA registration and licensing 75 per cent of all registered technicians are from the T3 category. Table 1.1 summarizes the licensed technicians' categories. The licensing process provides a clear indication of skill availability for solar uptake. Through licensing, it provides evidence of the gaps in skills and can be useful for policy recommendation and formulation.

Table 2.1: Registered solar energy technicians

License class	Number	Percentage
Basic (T1)	3	0.4
Intermediate (T2)	189	24.6
Advanced (T3)	576	75

Source: EPRA,2024

Kenya is showing a clear growth in trained solar photovoltaic technicians. This is a clear indicator of growing skill capacity in relation to solar uptake. Table 2.2 below summarizes growth in trade passes numbers from 59 in the year 2020 to 178 in the year 2022.

Table 2.2: Solar Photovoltaic Trade Test Passes, 2019-2022

Technician Grade	2019	2020	2021	2022
Grade 1	-	-	1	1
Grade 2	-	6	18	21
Grade 3	-	53	129	156
Total	-	59	148	178

Source: Statistical abstract,2023

The Kenya Off Grid Solar project (KOSAP) is the leading investment project in Kenya spearheaded by the Kenyan government in partnership with other non-state partners. It serves 14 counties with low connectivity to the power grid. This model shows how public-private partnerships can drive industrial growth. Table 2.3 shows the list of counties and private partners.

Table 2.3: KOSAP coverage in 14 underserved counties and some private partners

	County	Private partners
1	Marsabit	Bboxx Capital
2	Mandera	Brenhert Investments
3	Narok	Dlight
4	Turkana	Elcom Networks
5	West Pokot	Equity Bank

6	Samburu	Krystal Solutions
7	Isiolo	M-Kopa Solar
8	Taita Taveta	Engie Mobisol
9	Garissa	Solar Panda
10	Tana River	Solibrium
11	Lamu	Greenlight Planet
12	Kilifi	Barefoot Power
13	Kwale	Give
14	Wajir	Give Watts
		Solar Integrated Appliances

Source: Kenya off-grid solar project (2023)

The government of Kenya has shown commitment to investment in alternative renewable energy. This is evident by increased budgetary allocation from 400 million in 2018/2019 to 1.7 billion in 2022/2023 as shown in Table 2.4. The increased budgetary allocation is a clear indicator of the uptake of renewable energy sources. However, it is noted that the amount allocated to specific sources of renewable energy.

Table 2.4: Kenyan Government budget commitment on alternative renewable energy

	Budgetary allocation estimates in Ksh million				
Financial year	2018/2019	2019/2020	2020/2021	2021/2022	2022/2023
Alternative renewable energy sources	400	50000	19000	12800	1734060

Data source: OCOB, 2023

2.5 Policy Framework Analysis

Kenya has established a robust policy framework to support the growth of solar energy. Table five outlines a breakdown of some key policy initiatives and gaps

Table 2.5: Policy and regulatory framework analysis

National-level planning	**Gaps**
Draft National Integrated Energy Plan (2023): This overarching strategy aims for a sustainable energy future. It prioritizes increasing access to clean and affordable energy, promoting energy efficiency, and ensuring long-term energy security. It sets clear targets and timelines for achieving these goals.	The National Integrated Energy Plan (2023) is still a draft, which can create uncertainty for investors and developers in the solar sector.
National Energy Policy 2019: This policy expands on previous ones, addressing current energy sector challenges. It echoes the Integrated Energy Plan's focus on clean, affordable energy, efficiency, and security. Additionally, it emphasizes renewable energy adoption to lessen reliance on fossil fuels.	The current policies and initiatives seem to have a stronger focus on large-scale solar projects (e.g., Feed-in Tariff) compared to smaller residential installations.
Regulations and incentives	
Solar Photovoltaics Regulation (2012, 2020): These regulations establish a framework for licensing and registering solar PV systems. They outline technical standards, safety requirements, and licensing procedures for installation and operation. This is aimed at ensuring the safe and efficient deployment of solar PV systems nationwide.	• Absence of robust financial incentive mechanisms, such as feed-in tariffs or tax breaks, which are essential to encourage investment in solar energy production. • The regulations lack strict quality control measures for solar products and fail to define standardized installation practices, potentially leading to inefficiencies or safety hazards. • Does not address challenges with net metering and inadequate grid infrastructure for large-scale solar integration are areas that need improvement. • Limited focus on off-grid applications and inadequate guidelines for the disposal or recycling (E-waste management) of used solar panels, creating environmental concerns.

Feed-in Tariff Policy (2012): This policy encourages the development of small-scale renewable energy projects, including solar. It offers favorable pricing mechanisms by guaranteeing a fixed tariff for electricity generated from renewable sources. This gives investors a predictable income stream, making solar projects more attractive.	Capacity building is required to strengthen technical expertise in policy design and implementation.
Project-based initiatives	
Kenya Off-Grid Solar Access Project (KOSAP): This government project tackles the challenge of energy access in rural areas. KOSAP promotes off-grid solar solutions by funding the installation of solar home systems and mini-grids. It also provides technical assistance and capacity building for local communities, fostering long-term sustainability.	Investment in commercial solar projects is still low. There is still a huge potential for expansion.
Long-term vision	
Green Economy Strategy and Implementation Plan (2016-2030): This strategy outlines Kenya's vision for transitioning to a green economy. It prioritizes low-carbon development, resource efficiency, and social inclusivity. The plan sets targets and strategies for promoting renewable energy, like solar, alongside sustainable agriculture, eco-friendly transport, and responsible waste management. Monitoring and evaluation mechanisms are also included to track progress towards a greener future.	It brings out the general target of reducing carbon emissions. The energy mix implementation framework is not clear.

Source: Authors compilation, 2024

Table 2.6:Comparison of Legal, policy, and regulatory frameworks

Aspect	Kenya	China	South Africa
Solar Energy Investment	Solar energy investment is a product of public-private partnership. Lake Turkana Wind Power Project is a successful PPP delivering 310 MW.	Solar energy investment championed by the central government. Five-fold increase in solar power capacity from 2013 to 2019, driven by government targets.	Over 112 renewable energy projects procured through REIPPPP since 2010
Green energy financing	National and county government with international partners. Geothermal Development Company utilizes funding from World Bank and KfW.	Fully financed by central government. Green Bond issuance for renewable energy projects exceeded $1 trillion by the end of 2022.	The REIPPPP program plays a crucial role in green energy financing by providing power purchase agreements to renewable energy producers. Further, blending finance where public funds can be used to de-risk projects, making them more appealing to private investors.
Legal Framework	Evolving, lacks specific industrial focus	Renewable Energy Law (2009) sets ambitious targets for renewable energy capacity.	National Energy Act (2008) establishes REIPPPP for renewable energy procurement.
Policy Incentives	Includes REFiT Policy Framework which offers guaranteed electricity purchase rates for renewable energy producers.	Includes comprehensive renewable energy targets and incentives. Feed-in tariffs, tax breaks, and subsidies for renewable energy projects.	REIPPPP provides competitive bidding process for renewable energy projects with government power purchase agreements.

Public Private Partnership	Autonomy for solar energy developers where the Central government leads all PPP arrangements. However, the extent of PPPs is unclear.	State-owned enterprises dominate large-scale solar projects, but some PPPs exist.	Increased exploration in municipal PPPs for rooftop solar projects. The REIPPPP program itself is evolving to potentially incorporate more PPP structures.
Energy Storage	Research on solar storage is still low. The battery shelf life exported is between 3 to 5 years. Kenya Power and Lighting Company (KPLC) pilots' small-scale battery storage projects.	Advanced research on solar storage. Experiments on "artificial sun" using nuclear fission at an advanced stage. This is likely to ensure more than 18 to 23 sun hours per day. The lithium-ion battery experiments show a shelf life of 30 to 50 years.	Increased Lithium-ion Battery Adoption.
Incorporation of IoT in Value Chain	Limited utilization.	Integration of IoT sensors and smart meters for real-time data collection and grid management in solar farms.	Eskom (national utility) explores using IoT for smart metering and demand-side management in the grid.

Source: Authors compilation, 2024

3. Literature Review

This section presents theories and empirical studies on solar energy status, use, challenges, opportunities, and conceptualization of the study.

3.1 Theoretical Literature

3.1.1 Diffusion of Innovations Theory (DOI)

Developed by Everett Rogers (2003), the theory describes the process by which individuals and groups adopt new ideas, practices, or technologies over time. The Diffusion of Innovations Theory (DOI) is applicable at both the human and organizational levels. It demonstrates how, why, and at what pace new ideas are widespread among cultures. According to Rogers (2003), the DOI theory considers innovation being transmitted through channels with a significant amount of time taking place. In general, it takes individuals a considerable amount of time to adopt new technology (Rogers, 2003). Key factors influencing adoption include relative advantage, compatibility, observability, trialability, and complexity. It is considered that people have a particular degree of desire to accept innovation and that this willingness varies according to the individual. This theory provides a valuable framework for understanding the adoption of solar energy solutions in Kenya's clean energy transition and potential implications for industrial development. Studies such as Ali et al., (2021), utilizing the Diffusion of Innovations (DOI) theory, the research findings reveal several factors that significantly and positively influence the adoption of cloud-based services in local governments. The identified factors include compatibility, complexity, cost, security concerns, expected benefits, and organization size.

