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Assessment of Technological Innovations and Policy Frameworks in Promoting Green Energy Transition: Global Perspectives

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Abstract

Transitioning to a sustainable strength machine is vital in the face of weather change and aid depletion. Technological improvements in solar and wind electricity display promise in the assembly of worldwide energy demands, while hydropower faces demanding situations in environmental impact mitigation. Effective coverage frameworks like carbon pricing and regulatory standards play a critical role in facilitating the transition to green energy. Case studies from Germany's Energiewende and California demonstrate successful approaches to renewable strength adoption. However, challenges such as technological obstacles and monetary uncertainties avert development. To obtain the bold desires of the Paris Agreement, competitive decarburization, and adaptive rules are crucial, emphasizing the need for international cooperation and expertise sharing. Addressing those challenges through place-precise strategies and progressive solutions will pave the manner for a sustainable and rich destiny powered with the aid of renewable strength sources.

Keywords: Technological Innovation, Green Energy Transition, Policy Framework

1. Introduction

Due to the far-reaching impacts of climate change, the need for energy security, and the depletion of resources, it has become increasingly crucial for modern society to undergo a transition towards an energy system that is not only efficient but also renewable and environmentally friendly. In this ever-evolving landscape, technological advancements hold the key to unlocking new breakthroughs in energy security, most notably by reducing carbon emissions and effectively managing adverse environmental externalities. Additionally, the progress of policies has emerged as a powerful tool, employed to expedite the pace at which the world embraces greener forms of energy. (Agupugo, Ajayi, Nwanevu, & Oladipo, 2022)However, despite these efforts, the true effectiveness of these technological and policy change initiatives remains somewhat ambiguous, thereby necessitating a comprehensive and in-depth examination of these two pivotal factors in the green energy transition. It is within this backdrop that the focus of this article is firmly rooted in three overarching topics: technological innovations in the field of green energy, the formulation of effective policy frameworks supported by public finance, and the delicate balance between energy security and pressing environmental issues. By delving into these facets, we aim to shed light on various key economic issues that are intrinsically tied to the green energy landscape. Specifically, we intend to explore the impact of technological knowledge and technology transfer, the accessibility and consumption of energy, the crucial aspects of funding and implementation schedules, the reduction of greenhouse gas emissions, the necessary capacity planning requirements, and the lifecycle of these emerging technologies. It is crucial to note that due to the inherent complexities and unique characteristics of energy systems across the globe, each country adopts its own distinct design approaches, firmly rooted within the bounds of their respective governments. (Breyer, et al., 2022). Numerous reports from leading experts and esteemed organizations have emphasized the daunting and multifaceted nature of harmonizing the world's energy systems towards a sustainable trajectory. It is a scientific and technological challenge that equally encompasses both developing nations and industrialized countries. Therefore, it is imperative to include a careful investigation of the techno-economic landscape, both in terms of existing conditions and ongoing research and development efforts, from a global perspective. Only through this comprehensive examination can we hope to gain valuable insights into the present state of affairs and outline a strategic path forward, driven by technological advancements and supportive policies, that will navigate us towards a sustainable and prosperous future. (Zohuri, 2023).

2. Technological Innovations in Green Energy

Solar energy is the most attractive form of clean and renewable energy to assist in the development of sustainable energy systems. The potential for solar energy surpasses the global power demand. Therefore, the advantages offered by solar energy have attracted a lot of interest, and this has led to some significant developments in the technological evolution of photovoltaic and concentrating solar power. Wind energy is also recognized as an inexhaustible and available source of renewable energy that can assist in reducing the major global environmental threats by contributing distinctly to the economy. Commonly, wind energy technologies convert wind energy into mechanical energy and then use it for power generation in a wind turbine through the help of a generator. Hydropower is the most commercially used source of renewable energy to produce bioenergy in the world. It is the result of our historical heritage recording when it was first used in community development due to the availability of water resources in their habitat. (Maka & Alabid, 2022).

Bioenergy, the right solution for environmental problems, is getting the attention of developing nations. Bioenergy can be defined as a process of converting natural organic materials produced from plants, algae, or agricultural products into energy for some possible applications, such as electricity supply, heating, and cooling. These technological innovations have great potential to reduce the dependence on fossil fuels, reduce greenhouse gas emissions, and create energy security for the people. All technologies in increasing a renewable energy transformation plan must work reactively and support each other (refer to figure 1). The world is going through an era of innovation in technological thinking and innovation in behavioral matters. Knowledge itself is transforming the economic wealth of economies, industries, and individual companies. (Duarah, Haldar, Patel, Dong, Singhania, & Purkait, 2022).