The pay-as-you-go solar model for solar home systems is in perfect accordance with the principles of the Diffusion of Innovations Theory, showcasing multiple variables that contribute to its successful adoption. First and foremost, solar offers a comparative edge over conventional energy sources by providing cost-effective, dependable, and environmentally friendly energy in contrast to kerosene lamps and generators (Park, 2021). Solar systems are compatible with current lifestyles and infrastructure, ensuring seamless integration. Additionally, the observability factor enables neighbors and communities to directly observe the real benefits of shifting to solar power. The trialability component, provided by the pay-as-you-go approach, allows for incremental adoption, hence mitigating perceived risks. Moreover, the technology's user-friendly design reduces complexity and necessitates less maintenance.

The future presents two significant contrasting patterns in relation to the future of renewable energy sources (Kopetz et al., 2015). The utilization of small-scale renewable energy technologies, such as building-integrated solar power, is projected to grow. Simultaneously, there is an anticipated development of large-scale centralized solar and wind power facilities driven by economic considerations.

Solar companies have the potential to enhance local company growth and job creation by promoting rural economies through the provision of enhanced electricity access, resulting in more discretionary income. The implementation of sustainable energy sources also fosters prospects for emerging sectors and capital investments in rural regions (Onyeji-Nwogu, 2017).

3.1.2 Technological Innovation Systems (TIS) Theory

The TIS framework is a prominent methodology in the field of sustainability transition studies (Markard, 2020). Innovation systems (IS) theory is a heuristic framework that posits that innovation is not just driven by entrepreneurs or organizations in isolation. Instead, innovation takes place within the framework of a complete system. Specifically, a fundamental principle is that technology, actors, and institutions mutually influence and must be analyzed together. A Technological Innovation System (TIS) is seen as a dynamic network of agents that interact inside a certain economic or industrial sector, operating under a particular institutional architecture. These agents are engaged in the creation, dissemination, and application of technology. This definition was proposed by Carlsson and Stankiewicz in 1991. The TIS approach often commences by focusing on a certain technology and aims to comprehend its triumph or downfall by evaluating the performance of the TIS. The innovation systems method has been utilized at various levels, including national (Freeman 1995), regional (Cooke and Uranga 1997), sectoral (Malerba 2002), and technological (Bergek et al., 2008).

The current shift occurring in the power sectors, wherein renewable energy generation is replacing fossil and nuclear generation technologies, serves as an illustration of a sustainability transition. In the field of energy, the reduction in the use of some technologies has been facilitated by regulations that expedite the discontinuation of coal and nuclear power plants, as well as the use of incandescent light bulbs (Rosenbloom, 2018; Stegmaier et al., 2014). When analyzing solar energy in Kenya's shift towards renewable energy, the application of the TIS theory demonstrates strategic conformity with this sector. Therefore, technological innovation system theory was used to anchor this study.

3.2 Empirical Literature

3.2.1 Solar landscape and potential

Solar energy presents cross-cutting dilemmas in the energy sector in Kenya (Boamah, 2019). The solar PV transition potentially obstructs the state's socioeconomic transformation visions, undermines the monopolistic agenda of parastatals, restricts practices in households and expectations placed on energy infrastructure, and fortuitously creates low-carbon energy solutions in specific spaces. The electricity model of supply to commercial firms and households within 600 metres radius from an electric transformer will be interrupted by solar technology.

Presently, Kenya relies predominantly on oil, geothermal energy, and hydro resources for the generation of power. Nevertheless, all three sources encounter some problems. Electricity generation using oil as a fuel source has negative environmental impacts is costly and puts a strain on the national trade balance. Hydropower rivers and their tributaries are in dry and semi-arid regions characterized by unpredictable rainfall, which poses challenges to the reliability of water supply. Geothermal exploitation also faces various concerns, including cost and risk factors. Solar energy is a promising avenue for Kenya's renewable energy transition due to its exceptional solar irradiation levels and the government's commitment to clean energy. The country's strategic location near the equator ensures a consistent and reliable source of solar power (Takasa et al., 2021). Kenya's Vision 2030 and the Big Four Agenda prioritized clean energy access, reflecting the government's recognition of solar energy's potential (East Africa Power Pool [EAPP], 2023). Policies such as feed-in tariffs and net metering have incentivized solar power adoption, while collaborations with international partners on initiatives like Scaling Up Renewable Energy in Low-Income Countries (SREP) have accelerated progress (George et al., 2019)

Technological advancements have significantly reduced the cost of solar panels and installations in some advanced economies, making solar energy increasingly cost-competitive compared to other renewable energy sources and traditional fossil fuels (Shahsavari, 2018). Efforts to modernize the grid and develop energy storage solutions are crucial for integrating solar power effectively into the national grid. Renewable energy requires the support of energy storage systems (ESS) to provide ancillary services and save excess energy for use later (Sani et al., 2020)

Furthermore, mini-grid and off-grid solar solutions are playing a pivotal role in extending electricity access to remote areas not connected to the national grid, particularly benefiting rural communities and essential services like healthcare facilities (IRENA, 2019). Apart from the economic benefits, solar energy significantly reduces reliance on expensive fuel imports, contributing to energy security economic growth, and stability (Le and Nguyen, 2019).

Despite these promising prospects, challenges persist. Initial investment costs for large-scale solar projects remain a hurdle, necessitating innovative financing mechanisms to bridge the gap. Energy storage solutions are still under development, requiring further advancements to ensure grid stability with increased solar penetration. Additionally, upgrading and expanding the national grid infrastructure is crucial for efficiently integrating and transmitting solar power across vast distances (IRENA and AfDB, 2022).

Kenya's prospects for solar energy in the future are promising. Solar power could greatly change Kenya's energy situation with ongoing government backing, scientific progress, and creative funding methods. Adopting solar energy can lead to a more environmentally friendly, reliable, and enduring energy future for the country. This study will attempt to analyze solar utilization across the country.

3.2.2 Opportunities and challenges in solar adoption

Solar energy development in Kenya has enormous potential market opportunities for investment, poverty eradication, and spurring economic growth. Tax holidays as an incentive can spur growth in this industry (Adwek et al., 2019). Results-based financing has potential to drive the development of solar energy by enhancing access (GOGLA,2023). Kenya is strategically positioned to harness solar energy. It receives on average 5-7 peak sun hours (Adwek et al.,2019). Solar energy offers the lowest cost of electricity (IRA,2020). This provides solar energy potential to serve Kenyans affordably.

Several factors inhibit the growth of the value chain in solar energy-rich locations (Mutuku and Mbatia ,2020). These factors include a lack of manufacturers, restricted transmission and distribution networks, governmental and regulatory restrictions, insufficient financial investment, inadequate skills, and excessive capital prices. Mutuku and Mbatia (2020) suggest implementing vocational training programme to enhance capacity building. Skill development is important in the wake of the fourth industrial revolution (Mukhuty et al.,2022). Furthermore, harnessing renewable energy can be challenging. Solar energy is constrained by limited hours of sunlight, whereas wind and geothermal energies are location-specific, and hydroelectric power generation has seasonal constraints (Pandey et al.,2023). Their study focused on all renewable energy sources; this study focuses only on solar energy. Despite solar energy storage being a limiting factor, it can be stored in batteries. This study explores an opportunity for research on long-lasting batteries to reduce the effect of e-waste and enhance solar energy storage.

Virtual power plants can combine various intermittent energy sources to provide a steady power supply (Pandey et al.,2023). A virtual power plant is a cloud-based power system that unifies the capacities of distributed energy resources to improve power generation and the trading or selling of power on the electricity market. Virtual power plants combine various power sources to provide a consistent power supply. This concept is the basis for this study to explore ways of incorporating solar energy with the hydroelectric power grid in Kenya to ensure uninterrupted power supply for the Kenyan manufacturing sector.

The fourth industrial concept is on small smart microgrids as opposed to heavy power production and distribution in a centralized manner. There is a clear contrast between traditional energy and modern energy production and distribution (Pandey et al.,2023). Kenya's energy future is highly dependent on the heavy consumption of wood fuel (Takase, Kipkoech, and Essandoh, 2021). Energy accessibility is a major limiting factor in the energy sector. This study explores the option of harnessing solar energy and tapping into the Internet of Things to enhance access to energy.

3.2.3 IoT and the solar renergy transition

The Internet of Things (IoT) is an emerging computing technology. It uses a cloud portal to connect devices remotely located and controlled (Al-Ali,2019). With IoT the consumer pays for what he consumes, and the excess power is transmitted to the power grid as it provides two-way communication. IoT analyses power demand and wastage. The sensors and IoT help in achieving automation of solar-driven firms thus enhancing efficiency and reliability. IoT helps identify faults from data on solar PV, inform about maintenance requirements and if it meets demand (Ponnalagarsamy et al.,2022).