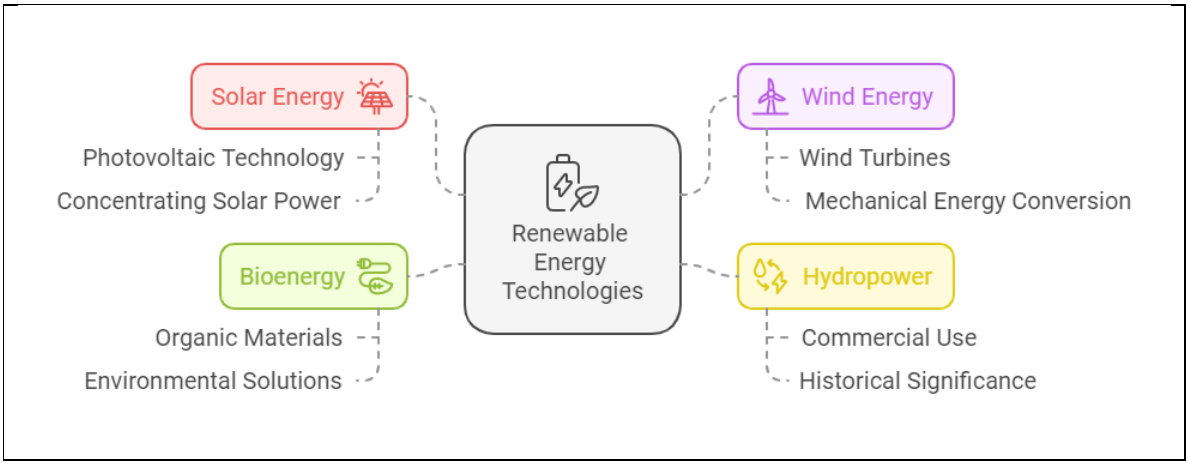

Figure 1: Renewable Energy Technologies

It is important to foster an increased awareness of the interrelationship and connectivity of various energy technologies in sustainable energy systems transitional planning for the globe. The purpose of this study is to identify these technology innovations in informational form necessary to enable policymakers to understand how those technologies, such as solar, wind, hydropower, and bioenergy, work and how they are beneficial in sustainable energy transition design. The main objective is to analyze and explore current technological innovations in promoting green energy transition for policymakers, energy planners, and organizations engaged in promoting green energy transition, such as projects in the renewable and sustainable energy field. This paper represents an objective analysis associated with the six groups of sources discussing technological trends in successful sustainable energy systems transitions, which are expected to involve a range of materials. (Cantarero, 2020).

2.1. Solar Energy Technologies

Current levels of solar power harvested globally, both in solar PV and solar thermal, rely on numerous technological advancements in the last several decades. The current two dominant solar technologies are as follows: (i) Photovoltaic, typically using single-crystalline or multi-crystalline silicon, which is earth abundant and non-toxic for residential and commercial use; and (ii) solar thermal systems for utility-scale requirements using concentrating solar power, where heat is generated using mirrors that concentrate solar energy onto a small area. The heat can then be used to produce electricity by driving a thermal heat engine connected to an electrical power generator. Other advanced PV systems include thin films, which are also evolving, although their share of global solar cell production is relatively small. The operational principle of photovoltaic conversion involves the absorption of photons and the generation of charge carriers that are separated and collected by p-n junctions, turning them into electrical energy. In solar thermal systems, solar energy is used directly as a heat source. (Hao, et al., 2022).

Optical concentration can enhance localized solar intensity significantly, resulting in increased operational efficiency and better cost-effectiveness. Over the years, the growing importance of solar energy is clear from the literature, which shows rapid technical advancement and massive penetration throughout the world. The commercially driven manufacturing and R&D pushes have significantly reduced both solar PV and CSP costs, thereby giving impetus to distributed and utility-scale solar power plants as a viable alternative to liquid fossil fuels and coal. Economies of scale, societal benefits, and the reduced environmental externalities of large-scale solar power could eventually displace considerable amounts of land commitment for mining and combustion/industrial purposes. Moreover, building applications of solar power for electricity, heating, and cooling (as well as other fuel needs such as hydrogen production) can also supplement existing resources, both fossil and alternative energy, adding economic competitiveness and consumer choice. (Yasmeen, Yao, Padda, Shah, & Jie, 2022)

The evolving cost-effectiveness and efficiency of solar technologies are detailed in a recent review. Intermittency or non-controllability and land-use concerns have been raised as primary challenges for the capture of solar energy in meeting shifting patterns of demand. Additionally, potential technical solutions exist, such as the combination of CSP or PV technologies with thermal, mechanical, or electrochemical energy storage solutions. Furthermore, advancements are being made in smart grid technology applications that can promote consumer demand-side response towards reducing electricity demands during peak periods of supply; this is typically achieved by improved electrical grid storage and distribution systems such as advances in operating voltage and reactive power flow. Other research work shows the integration of thermal energy storage with building heating, ventilation, and air conditioning. During high solar radiation, surplus electrical energy can be converted into refrigeration to store solar-produced thermal energy. Recent data indicates a significant global reduction in greenhouse gas emissions with even marginal solar energy penetration across regions. Global large-scale utility solar photovoltaic and concentrating solar power case applications, benefits, and challenges are discussed in the following sections. Some of the typical solar projects that are operating or being commissioned in the developed and developing economies are highlighted in the following sections. (Lamb, Grubb, Diluiso, & Minx, 2022).