In solar-based irrigation farms, IoT provides real time on soil moisture, humidity, and temperatures and provides command signals to operate irrigation pumps (Al-Ali,2019). To meet energy demands in sub-Saharan Africa, upgrading of existing grids to smart grid is required. Smart Grid allows integration of renewable energy into the power grid thus reducing dependence on fossil fuels. Smart grids have numerous benefits including consumer financial plans on electricity usage, enhancing energy mix, offering opportunities for home automation, reducing carbon print, and creating jobs (Ahmed and Al Turjman, 2021).

This study focused on the utilization of IoT in the solar value chain to enhance efficiency and reliability.

3.3 Knowledge Gaps

The use of solar energy has proven to be of immense potential if harnessed and utilized. Studies have shown solar energy's potential in job creation. This study focuses on how solar energy can drive industrial growth. Studies on solar use have applied systematic review. Futures foresight has been applied in developed countries in relation to renewable energy. This study applied the futures methodology in the Kenyan context.

4. Methodology

This section presents the sampling design, the analytical framework, and data sources.

4.1 Sampling Design

Purposive sampling design was adopted in this study. Actors in the solar energy value chain were identified as key respondents and classified into seven categories, that is, residential solar owners, commercial and industrial solar users, solar energy producers, solar energy distributors, solar energy regulators, solar energy technology manufacturers, solar energy financiers, and energy analysts. From each category, five respondents were selected. This gives a target sample of 35 respondents.

Two sets of questionnaires were prepared and administered to selected respondents (Appendix I and Appendix II). The first round (Delphi Round 1) of the questionnaire was to reduce the drivers of the future of solar energy from 34 drivers to 12 drivers. The second (Delphi Round 2) set of the questionnaire was to determine the influence of each driver on other drivers.

4.2 Analytical Framework

4.2.1 Assessing the current solar energy landscape in Kenya's industrial sector

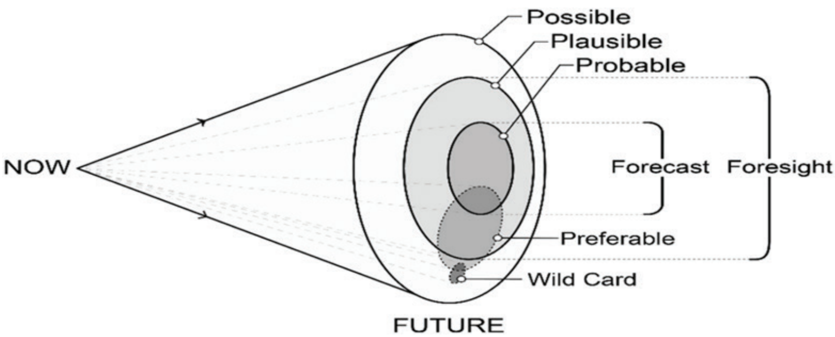
This objective was analyzed by looking at the status of the solar energy value chain. A wide range of data sources were utilized. Quantitative analysis was used to understand this objective. Descriptive analysis was crucial in establishing the current landscape. The analysis followed a methodology applied by Oudes, Brink, and Stremke (2022). A review of the existing legal and policy framework was done with gaps identified and lessons from leading solar energy-producing countries; their challenges and opportunities leveraged on. This provided information on innovations in the solar energy subsector, learning lessons and insights for upscaling, and providing policy recommendations.

4.2.1 Exploring the future drivers of change associated with accelerating the solar energy transition in Kenya

Popper (2008a, b) classifies foresight methods into three categories: qualitative, quantitative, and semi-quantitative. Semiquantitative methods utilize mathematical concepts to measure the subjective nature, logical assessments, and perspectives of experts, such as cross-impact analysis and Delphi (Popper 2008a, b; Popper and Medina 2008). This study utilized semiquantitative techniques.

This study applies cross-impact/structural analysis as a semi-quantitative method. An extensive literature review was conducted to identify the drivers, and possible and plausible scenarios. The characteristics of solar energy are discussed, and challenges and barriers are reviewed in relation to future growth. In the next step, the key driving factors of solar were extracted using the Delphi method through questionnaires and interviews with the key Stakeholders. The future of solar energy was categorized as probable future, plausible future, and possible future as shown in Figure 4.1. The last stage involved utilizing the MICMAC tool to identify the driving forces of solar energy transformation from cross-impact analysis.

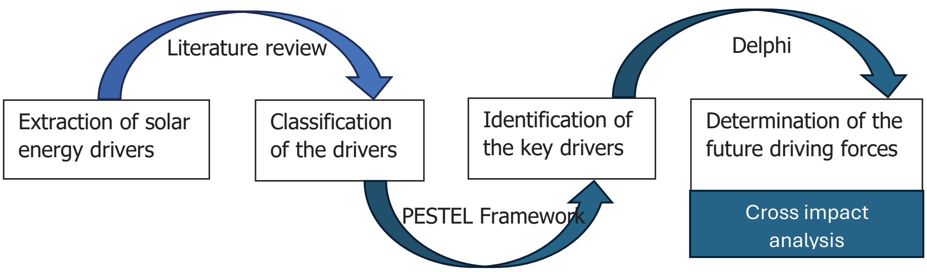
Figure 4.1: Renewable energy future cone



Source: Gilmore et al. (2022)

In arriving at the key drivers that informed solar energy future operations and strategies the four-step method to reach the key driving forces can be illustrated using Figure 4.2. Each step was described.

Figure 4.2: Illustration of step-by-step drivers' extraction



Source: Authors' Conceptualization, 2024

Step1: Extraction of solar energy drivers

In this study, a systematic literature review was conducted to explore the future drivers of solar energy adoption, classified under the PESTEL framework (Political, Economic, Social, Technological, Environmental, and Legal factors).

The methodology outlined the process for identifying, selecting, and analyzing literature published between 2014 and 2024, ensuring a comprehensive and relevant review.

The search strategy involved using multiple academic databases, including Scopus, Web of Science, Google Scholar, IEEE Xplore, and ScienceDirect, to collect a broad range of articles. A combination of keywords and Boolean operators was used to search for relevant literature, such as Solar energy future drivers, PESTEL analysis of solar energy, and others related to specific PESTEL factors.

Criteria for inclusion required articles to be published in English between 2014 and 2024, to focus on solar energy future drivers within the PESTEL framework, and to be empirical, theoretical, or case study-based. Exclusion criteria eliminated irrelevant articles, non-peer-reviewed sources, and duplicates.

The selection process involved an initial screening of titles and abstracts, followed by a full-text review to determine relevance and adherence to inclusion criteria. Discrepancies between reviewers were resolved through discussion or by involving a third reviewer.

Data extraction was performed using a standardized form to collect information on the author(s), publication year, source, PESTEL category, key findings, methodology, and implications for the future of solar energy. Data analysis employed a narrative synthesis approach, organizing findings under the PESTEL framework to identify common themes, trends, and gaps in the literature.

Results indicated that out of an initial sample of 100 papers, 70 met the inclusion criteria and were included in the analysis. These papers provided insights into the future drivers of solar energy adoption, offering valuable implications for policymakers, stakeholders, and researchers. The systematic approach outlined in this research ensures the inclusion of high-quality and relevant literature, contributing to a comprehensive understanding of the factors shaping the future of solar energy.

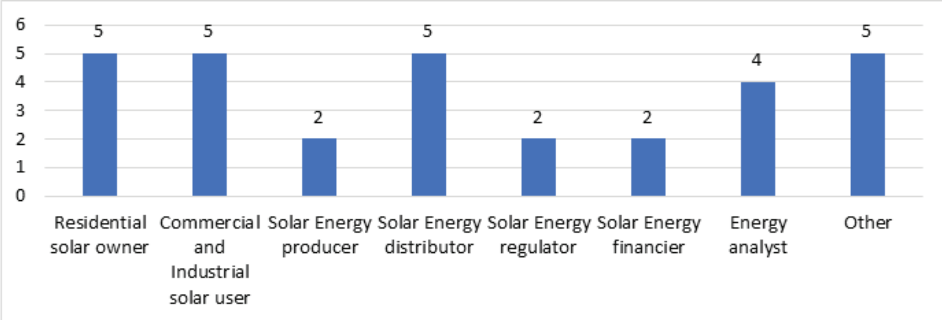
Step 2: Classification of the drivers

The drivers from the literature were classified using the PESTEL framework. This involved scanning on Political, environmental, social, technological, economic, and legal drivers. This stage provided the key factors and their indicators.

Step 3: Scenario Development

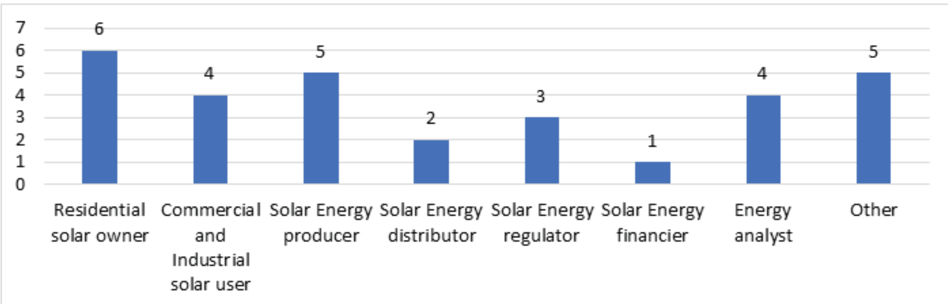
This stage involved a Delphi technique, that is, subjecting drivers from the PESTEL framework to a panel of experts. The desirable panel consists of heterogeneous experts in the domain of study (Belton et al.,2019). This study t involved experts in the energy sector that is regulatory (EPRA), co-ordination (ministry of energy), private sector (independent power producers) dealing with solar, financing (Kenya Off-Grid Solar Access Project), and consumers. The first questionnaire was administered to the 35 experts as shown in Figure 4.3 and identified twelve key future drivers in the solar energy subsector by 2050.

Figure 4.3: Delphi round one respondents



The second round of the Delphi process with the experts was then done to draw the scenario matrix map based on influence and dependence. From Figure 4.4, a total of 30 respondents participated in this process, representing various categories within the solar energy sector. The largest group of respondents were residential solar owners, comprising six (6) individuals. Following closely were solar energy producers and commercial and industrial solar users, with five (5) and four (4) respondents respectively.

Figure 4.4: Category of respondents who participated in the second round of the Delphi process



Source: Data analysis results, 2024

Each expert was to give an opinion on the extent of a driver influencing another driver. This was based on a Likert scale where one was for low influence, 2 for moderate, and three (3) for high influence. This led to a 12 by 12 matrix as shown in Table 4.1. The drivers are represented by D1 for driver one (1) to D12 for driver 12. A mean was calculated for each driver from the responses. The mean denoted by M represented the strength of influence of the specific driver. The means were added across to give active sum and passive sum representing its general influence and dependence consecutively.

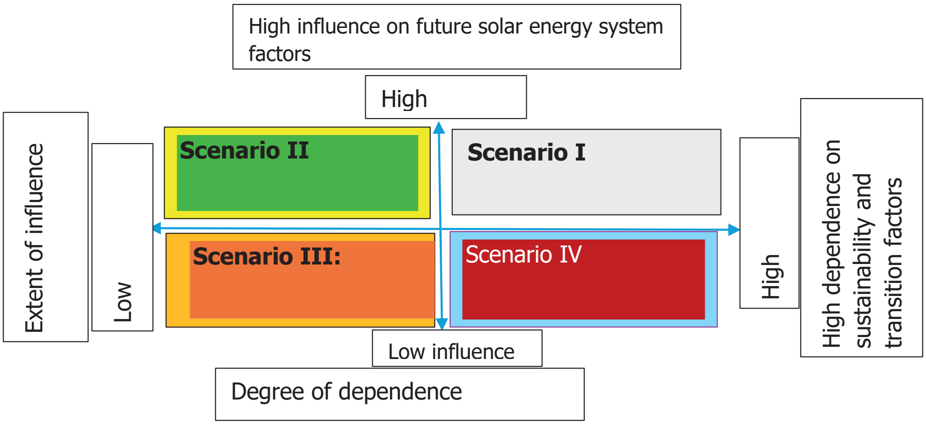
Table 4.1: Cross-impact analysis table

PESTEL elements	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	Active Sum/ Influence
D1	o	M	M	M	M	M	M	M	M	M	M	M	**D1_Total**
D2	M	o	M	M	M	M	M	M	M	M	M	M	**D2_Total**
D3	M	M	o	M	M	M	M	M	M	M	M	M	**D3_Total**
D4	M	M	M	o	M	M	M	M	M	M	M	M	**D4_Total**
D5	M	M	M	M	o	M	M	M	M	M	M	M	**D5_Total**
D6	M	M	M	M	M	o	M	M	M	M	M	M	**D6_Total**
D7	M	M	M	M	M	M	o	M	M	M	M	M	**D7_Total**
D8	M	M	M	M	M	M	M	o	M	M	M	M	**D8_Total**
D9	M	M	M	M	M	M	M	M	o	M	M	M	**D9_Total**
D10	M	M	M	M	M	M	M	M	M	**0**	M	M	**D10_Total**
D11	M	M	M	M	M	M	M	M	M	M	o	M	**D11_Total**
D12	M	M	M	M	M	M	M	M	M	M	M	o	**D12_Total**
Passive Sum/ Dependence	**D1_ Total**	**D2_ Total**	**D3_ Total**	**D4_ Total**	**D5_ Total**	**D6_ Total**	**D7_ Total**	**D8_ Total**	**D9_ Total**	**D10_ Total**	**D11_ Total**	**D2_ Total**	

Source: Authors, 2024

The cross-impact results were analyzed using MICMAC software. This resulted in a scenario matrix map as shown in Figure 4.5, showing various scenarios as per the key drivers Delphi process. The scenario matrix shows how various factors can influence the transition towards solar and those factors that require input (dependence) of other factors.

Figure 4.5: Scenario matrix map



Source: Authors' conceptualization, 2024

Step 4: Scenario description

This was the final step where each scenario from scenario matrix was described. Each scenario was then pegged with a strategy and policy recommendation to accelerate solar energy transition by 2050.

4.2.3: Investigating how IoT technologies can be applied to optimize and enhance the efficiency, reliability, and affordability of solar energy in Kenya

A systematic literature review was done to identify factors that will enhance the integration of IoT in the entire solar energy value chain. The study adopted the methodology applied by Ghobakhloo and Fathi (2019). The systematic literature review on the application of IoT in the solar energy value chain followed a structured process. The research question was defined as: How can IoT be applied to improve efficiency and transparency in the solar energy value chain? Next, inclusion and exclusion criteria were established, focusing on articles published in peer-reviewed journals between 2018 and 2024 that addressed aspects of the solar energy value chain in relation to IoT. Articles outside these criteria were excluded.

A comprehensive search using the keyword "IoT and solar energy" initially identified 71 articles. From these, 30 were selected based on the inclusion and exclusion criteria. The quality of these 30 articles was then assessed to ensure they met the necessary standards, resulting in a final selection of 23 articles. Data were extracted from these articles to identify insights on incorporating IoT into the solar energy value chain.

4.3 Data Sources

This study utilized both primary and secondary data. Primary data was collected through online questionnaires sent to experts in the energy sector. Secondary data was from various sources including Office of the Controller of Budget (OCOB), Statistical abstracts, Kenya National Bureau of Statistics (KNBS), and Energy and Petroleum Regulatory Authority (EPRA). This was supplemented by data from the International Renewable Energy Agency (IREA). An extensive literature was done to identify key drivers of future solar energy and the role of IoT in the solar energy value chain.

5. Solar Energy Futures and Sustainability

This section presents research findings including solar futures and explores the utilization of Internet of Things across the solar energy value chain in Kenya to enhance sustainability.

5.1 Solar Energy Future Scenarios

A literature review on drivers of solar energy identified 34 drivers. The drivers are as presented in Table 5.1.

Table 5.1: PESTEL Classification of Drivers

Aspect	Driver	Description	Sources
Political	Bilateral agreements	Joint government-to-government agreements and projects on solar	Soares et al. (2023); Iglińska et al. (2016); Hassan et al. (2024); Dahlke et al. (2021)
	Policy incentives	This includes tariffs, taxation, and subsidies that encourage the adoption and use of solar energy	Soares et al. (2023); Thomas et al. (2021); Sheng et al. (2024)
	Domestic politics	Political factors within a country that can affect the implementation of solar energy policies and projects	Shidore, S., and Busby, J. W. (2019); Hughes, L., and Meckling, J. (2017); Bazilian et al. (2020)
	Devolution of energy power	Transfer of power decisions to counties on energy issues	Ahlborg, H., and Hammar, L. (2014); Groves et al. (2021)
	Global pressure and partnerships	International pressure and collaborations that can drive countries to adopt solar energy and other renewable energy sources	Shidore, S., and Busby; J. W. (2019); Bass and Grøgaard (2021)

Aspect	Driver	Description	Sources
	Energy sovereignty	The ability of a country to control its own energy sources, including solar energy, without relying heavily on imports	Torres, I., and Niewöhner, J. (2023); Stefanelli et al. (2019); Wetzel et al. (2023)
	Political stability	The stability of a country's political environment, which can influence investor confidence in solar energy projects	Ahlborg, H., and Hammar, L. (2014); Soares et al. (2023); Raghutla and Kolati (2023)
	Public-private Partnerships	Collaboration between government and private sector entities to develop and implement solar energy projects	Ibegbulam et al. (2023); Stock, R., and Sovacool, B. K. (2023); Xu and Wudi (2024)
Economic	General economic stability	The overall economic stability of a country, which can affect investment in solar energy	Soares et al. (2023); Iglińska et al. (2016); Hassan et al. (2024); Li et al. (2023)
	Cost of solar energy investment	The initial cost of installing solar energy systems, which can impact the adoption rate	Soares et al. (2023); Creutzig et al. (2017); Nawaz et al. (2024)
	Attracting investment-direct/ foreign	The ability to attract both domestic and foreign investment in solar energy projects	Shidore and Busby (2019); Fan and Hao (2020); Horvey and Odei-Mensah (2024)
	Economic environment	The broader economic conditions that can affect the viability of solar energy projects	Soares et al. (2023); Woolston, A. (2022); Slam and Mamun (2017); Hassan et al. (2024); Li et al. (2023)