2.2. Wind Energy Technologies

This sub-section focuses on wind energy technologies. It can be seen from figure 2 that wind is one of the abundant renewable energy sources. A wind turbine is a machine that converts kinetic energy from natural wind into mechanical energy, which is then used to produce electrical power. The most common is the onshore wind turbine. Recent successful offshore wind energy developments also show the potential of wind energy to lead the way to a greener future. By the end of 2016, the global installed onshore wind energy had reached 490 GW, with Europe, Asia, and North America being the top markets. The advent of offshore wind energy prompted the introduction of the first Directive for Renewable Energy, targeting a share of 12% of the electricity generated from offshore wind by 2010. In 2016, Asia dominated with 45% of new offshore wind installations, followed by Europe and North America. As of September 2017, the offshore wind capacity was reported at 15.8 GW. National policies have been a major force in shaping national markets for both onshore and offshore wind energy. (Siram, Sahoo, & Saha, 2022).

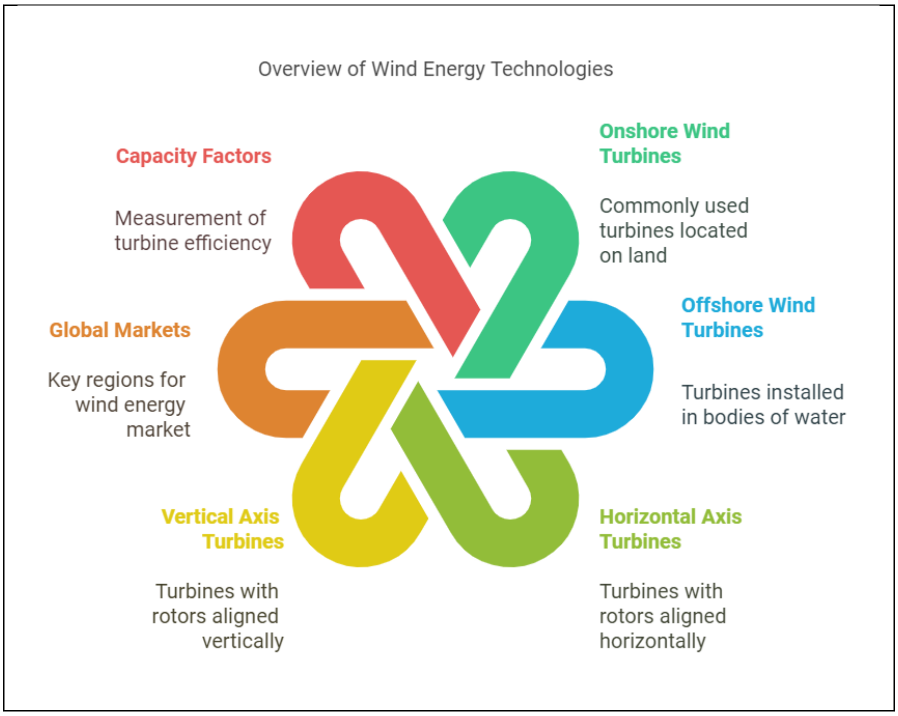

Figure 2: Overview of Wind Energy Technologies

Wind turbines have been developed in the past decades because the amount of electricity generated from a turbine depends on the availability of natural wind. A greater hub height and larger rotor diameter improve the capacity factor. The capacity factor is defined as the fraction of electrical power production over a period of time compared to the maximum electrical power production of the turbine. Over the past few decades, wind turbine design has evolved from traditional horizontal-axis rotors to vertical axis, and to a new trend of mixed-energy designs, such as the integrated vertical and horizontal design. In general, there are two types of wind turbines. The horizontal axis wind turbine has the main rotor shaft and generator at the top of the tower. Upwind machines have the turbine pointed into the wind, while the downwind design has the turbine facing away from the wind. In the vertical axis wind turbine, the rotors are arranged vertically, which reduces the weight and footprint of the turbine. Both horizontal and vertical axis turbines are used today. Onshore wind energy technologies: The United States has the fifth largest wind energy capacity with an installed capacity of 89 GW by the end of 2016. This is around 20% of cumulative global capacity. The