Aspect	Driver	Description	Sources
	Green energy financing	Financing mechanisms specifically designed for renewable energy projects like solar	Elsherif, M. (2023); Woolston, A. (2022); Sun et al. (2023)
	Viable business models	Sustainable and profitable models for deploying solar energy solutions	Soares et al. (2023); Akinyele, D. (2018); Mendoza and Ibarra (2023)
Social	Social stability	The stability of society, which can influence public acceptance and support for solar energy	Hu (2023); Rodríguez-Segura et al. (2023)
	Public acceptance and willingness to pay	Public attitudes towards and readiness to use and pay for solar energy	Bashir et al. (2024); Soares et al. (2023); Badole et al. (2024)
	Rural solar uptake	Level of rural solar uptake as an indicator of adoption and growth	Briguglio, M., and Formosa, G. (2017); Sommerfeld et al. (2017)
	Social background	Cultural, religious, and ethnic factors that can impact the adoption of solar energy	Soares et al. (2023); Cousse, J. (2021); Krumm et al. (2022)
	Demographics	Characteristics of a population, such as age, income, and education, which can influence the demand for solar energy	Cousse (2021); Sommerfeld et al. (2017); Badole et al. (2024)
Technological	Connectivity	Access to reliable and efficient communication and information technologies, which can enable the integration of solar energy into the grid	Alzahrany, A., Kabir, G., and Al Zohbi, G. (2022); Tayal, D. (2017)

Aspect	Driver	Description	Sources
	Locally available technical expertise	The availability of skilled labor and expertise for designing, installing, and maintaining solar energy systems	Soares et al. (2023); Ockwell et al. (2018); Rae et al. (2020)
	Energy storage	Technologies for storing solar energy for later use, which can improve reliability and efficiency	Cole et al. (2018); Koskinen, O., and Breyer, C. (2016); Chatzigeorgiou et al. (2024)
	Efficiency of the end-user technology	The efficiency of solar panels and related technology, which can impact the overall effectiveness of solar energy systems	Soares et al. (2023); O'Shaughnessy et al. (2018); Chatzigeorgiou et al. (2024)
	New technologies and technology transfer	Innovation in solar energy technology and the transfer of technology from developed to developing countries	Haessler, P., Giones, F., and Brem, A. (2023); Soares et al. (2023); Lema and Lema (2016)
	Automation Level	The degree to which solar energy systems can be automated and controlled remotely, improving efficiency and reducing costs	Afroz, A., Khamari, S. S., and Behera, R. K. (2023); Rout et al. (2018); Alvarez-Alvarado et al. (2024)
	Operation and maintenance	The ongoing management and upkeep of solar energy systems to ensure optimal performance	Soares et al. (2023); Kabir et al. (2018); Keisang et al (2021)
Environmental	Renewable energy sources	The availability of other renewable energy sources, which can influence the overall energy mix and competitiveness of solar energy	Kabir et al. (2018); Weitemeyer et al. (2015); Jain et al. (2022)
Aspect	**Driver**	**Description**	**Sources**

	Geographical location	The location of a country or region, which can affect the amount of sunlight received and the potential for solar energy generation	Soares et al. (2023); Kabir et al. (2018); Anam et al. (2022)
	E-waste management	The proper disposal and recycling of electronic waste from solar panels	Hansen et al. (2022); Samarakoon et al. (2022); Salim et al. (2022)
	Accountability of emissions and pollutants	Measures to monitor and reduce the environmental impact of solar energy production	Soares et al. (2023); Xu et al. (2018)
	Resilience to environmental risks	The ability of solar energy systems to withstand and recover from environmental challenges such as extreme weather events	Mango et al. (2021); Javed et al. (2020)
Legal	Clear and transparent regulatory framework	The existence of clear and consistent regulations governing solar energy projects	Soares et al. (2023); Majid (2020); Burghard et al. (2022)
	Timely update of the legislation	The regular updating and adaptation of laws and regulations to keep pace with technological and market changes	Soares et al. (2023); Ländner et al. (2019)
	Policy reforms aimed at promoting solar energy	Changes in government initiatives and regulations aimed at promoting solar energy	Cunial (2024); Soares et al. (2023)

Source: Authors' compilation

The 34 drivers of change, which were determined by a review of the literature and categorized using the PESTEL framework, were then presented to experts through the Delphi process. The objective was to identify key future drivers in the solar energy sector for each facet of the PESTEL framework.

These resulted in 12 drivers, classified into six categories: political (bilateral agreements, Public-private partnerships, policy incentives), economic (cost of solar energy investment, green energy financing), social (public acceptance and willingness to pay, rural solar uptake), technological (energy storage, locally available technical expertise), environmental (availability of other renewable sources, accountability of emissions and other pollutants) and legal (clear and transparent regulatory framework, policy reforms aimed at promoting solar energy). The 12 drivers were subjected to experts for the second round (Delphi Round 2). This resulted in a cross-impact matrix.

5.2 Cross-impact matrix

In the cross-impact analysis, factors with higher values indicate stronger influences or dependencies. From Table 5.2 each factor's influence and dependence were assessed to determine its significance in shaping the future of solar energy. Factors with high influence and low dependence, such as Public Private Partnerships (PPP) are considered critical drivers that strongly impact other factors but are themselves influenced by external factors. Factors like Availability of other Renewable Energy Sources (AoORS) and Clear and Transparent Regulatory Framework (CandTPRF) showed moderate influence and moderate dependence, indicating that while they play a significant role, they are also influenced by other factors to a certain extent. These findings suggest that to effectively promote solar energy, policymakers can focus on enhancing critical drivers like PPP, while also addressing interdependencies among various factors to create a supportive ecosystem for solar energy development.

Table 5.2: Cross impact analysis table

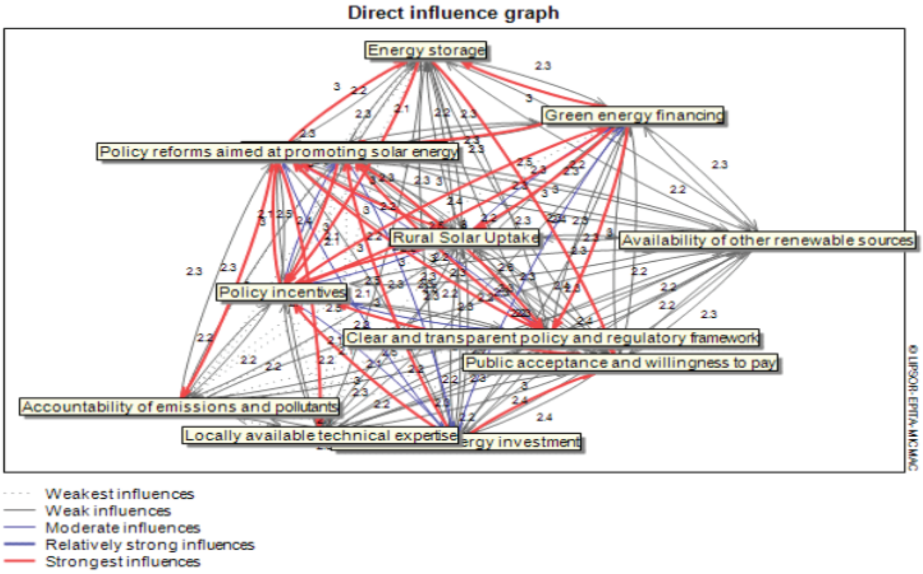
PESTEL elements	PPP	PI	CoSEI	GEF	PAand-WTP	RSU	ES	LATE	AoORS	AoEandP	CandT-PRF	PRPSE	Active Sum/ Influence
PPP	**0**	2.4	2.5	2.3	2.2	2.3	2.2	2.1	2.3	2.1	2.4	2.4	**25.2**
PI	2.5	**0**	2.5	2.4	2.3	2.4	2.3	2.2	2.3	2.2	2.3	2.4	**25.9**
CoSEI	2.4	2.4	**0**	2.6	2.4	2.3	2.4	2.3	2.4	2.2	2.3	2.5	**26.1**
GEF	2.3	2.4	2.3	**0**	2.2	2.4	2.4	2.3	2.3	2.3	2.5	2.4	**25.9**
PAand-WTP	2.3	2.4	2.4	2.3	**0**	2.3	2.2	2.2	2.2	2.2	2.3	2.3	**25.0**
RSU	2.2	2.5	2.2	2.5	2.4	**0**	2.3	2.4	2.3	2.1	2.3	2.4	**25.6**
ES	2.1	2.5	2.3	2.3	2.4	2.3	**0**	2.2	2.2	2.1	2.3	2.3	**25.0**
LATE	1.9	2.2	2.1	2.2	2.2	2.2	2.1	**0**	2.2	2.1	2.2	2.2	**23.7**
AoORS	2.3	2.3	2.3	2.2	2.3	2.3	2.2	2.3	**0**	2.2	2.2	2.3	**25.0**
AoEan-dP	2.3	2.2	2.2	2.2	2.1	2.1	2.1	2.3	2.2	**0**	2.1	2.3	**24.0**
CandT-PRF	2.4	2.5	2.4	2.4	2.4	2.2	2.4	2.3	2.2	2.3	**0**	2.4	**25.9**
PRPSE	2.3	2.4	2.3	2.2	2.3	2.3	2.5	2.5	2.3	2.5	2.5	**0**	**26.0**
Passive Sum/ Dependence	**25.1**	**26.3**	**25.4**	**25.6**	**25.2**	**25.1**	**25.1**	**25.0**	**24.9**	**24.2**	**25.3**	**25.9**	

Source: Data Analysis Results, 2024

Key:PPP-Public private partnership, PI- policy incentives, CoSEI- cost of solar energy investment, GEF-Green energy financing, PAandWTP-Public acceptance and willingness to pay, RSU-Rural solar uptake, ES-Energy Storage, LATE- Locally available technical expertise, AoORS-Availability of other renewable source, AoEandP- Accountability of emissions and other pollutants, CandTPRF-Clear and transparent policy and regulatory framework and PRPSE- Policy reforms aimed at promoting solar energy.

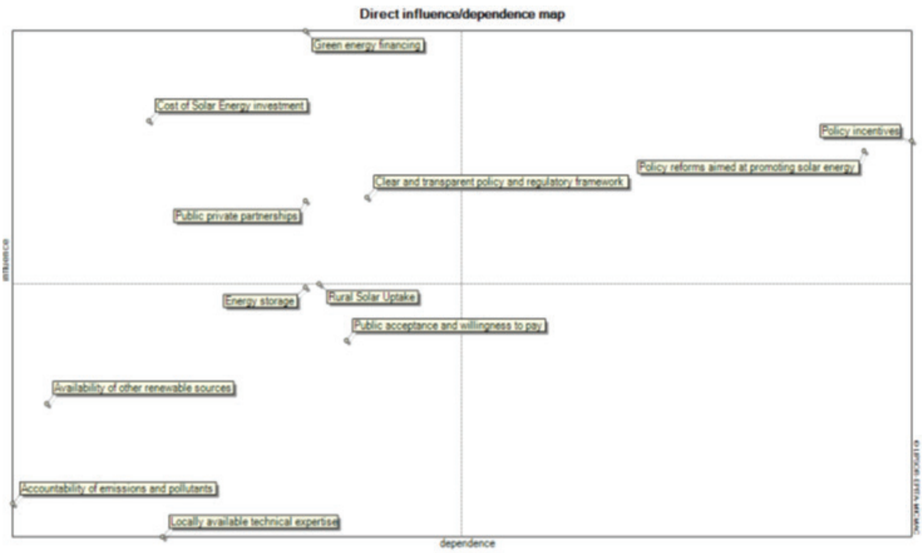
The results from the cross-impact analysis were analyzed using MICMAC to visualize the level of influence of drivers against each other. Figure 5.1 shows a direct influence map while Figure 5.2 shows a direct influence scenario map. The direction of the arrow shows the direction of the influence while the colour of the arrow indicates the strength of the driver.

Figure 5.1: Potential direct influence of factors on each other graph



Source: Data Analysis results, 2024

Figure 5.2: Direct influence map



Source: Data Analysis results, 2024

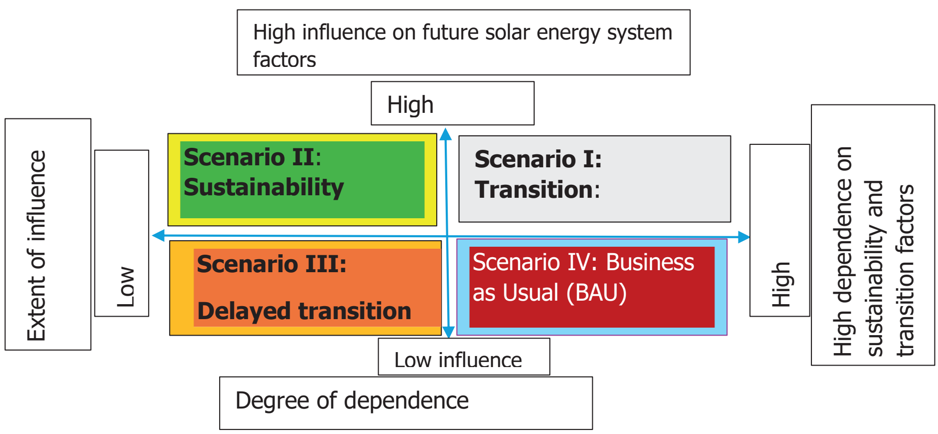
Table 5.3:Classification of variables according to their rank of influence and dependence on other variables

Influence rank	Dependence rank
Green energy financing	Policy incentives
Cost of solar energy investment	Policy reforms aimed at promoting solar energy
Policy incentives	Clear and transparent policy and regulatory framework
Policy reforms aimed at promoting solar energy clear and transparent policy and regulatory framework	Public acceptance and willingness to pay
Public-private partnerships	Rural solar uptake
Rural solar uptake	Green energy financing
Energy storage	Energy storage
Public acceptance and willingness to pay	Public-private partnerships
Availability of other renewable sources	Locally available technical expertise
Accountability of emissions and pollutants	Cost of solar energy investment
Locally available technical expertise	Accountability of emissions and pollutants
	Availability of other renewable sources

Source: Data Analysis results, 2024

Based on the results from the second round of the Delphi process, four possible future scenarios were identified as illustrated by the scenario map in Figure 5.3, that is, business as usual, delayed transition, transition or sustainability scenario.

Figure 5.3: Scenario matrix map



Source: Research data, 2024

Business as usual scenario: The adoption and implementation of solar energy progress without significant changes or interventions in policies, technologies, or societal behaviors. The factors at play continue to operate at their current levels, leading to a slow and steady advancement of solar energy but without the acceleration seen in more proactive scenarios. Existing policies, incentives, and partnerships remain in place, contributing to gradual improvements in solar technology and adoption. However, without significant new interventions or innovations, the pace of change is slow, and solar energy remains one part of a diverse energy landscape rather than a dominant force. This scenario reflects a stable but conservative approach to solar energy, with incremental progress rather than transformative change.

Delayed transition: Delayed transition is one of the possible future scenarios. This is characterized by technological, social, and environmental challenges that slow down the adoption process, such as limited energy storage, slow rural uptake, public willingness to pay, competing renewable sources, environmental accountability, and limited local technical expertise. The scenario is therefore highly dependent on skilled labour for solar generation, installation, distribution, and maintenance. Building skill capacity delays the transition from the current fossil fuel consumption. Countries utilize other available renewable sources including thermal, hydro-electric, and wind among others. It is also characterized by a slower pace of increased solar consumption. This is characterized by climate campaigns. Carbon emission reduction reaching 50 percent. This scenario provides indicators for preparedness and action plan.

Transition scenario: This is a highly influential and dependent factor driving solar energy consumption. Driven by policy incentives and reforms that create a supportive environment for the rapid adoption of solar energy. The signing of climate-related agreements. Numerous reforms towards solar uptake including infrastructural development. Innovations in harnessing and storing solar energy advance. There is also increased private investment in solar technologies with solar industries shifting fully to solar while others embrace a hybrid of solar and other energy sources. High public-private partnerships were witnessed. The Ministry of Environment focuses on renewable energy policies. Tax exemptions are provided to players to enhance uptake. High investment in renewable energy. There is increased automation of firms. Carbon emission reduction by up to 75 percent. A policy and legal framework guiding the solar sector is developed. Medium-term battery storage for solar energy.