U.S. was expected to add approximately 848 MW of new onshore wind energy capacity in 2016, and wind energy would represent approximately 40% of the total new installation. Texas has the largest onshore wind capacity in the U.S., followed by Iowa and Oklahoma. Leading U.S. corporations and businesses were in full swing with more than 100 companies using wind power to generate 100 percent of their electricity today, making wind a key component of their sustainability strategy and commitments. This was up 22% from January 2016 when 82 companies had 100% wind and solar targets. Wind energy provided over 73,000 jobs in the U.S. in 2016 and accounted for nearly 30% of all new American electric growth credited over the past five years – more than any other source. (Walker, 2020).

2.3. Hydropower Technologies

Hydropower is an energy generated from water flow using a system or cycle for converting the mechanical energy of a water stream to that of electricity. The mechanical energy accumulates in a hydropower system, which converts it into electricity through the so-called generator. The basic system of hydropower operation is water flow (potential energy) → mechanical energy of turbine wheel → electrical energy of generator. Based on the systems, hydropower can be categorized as: - Run-of-River plants - Storage type plants - Pumped storage plants. (Gemechu & Kumar, 2022).

Hydropower has several advantages such as reliability, low operating cost, scalability, energy storage, and high capacity factor. Despite these advantages, hydropower projects have several social and ecological impacts. A hydropower plant dams the rivers, which has implications on the ecology of the rivers, such as fish migration, the river’s thermal regime, flow regime, etc. This might also have implications on the transportation of sediment. The residential and ecological displacements have been another major issue while developing hydropower projects. In principle, the flow or the cycle of water power main systems needs to be integrated with the minimum possible environmental impacts. This makes it difficult and could be a theoretical barrier - the chances of imbalance between 'the water reserves for power production' and the ecological flow in or downstream of the systems. However, a range of innovative technologies and improved operations are being developed for both run-of-river and storage type plants to minimize the ecological impacts or to make the systems environmentally friendly. (Aung, Fischer, & Azmi, 2021).

For the readers’ interest, we try to touch on a couple of interesting hydropower innovations from around the world. There are a number of countries that are using hydropower as a main source of electricity. The largest hydroelectric production in the world comes from China, which is followed by Brazil, the United States, Canada, and the Russian Federation. These leading countries mainly depend on glacial melt that provides an uninterrupted flow of water, which enhances electricity production. In Pakistan, run-of-river hydropower projects contribute about 6-7% to the total electricity production. However, the country is planning to increase the share to 15% of the total electricity production. (Zhang, Pang, Bahaj, Yang, & Wang, 2021)

2.4. Bioenergy Technologies

Bioenergy is produced from biomass, biological materials that can be used as fuel.

There are many different types of bioenergy, the main ones being biofuels, biomass, and biogas. By reducing greenhouse gases, boosting rural development, creating jobs, and improving energy security, bioenergy is a vital component of the renewable energy sector and has several renewable energy sources. Bioenergy production uses leftover or waste biological material that would otherwise produce methane, which has a significant impact as a greenhouse gas. The use of locally produced resources may enhance energy security, especially if these are residual or waste materials. Furthermore, sustainably produced bioenergy can provide a means of dealing with toxic and other waste materials. (Reid & Field, 2020)

Bioenergy can pose land use competition risks between energy crop and food crop production and may also induce changes in land use that result in GHG emissions, offsetting the gains of bioenergy. There are concerns about the carbon and energy balance of bioenergy, reduced food security as more fertile land is used for energy crops, and the energy and GHG emissions associated with bioenergy infrastructure and production. Nevertheless, the development of new production technologies with the potential to greatly enhance the yield and reduce the GHG emissions associated with bioenergy makes bioenergy very promising, particularly in terms of its potential to become a staple tool in reaching bioenergy development goals. Developing second and third-generation biofuels could allow bioenergy to contribute 20%—or even more—of the global total in renewable energy sources by 2050. Like municipal waste, most of the technologies developed for, and obstacles faced by, bioenergy are relevant to biogas, so this section highlights case studies around the use of waste biomass to produce biogas. Bioenergy to electricity is addressed as part of the electricity overview. Bioenergy case studies illustrate different technologies for converting waste into energy. Policy frameworks strongly supporting the use of advanced, second-generation biofuels have resulted in over a billion liters produced globally thus far. In Finland, energy policy objectives have been set for 2020—higher than those of the other Nordic countries—establishing demand for their production. (Errera, Dias, Maya, & Lora, 2023).