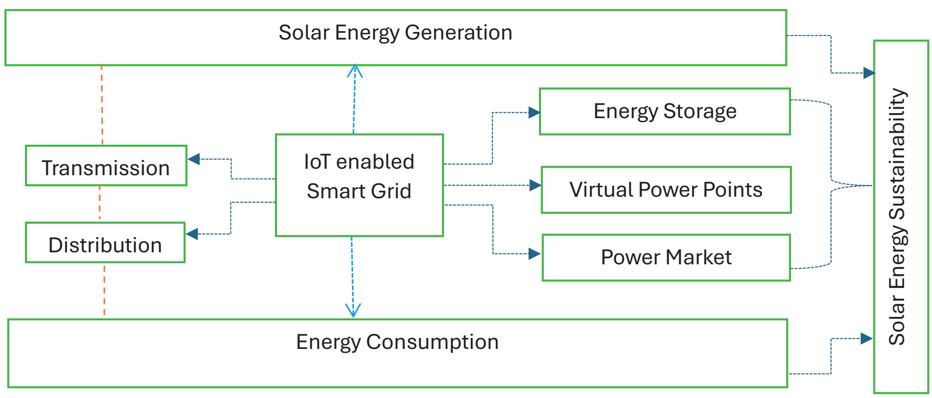
Sustainability scenario: There is political, economic, and social stability. There is increased focus on cost-effective investments, robust financing, clear regulations, and strong public-private partnerships to ensure the long-term viability and growth of solar energy. The cost of investment drops as manufacturing companies enjoy economies of scale. There is adequate skilled labour in renewable energy value chains. High solar connectivity is evident. A clear framework for e-waste management is developed and actively guides waste disposal. Carbon emission reduction by more than 95 percent. Technology advancement including innovations. Long-lasting battery with the capability to store solar energy. Internet of Things managing solar energy distribution. High reliance on renewable energy. Solar energy is among the key drivers of industrial growth.

5.3 Sustainability of Solar Energy in the Phase of Fourth Industrial Revolution

5.2.1 Solar energy value chain analysis

This study conceptualized a future driven by solar energy among other energy sources. The Internet of Things will enable monitoring of the solar energy generation, transmission, distribution, and consumption. This will provide real time data across the solar value chain. Consumption includes residential, industry, and commercial purposes. Artificial intelligence can reduce systemic losses and provide real time data on energy storage, the capacity of the virtual power points, and the share market of solar energy in relation to other sources. With the Internet of Things there will be sustainability in the whole solar value chain. The leading source of energy is wood fuel mainly in rural Kenya. Fossil fuel consumption is still high, mainly in the transport sector. Hydroelectric integration with solar energy is possible, probable, and plausible in the future. Financing, research, and development on solar energy can transform it to be the leading driver of industrial growth. Figure 5.4 shows solar energy value chain conceptualization.

Figure 5.4: IoT enabled solar value chain



Source: Authors conceptualization (2024)

IoT utilization across the solar value chain

The solar energy system in Kenya can be understood by examining a value chain that incorporates IoT technology. In this chain, solar panels tap sunlight and transform it into power. This electricity can be utilized instantaneously or preserved in batteries for future utilization. Electricity would conventionally be sent over transmission lines, although they are not depicted in the artwork. The primary advancement in this case is the Internet of Things (IoT)-)-enabled intelligent power grid. The sensors installed on the panels and the smart meters installed in residences monitor and record the amount of energy being produced and consumed. The real-time data is evaluated to enhance the entire system.

Virtual Power Plants (VPPs) can aggregate energy from multiple sources, such as rooftop solar installations, to function as a unified and sizable power plant for the electrical grid.

IoT role in solar energy generation

IoT can be used to enhance the real-time monitoring of solar panel performance using sensors. These sensors track various parameters such as solar panel performance, temperature, and sunlight intensity. By continuously monitoring these factors, the system can identify issues with the solar panels and optimize cleaning schedules, ensuring maximum power generation (Bhau et al., 2023; Chandrasekaran et al., 2023; Rani et al., 2023)

Application of IoT in real-time monitoring approach is crucial for growing solar installations, as it can help maximize energy output and efficiency, ultimately contributing to the country's renewable energy goals. This finding falls under the generation stage in the solar energy value chain. The generation stage involves the actual production of electricity from solar energy, which in this case is optimized through real-time monitoring of solar panel performance (Olorunfemi et al.,2022; Ahmed and AlTurjman ,2021; Hassan et al., 2023 and Zhang et al., 2023).

Utilizing IoT to enhance solar energy storage

The research findings on storage in the solar energy value chain mostly concentrate on the monitoring of battery health. IoT sensors are employed to observe battery temperature, charge/discharge cycles, and capacity. This monitoring allows for the anticipation of maintenance requirements and aids in the prevention of malfunctions, thus prolonging the lifespan of the battery. The batteries' self-monitoring capabilities, offer significant advantages to solar-powered companies and mini-grids in Kenya (Ahmad et al.,2018; Sinha et al.,2022; Hassan et al., 2023; Zhang et al., 2023). By maximizing battery efficiency and durability, these technologies can enhance the dependability and eco-friendliness of energy storage systems in Kenya's solar industry.

The research findings on the transmission and distribution aspects of the solar energy value chain primarily concentrate on the integration of smart grid technology. IoT sensors are employed for monitoring power flow throughout the grid, facilitating instantaneous modifications to optimize transmission and distribution. Kenya can in effectively handle its increasing dependence on solar energy and minimize grid losses (Alomar, M. A. 2023; Moradi et al.,2019; Estebsari et al.,2021; Swain et al.,2022 and Ullah et al., 2023;). Smart grid integration can enhance the efficiency and reliability of the grid, hence facilitating the integration of solar energy into Kenya's energy mix.

The findings related to the use of IoT in the consumption and metering stage in the solar energy value chain focus on the use of smart meters. These meters, equipped with two-way communication capabilities, enable dynamic pricing based on real-time demand. This approach encourages responsible energy consumption among industries, households, and businesses. The benefits of smart metres, include the end of estimated bills and the facilitation of two-way information exchange between users and utility providers (Avancini et al.,2019; Moreira et al.,2019); Bajerano et al.,2020; Sivaraman et al., 2023; Shahed et al., 2023 and Touloumis et al., 2024). Hybrid metering, enabled by smart meters, enhances billing accuracy and ensures that users are not overpaying or underpaying for their energy consumption.

The research findings on the utilization of IoT in the overall value chain optimization in the solar energy value chain highlight the importance of data-driven insights. By collecting data across the entire value chain, AI and machine learning algorithms can identify inefficiencies, predict maintenance needs, and optimize solar energy production and utilization. IoT provides real-time data and analytics, which can lead to increased efficiency and cost savings in the solar energy sector (Ahmed et al.,2022; Najafi and Atighi, 2024; Richter et al.,2022; Strielkowski et al.,2023; Shahed et al., 2023 and Yu et al., 2023). This approach enables better decision-making and helps to maximize the benefits of solar energy production.

By utilizing a data-driven methodology, the solar sector in Kenya can be able to enhance its efficiency, dependability, and cost-efficiency, thereby fostering a more sustainable energy future.

6. Conclusion and Policy Recommendations

6.1 Conclusion

The Country has the resources and potential to become a major solar energy player. The current landscape signals a future of renewable energy. With impressive growth in effective solar capacity, particularly notable between 2020 and 2021, the country has demonstrated a commitment to renewable energy. Government support, as evidenced by increased budgetary allocations, further strengthens Kenya's position. Additionally, a skilled workforce, bolstered by a well-established technician licensing system by EPRA, ensures the availability of qualified professionals for large-scale solar projects. However, challenges remain, including policy inconsistency, a capacity dip between 2019 and 2020, and a shortage of T1 and T2 technicians, which may impede smaller residential installations are notable issues. Additionally, limited battery capacity for the storage of generated solar energy for future use presents another hurdle.

Each scenario presents a possible future and thus presents an opportunity to plan, and prepare to take up opportunities while mitigating risks. Whether facing a delayed transition, accelerating progress in a transition phase, or embracing sustainability as a cornerstone of energy systems, clear recommendations emerge to guide stakeholders toward a common goal of ensuring a sustainable and resilient energy future powered by solar energy.

Furthermore, the integration of IoT in the solar energy sector, as seen in different countries, promises a smart upgrade. Sensors and smart meters that collect real-time data can optimize everything from power generation to consumer use. This data-driven approach can create a more efficient, reliable, and cost-effective solar energy system.

By implementing the outlined recommendations, Kenya can overcome existing challenges and fully capitalize on its solar energy potential. The combined efforts of the government, private sector, and educational institutions will be crucial in driving the country towards a sustainable and green energy future.

6.2 Policy Recommendations

To accelerate the transition to solar energy and ensure its sustainable growth, this study recommends the following:

1. Policies and policy incentives

The Ministry of Energy and Petroleum and the National Treasury to develop comprehensive policies and offer financial incentives such as tax breaks and subsidies to support rapid solar energy adoption and infrastructure development. They may also establish a dedicated Green Fund to support renewable energy projects, particularly in underserved areas.

2. Technological and social barriers

The Ministry of Energy and Petroleum, along with TVET institutions, may consider implementing specialized training programme and integrate renewable energy courses to build local technical expertise. They should also conduct public awareness campaigns to educate the public on the benefits of solar energy and promote its adoption.

3. Environmental accountability

The Ministry of Environment and Forestry can enforce strict regulations to hold solar companies and manufacturing firms that have installed solar energy accountable for their environmental impact and develop a robust framework for managing electronic waste from solar technologies to ensure sustainability.

4. Investment in hybrid systems

Kenya Power and Lighting Company (KPLC) to invest in hybrid energy systems that combine solar with other renewable sources like wind and hydro. KPLC should also upgrade the national grid to support solar energy distribution, especially in rural areas.

5. Localized incentives

County governments may facilitate community-based solar projects and provide localized incentives to encourage rural adoption of solar energy. They should also partner with institutions to train technicians in solar technology.