3. Policy Frameworks for Green Energy Transition

In addition to the development and diffusion of technological innovations, policy frameworks can also have significant implications for the transition to green energy. National renewable energy targets and transition policies can be considered as drivers in shifting technologies towards green energy to compensate for possible initial costs. Most governments around the world have established incentives for investments in renewable energy by adopting policies such as feed-in tariffs, portfolio standards and trading, direct subsidies, green certificates, tax credits, and easy and low-cost access to finance. Carbon pricing is another policy measure that has been introduced in several countries to render the pollution externality visible and to make emission reductions more attractive for energy companies. (Hoicka, Lowitzsch, Brisbois, Kumar, & Camargo, 2021).

When we consider the role of carbon pricing strategies, their main purpose is to internalize the environmental cost of emitting CO2 and thus provide an economic grounding for emissions reduction policy. Another group of market-based incentives are subsidy measures that support renewable energy development and promote emissions reductions. In addition to establishing targets and incentives, regulatory policies and standards are also increasingly implemented. The application of regulatory policies and standards can become an effective tool in securing compliance and promoting sustainable approaches to the supply and consumption of energy. In different regions, different types of energy policies have been adopted to facilitate the transition to low-carbon energy. Successful implementations and best practices that have emerged in different regions include the Renewable Energy Obligation, state feed-in laws, and the Emissions Reduction Fund. (Polzin & Sanders, 2020).

Developing an effective policy framework is a significant challenge due to political difficulties and economic expenses. Political resistance often emerges when energy and climate policies deviate from those based on fossil fuels, as those policies will encounter opposition from traditional energy users. The international dimension should also be considered, as a global challenge, as the environment does not have any physical borders, meaning that policy options for informal, formal, and emerging international partnerships should be broader still. At the same time, the regulation of the externalities related to the energy sector, including greenhouse gases through efficiently designed policies for regulations, taxes, and subsidies has to be addressed internationally, fostering cooperation among countries. Multilateral international cooperation on climate could basically have two treaties, across which it is possible to have common measures and safeguards. This might lead to the start of a policy framework addressing the transition to green energy by the introduction of hybrid institutional forms to generate cooperation among countries. In summary, the policy regime is very important for technology and innovation development and implementation, thus leading to the successful creation of a green power grid. (Muscio & Sisto, 2020).

3.1. Renewable Energy Targets and Incentives

3.1.1. Renewable Energy Targets Setting and implementing tangible renewable energy (RE) targets is essential for promoting green energy in the country. This will describe a clear path of country policy to promote RE and the technological development of the sustainable green energy initiative. Incentive mechanisms can be set up based on the national target, reflecting the country's technology trend under the RE power system. To do this, the government can set up an RE power generation target in two ways. First, setting up a sector-based generation target can be the power used for heating, transportation, or electricity generation in individual sectors like industry, commercial, residential, agriculture, and others. Second, setting up an integrated sector-based generation target is valid. An integrated sector-based generation target, the power generation for heat, transport, and electricity sectors can be addressed in the sector approach. Incentives Incentive mechanisms include various direct financial grants, subsidies, and tax incentives, as well as indirect measures such as advantageous loans, research and development funding, market creation, regulatory support, and lead market incentives. Direct financial incentives, which include grants, tax credits, feed-in tariffs, and rebates, provide the investor with payments for the electricity or heat produced by the RE generator, reducing the initial costs for the installation since the investor can raise capital based on revenues from the incentives. Initially, the tariff rate was very high to attract bankable projects, but it increased gradually, accompanied by the learning curve of RE technology. The objective of the adjustment of FIT is not only to trigger the financing of RE generation but also to incorporate the external factors of the RE system. FIT provides an investor with an economic and financial return that can attract market interest rate investments. The major role of FIT implementations is to offer economic returns by integrating various factors, including externality costs. (Gawusu, Zhang, Jamatutu, Ahmed, Amadu, & Djam Miensah, 2022).

3.2. Carbon Pricing Mechanisms

Carbon pricing is established to be the most effective system to promote the reduction of greenhouse gas (GHG) emissions. Generally, there are two primary approaches to implement the carbon pricing system: carbon taxes and cap-and-trade. In carbon taxes, the polluters are obliged to pay taxes for each tonne of carbon (or equivalent GHG) they emit through their economic or industrial activities. The other approach, cap-and-trade system, is designed to allocate a certain amount of emission permits against the general emissions cap, which is specified in the permit market. There must be carbon exchanges to interact with the governments' registries and establish an electronic trading platform. It customizes legal requirements like settlements, clearing, and offsetting, etc. The carbon credits are listed on an electronic platform and are exchanged by the companies or entities to meet their compliance requirements. (Green, 2021).