6. Research and development

The National Treasury, Ministry of Energy and Petroleum, and the private sector may consider increasing funding for research and development in solar technology, focusing on energy storage solutions and efficiency improvements. The relevant ministry should also promote public-private partnerships to drive technological advancements in the renewable energy sector.

7. Financial mechanisms

The National Treasury, the Ministry of Energy and Petroleum, and the Ministry of Environment and Forestry may create financing mechanisms that attract private sector investments and ensure sustainable funding for solar projects. They may explore green bonds and revisit feed-in tariff policies to attract investment for renewable energy projects.

8. Public awareness and education

The Ministry of Energy and Petroleum, the Ministry of Environment and Forestry, and the Ministry of Education may partner to conduct public awareness campaigns highlighting the economic and environmental benefits of solar energy. They should promote participation in Virtual Power Plants and build technical expertise in IoT applications within the solar energy value chain.

9. Sustainable green energy financing

Lastly, the Ministry of Energy and Petroleum, the Ministry of ICT, and the private sector may promote investments in cost-effective and advanced solar technologies, including IoT solutions for energy management. They should encourage automation and optimize Kenya's geographical advantages to ensure the long-term viability and growth of solar energy by 2050.

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Appendices

Appendix I: First Round Delphi Questionnaire

Dear Respondent,

The Kenya Institute for Public Policy Research and Analysis (KIPPRA) is conducting a study on the future of solar energy driving industrial growth by 2050. The emergence of solar energy presents opportunities for industrial growth. The research study focuses on determining key drivers that have the greatest impact on the future of solar energy development.

Kindly spare a few minutes to fill out the questionnaire. Your responses will be kept confidential. Thank you for your participation. The survey involves three (3) rounds of expert opinion. This round intends to identify factors with the greatest impact on the future of solar energy development.

- What is your role in the solar energy subsector?
- Residential solar owner
- Commercial and Industrial solar user
- Solar Energy producer
- Solar Energy distributor
- Solar Energy regulator
- Solar Energy technology manufacturer
- Solar Energy financier
- Energy analyst

1. In your own opinion which are the two major political factors that will influence solar energy driving industrial growth by 2050?

	Driver	**Remarks**
Political	Bilateral agreements	International funding, joint government-to-government projects on solar
	Policy incentives	This includes tariffs, taxation, and subsidies
	Domestic politics	This is energy politics
	Devolution of energy power	Transfer of power decisions to counties on energy issues
	Global pressure and partnerships	Global pressure to invest in renewable energy
	Energy sovereignty	Ability to generate power, distribute independently

	Political Stability	Favourable political environment for solar development
	Public Private Partnerships	

2. In your own opinion which are the two major Economic factors that will influence solar energy driving industrial growth by 2050?

Economic	**General economic stability**	**General economic growth and favourable economic policies**
	Cost of Investment	Initial capital investment on solar
	Attracting investment- direct/ foreign	The ability of solar to attract investment locally and internationally
	Economic environment	Interest rates, inflation, exchange rate, GDP
	Local energy Financing	Government allocation towards solar projects
	Viable business models	Solar feasibility and sustainability

3. In your own opinion which are the two major social factors that will influence solar energy driving industrial growth by 2050?

Social	**Social stability**	
	Public acceptance and willingness to pay	
	Rural uptake	Level of rural solar uptake as an indicator of growth
	Social background	Cultural, religious, ethnic
	Demographics	Growth rate, density, migration

4. In your own opinion which are the two major technological factors that will influence solar energy driving industrial growth by **2050?**

Technological	**Solar connectivity**	**Growth in solar connectivity and contribution to the power grid**
	Locally available technical expertise	Skilled Labour on solar development
	Energy storage	Level of storage of solar energy
	Efficiency of the end-user technology	
	New technologies and technology transfer	Innovations surrounding the energy sector
	Automation level	
	Operation and maintenance	Spare parts availability

5. In your own opinion which are the two major Environmental factors that will influence solar energy driving industrial growth by 2050?

Environmental	**Renewable energy sources**	**Availability of other renewable sources of energy**
	Geographical location	Kenya receiving longer sun hours
	E-waste management	Disposal and reuse of solar waste like panels, batteries etc
	Accountability of emissions and pollutants	Countries taking responsibility for their emissions
	Resilience to environmental risks	Preservation of environment

6. In your own opinion which are the two major legal factors that will influence solar energy driving industrial growth by 2050?

Legal	**Clear and transparent regulatory framework**	**The regulatory framework is well-stipulated**
	Timely update of the legislations	Legislation on solar matching current trends and needs of solar development
	Policy reforms	Changes in government initiatives and regulations aimed at promoting solar energy

7. How will Internet of things (IOT) influence solar energy in driving industrial growth?

8. How can Internet of things be utilized to enhance solar energy contribution to the industrial sector growth?

9. Any other comment on the innovation of solar energy to drive industrial growth?

Appendix II: Round II DELPHI Questionnaire

Accelerating solar energy transition towards green industrial revolution in Kenya by 2050

A. Political factors influencing solar energy transition towards the green industrial revolution in Kenya

To what level of influence do you consider the following political factors to be influencing the solar energy transition towards the green industrial revolution in Kenya in the coming years? Where low=1; moderate=2; high=3

	Low	Moderate	High
Increased external engagement with international organizations and initiatives that can provide funding, expertise, and knowledge transfer on renewable energy.			
Devolution of energy-related functions to counties leading to more localized decision-making and potentially faster implementation of renewable energy projects.			
A stable political environment that fosters investor confidence and encourages long-term investments in renewable energy infrastructure.			
Increased PPPs that can leverage private sector expertise and resources to accelerate solar energy development.			
Increased bilateral agreements with other countries that can facilitate technology transfer, knowledge sharing, and joint ventures in solar energy.			

B. Economic factors influencing solar energy transition towards green industrial revolution in Kenya

To what level of influence do you consider the following economic factors to be influencing solar energy transition towards green industrial revolution in Kenya in the coming years? Where low=1; moderate=2; high=3

	Low	Moderate	High
A strong and stable economy that provides resources for investment in renewable energy infrastructure and reduces risks for private investors.			
Streamlined regulations and incentives for private investment that can attract more capital into the solar energy sector.			

Tax breaks and other incentives that can make solar energy more affordable and attractive for businesses and individuals.			
Initiation of Local/county renewable energy projects that can improve energy generation, and access, create jobs, and boost county economies.			
Access to local financing that can reduce reliance on foreign capital and make solar energy projects more sustainable.			

C. Social factors influencing solar energy transition towards green industrial revolution in Kenya

To what level of influence do you consider the following social factors to be influencing the solar energy transition towards the green industrial revolution in Kenya in the coming years? Where low=1; moderate=2; high=3

	Low	Moderate	High
Social unrest and insecurity that can disrupt renewable energy projects and discourage investment.			
Increased adoption of solar energy demonstrating public interest in renewable energy solutions and reduces reliance on traditional fuels.			
Increased number of skilled workforces that are essential for installing, maintaining, and managing solar energy systems.			
Enhancement of staff development programme that can lead to a motivated workforce within relevant institutions that can accelerate the implementation of solar energy initiatives.			

D. Technological factors influencing solar energy transition towards green industrial revolution in Kenya

To what level of influence do you consider the following technological factors to be influencing the solar energy transition towards the green industrial revolution in Kenya in the coming years? Where low=1; moderate=2; high=3

	Low	Moderate	High
Widespread access to the grid/increased connectivity which is necessary to integrate solar energy into the national power system.			
Adoption of improved Energy storage solutions that are crucial for managing the intermittency of solar energy and ensuring grid stability.			

Enhancing the capacity of existing reservoirs to store hydroelectricity that affects the ability to integrate solar energy and maintain grid stability.			
Embracing advanced automation with machine learning that can optimize grid management, improve efficiency, and integrate solar energy more effectively.			

E. Environmental factors influencing solar energy transition towards green industrial revolution in Kenya

To what level of influence do you consider the following environmental factors to be influencing the solar energy transition towards the green industrial revolution in Kenya in the coming years? Where low=1; moderate=2; high=3

	Low	Moderate	High
Increased exploitation of Kenya's diverse renewable energy resources (solar, geothermal, wind) that offer a strong foundation for a transition away from fossil fuels.			
High sunshine hours (5-7hrs) that provide more opportunities to generate solar power.			
Increased public awareness campaigns that can educate the population about the E-waste management			
The urgency and compliance with SDG 7 of addressing climate change that can drive investment in cleaner energy sources like solar.			

F. Legal factors influencing solar energy transition towards the green industrial revolution in Kenya

To what level of influence do you consider the following legal factors to be influencing the solar energy transition towards the green industrial revolution in Kenya in the coming years? Where low=1; moderate=2; high=3

	Low	Moderate	High
A clear and comprehensive policy framework for renewable energy that creates a stable and predictable environment for investors and developers.			
Existence of clear and enforceable policy reforms essential for ensuring the successful implementation of the solar energy transition.			

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