It is seen that various carbon pricing systems have been introduced at regional, national, and sub-national levels, which leads to the reduction of emissions, but various challenges are also observed during the implementation. Initially, carbon management incurs additional financial costs, and thus businesses will operate leaner, opting for cleaner technologies that result in tangible reductions in emissions or carbon savings. Although, if not administered adequately, utilities may far surpass their mandatory emissions or total production thresholds. As a result, the effectiveness of the system varies as various barriers need to be eradicated. Generally, carbon pricing systems are expected to have an adequate and strict monitoring and oversight regime in order to maintain integrity and uphold compliance. In addition, output-based allocations are required to keep utilities stable. In some countries, low-income, energy-intensive subsidies are offered to large industry emitters. To maintain carbon price levels, it is proposed to have adequate intervention measures. In conclusion, carbon pricing is considered an effective strategy to promote the shift to cleaner energy systems by having a unanimous and strong desire in the global context. (Raghoo & Shah, 2022)

In conclusion, carbon pricing seems to be more efficient compared to other alternatives like regulations, tax credits, renewable portfolio standards, and loans. For instance, the price of carbon led to a considerable reduction in GHG emissions of approximately 6 to 7 percent. It has been observed that the establishment of a regional initiative has also shown remarkable success. Likewise, the emissions cap was decreased at an annual rate of around 2.5 percent, while the decrease in the actual emission rates of seven utilities was around 5 percent. However, the initiative experienced several challenges as well, which include the allowance prices dropping under a certain amount. Another successful example of CCS projects is that of a commercial power plant that is newly constructed and is designed to have CO2 emissions of the order of 1.5 Mt per year. (Känzig, 2023).

3.3. Regulatory Policies and Standards

Regulatory approaches and standards are vital to ensure sustainable growth in renewable energy projects. These regulations and standards provide an implementing framework for jurisdictions to facilitate and promote clean and green energy. As such, a clear and stable policy and regulatory environment is important in creating a governmental approach and investor confidence in any renewable energy project. In the renewable sector, a diversity of standards touch on safety, efficiency, and environmental concerns, providing consumer confidence and supporting trading success. However, one problem with standards is that due to market unification, one rule set in one country has the possibility of dictating the standard set in other regions. (Lu, Khan, Alvarez-Alvarado, Zhang, Huang, & Imran, 2020).

The solutions to this are user-based measures on improving the house, and under the "Soft Path" (reducing demand); it is noted this sees inconsistent governmental support. Regulators will need to adapt to rapidly changing technologies. Factors such as statutory support arrangements are often used as a key driver for investment in renewables. Such policies need to evolve with technology and ensure monopolies are not created, as seen in relation to their decay control for solar panels. Consequently, incentives need to be for using the power, not generating power. Regulations such as building codes also need to move to SMART social, economic, and environmental systems and make the best use of energy efficiency, developing microgrids, with lifestyle implementing smart appliances that help reduce energy use. Effectiveness of policy is also the subject of ongoing research and review, with a collection of best practice case studies showing a review of wind energy and policy effectiveness across various regions. In this review, six case studies were considered worthy of mention. While not limited to regulation, these studies potentially have crossover relevance, including developing legislative frameworks. (Egli, 2020).

The research to date shows that advancement in renewable technology has led to changes in regulation, and so too do means of infiltration to new players in the market. Therefore, the change needs to continue in order for conventional markets to accept innovations. The best example comes from Australia, which is considered timely and relevant to this project. The Australian regulator has been instrumental in allowing market participation through the development of a National Electricity Market, through generating legislation and administering market regulation, which upholds national environmental policies and supports the introduction of a renewable market with Renewable Energy Certificates. Furthermore, despite rumors and agitation to "undo" the RET, currently around 20% of the electricity supply is being generated by renewables, which shows that we are moving, albeit at a slow rate. As discussed in a previous paragraph, it is important to consult with industry, local communities, and obtain legal advice in relation to any regulatory changes, as such a forum is recognized and rated highly ingrained consultation as part of ethical consideration. The barometer of excellence in regulatory design and implementation underpins the preservation and strengthening of natural and human capital endowments and is seen in the administration by the governing body looking at the effects of the interaction of trade on environmental and consumer laws. Moreover, regulators can provide robust information through reports and their annual report measurable outputs for including targets. (Litvinenko, Petrov, Vasilevskaya, Yakovenko, Naumov, & Ratnikov, 2023).

4. Case Studies of Successful Green Energy Transitions

Case studies of successful green energy transitions that this paper presents are all aimed at studying the successful examples of prominent renewable energy transitions taking place worldwide to gain insights into the technological innovations and policy frameworks that are currently being implemented. In perspective, this study hopes to provide empirical evidence to show that different countries adopt different innovative energy technology systems according to their contexts and resources, which have worked for them. Contrary to early literature positing a required one-size-fits-all solution for energy transitions, these exclusions will set a basis for region and market-specific pathways for transitioning to renewable energy. Project contexts and relationships to each of the countries with renewable energy experience are as follows. 1) Transforming the energy sector initiated by citizens—The case of Energiewende in Germany. The case of Germany discusses the concept of Energiewende, a technically, economically, ecologically, and socially ambitious transformation process of reducing CO2 and three of the five energy transitions, considered by the European Union as the blueprint for a transformation and a source of leading by example for the much grander world energy revolution. 2) Renewable energy growth in China: Potential, challenges, and a case study. The case of China discusses the development of renewable energy in China, the restructured electricity distribution and pricing system that led to a renewable energy growth rate, the Three Oceans project for building offshore and intertidal wind farms with a capacity to produce, as well as solar power that rounds up to announced in 2013. 3) California: A blazing pathway demonstrating a renewable-rich future. The case of California discusses a spectrum of innovative renewable energy technologies in six segments: utility-scale solar, distributed solar photovoltaic, concentrated solar power, electricity storage with regional grid integration, microgrids for educational institutions and communities, and energy-efficient and green construction designs for buildings and transportation. (Esmailzadeh, Noori, Nouralizadeh, & Bogers, 2020).

4.1. Germany: The Energiewende

The Energiewende is a comprehensive initiative designed to establish a sustainable energy system in Germany. As part of the Energiewende, Germany aims to double energy efficiency by 2050 compared to 2008, increase renewables to 60% in the electricity sector by 2022, 80% by 2050, and 60% of the total energy consumption. Also, for individual sector targets, 50% of households must meet heating needs with renewable energy sources by 2030 and 80% by 2050. The Energiewende focuses on four themes: energy efficiency, expanding renewable energy production, restructuring the electricity market, and engaging citizens on the need for a sustainable energy system. The underlying principles are reliability, security, and economic competitiveness. One of the most significant achievements of the

Energiewende is that, in recent years, a significant portion of the new power capacity is now based on renewables, particularly wind and solar. (Brugger, Eichhammer, Mikova, & Dönitz, 2021).

Rationale for selection: While many efforts towards a sustainable energy future are somewhat of a piecemeal approach, the German Energiewende offers a comprehensive package of all relevant thematic compliances, also aiming at systemic change in different sectors and involving research for renewable as well as socio-political implications of such a shift. The Energiewende developed as a national past-tariff policy reform in 2000, leading to a decrease in the price of solar panels, which has dropped by half from above 30 cents per kWh of power generated to today's almost 6 cents per kWh. The major challenge, however, is the price of electricity, which has doubled in the same period up to 2014. Current developments, however, see a fast adaptation of all electricity markets, turning the situation dramatically. Another of the major benefits of the Energiewende is the new energy mix and self-power supply, especially for local industrialists. For local industrialists, the new plans of creating more jobs and investments in electric power and grid are significant. However, financial demands in building grids like wind energy are the expensive part of their future plans. Realizing a model of a CO2-neutral regime satisfying the highest ecological demands – it thus combines climate protection and local employment. (Leiren & Reimer, 2020)

4.2. China: Renewable Energy Growth

China has witnessed rapid growth in renewable energy capacity, making it the global leader in renewable energy today. Capacity expansion has been driven by various government policies and considerable system investment from 2005 to 2010. China’s 13th Five-Year Plan set capacity addition targets of adding 60 GW a year for both solar and wind until 2020. In 2017, China alone added 53 GW of solar capacity and 18.6 GW of wind power capacity. Most of this growth in China was driven by solar and wind installations, which increased from 2% of total installed capacity in 2007 to 15% in 2016 and about 27% in 2017. China accounted for 50% of global newly installed solar generation in 2017. Most of this installed capacity was for utility-scale power generation projects since 70% of the total solar installation in China is ground-mounted; however, as of the end of 2017, the capacity utilization factor is only about 10%. (Li, Virguez, Shan, Tian, Gao, & Patiño-Echeverri, 2022).

Technological innovations and manufacturing capabilities of China’s solar modules and their ancillary accessories have expanded rapidly over the last decade due to strong domestic and overseas market demand and government support. Rising inventories, overcapacity, levelized costs of power of solar and wind power, which have fallen below coal generation costs, and government subsidies have also led to significant growth in wind and solar power capacities in China. The National Energy Administration of China reported new solar and wind benchmark electricity prices of 0.55 RMB and 0.43 RMB per kWh, respectively. The current growth and ambitious future renewable energy targets reflect the significant role played by policy incentives, market demand, and also institutional form and capacity in energy transition. However, the emergence of local environmental economic costs and political economy issues raises a question about the sustainability of market forces to achieve rapid green transition. (You, Khattak, & Ahmad, 2024).

4.3. California: Leading in Solar Energy

California: Leading in Solar Energy. California, in the United States of America, is the sixth largest economy in the world. With over 39 million inhabitants, it would be the 35th most populous country, ranking behind Canada. It would be the 14th largest country by land area. By the end of 2020, California had approximately 38,867 MW of installed solar capacity, with an annual net generation of 94.3 TWh. The state has the potential to generate 780,479 GWh of solar energy. California has a Renewable Portfolio Standard (RPS) of 60% by 2030 and aims for 100% of its energy to come from zero-carbon energy resources by 2045. Gone are the days of uninterrupted imports of coal and oil from around the world and the unstable prices that come with them. Solar is at the top of California's renewable energy sources. (Mohammadi, Khanmohammadi, Khorasanizadeh, & Powell, 2020)

California has large solar resources and targets to generate half of its electricity from renewable energy sources by 2030 and maintain 100% zero-carbon electricity by 2045. It stands out in terms of policies, programs, and initiatives to promote solar, as well as satisfied customers. Under the "net metering" policy, California compensates companies (mainly households) with photovoltaic equipment for the energy they export to the electricity grid, for which subsidies are given. At the end of 2020, solar power plants in California had a total capacity of 21.374 GW. Heat and temperature management continues to be a permanent focus of great interest. Community solar projects, in which solar panels are installed on local, state, and institutional land and provide clean, locally generated energy for a variety of consumers, are growing rapidly. Countries and states can adopt California's golden standards as their own to harness solar energy. (Baik, Siala, Hamacher, & Benson, 2022).

5. Challenges and Barriers to Green Energy Transition

Green energy transition initiatives face a variety of challenges and barriers. The most immediate are technological and economic. Technological issues, like intermittency or specific requirements for the availability of local resources, determine their role. It is then the growing international division of labor that is created, with the corresponding need to connect electricity grids, also opening the way for other structural changes that must necessarily be considered in more comprehensive strategies. Economic challenges, especially on the eve of the pandemic, were mainly related to regulatory security of the market, which is also aggravated by unexpected events, such as tumultuous political changes or war conflicts. This often leads to energy investment having lower economic risks. An initial analysis of the socio-economic dimension and basic theoretical foundations of systemic problems of dissemination of renewable energy technologies has been developed. (Qadir, Al-Motairi, Tahir, & Al-Fagih, 2021).

Challenges and barriers to the use of renewable energy sources have many dimensions. These are the long-standing barriers stemming from various structural embeddedness, or relatively recent challenges, many of which are the result of technology and technological positions being dynamically developed in the industry undergoing constant digitalization. One of the last to be discussed is the market influence of the power plant with storage, produced using renewable energy technologies, which is close to the level of conventional electricity prices. However, it should be noted that market, societal, and political obstacles to the development of renewable energy sources do not only appear in Poland. There are, therefore, problems that are universal and can also be the subject of international scientific studies, which is confirmed by dozens of reasons identified in various countries or even continents. Their domestic descriptions will be presented below. (Yadav, Pal, Patra, & Yadav, 2020)

6. Conclusion and Future Directions

The synthesis and testimony delivery demonstrate the current stage of technological innovations and policy frameworks towards promoting the green energy transition across the globe. Promising progress is observed across all focused regions, but challenges to cope with the fast-paced green energy transitions remain evident. In order to comply with the Paris Agreement objective of a warming limit of 1.5 °C, even more aggressive decarbonization in the energy sector is crucial. Adaptive policies are necessary to establish a supportive framework for the energy transition by proactively considering key aspects such as opportunities and risks, mitigation of negative impacts, and capacity building. Policy innovation beyond current mainstream policy is also crucial. Knowledge and innovations are required to meet the potential barriers to the identified issues of sustainable energy transitions. There is a need to develop new technology and accelerate the diffusion of existing technology, since the attainment of renewable energy targets, in all settings whether global, regional, or sub-national, relies on the extent of innovation and deployment.

Translating the knowledge from innovation policies to technical technologies, access, and diffusion challenges is essential in advancing comprehensive global responses. International cooperation is important in formulating and sharing this best evidence through a country-responsive approach so that knowledge can be used close to policymakers as operational solutions on the ground. Shaping the research agenda and complementary policy initiatives has significant synergistic potential with emerging issues in the global response. Looking ahead, the field and future research focus demands new research and open discussions related to the assessment of the progress and intervention on emerging new approaches, tools, and mechanisms. Such discussions should focus on the scope of the blue and circular economy, the full integration of related innovations and interventions in the transition of green and clean energy systems. They should also address how research about integrated development and solutions seeking can more actively include social-technological entrepreneurial input and feedback, with coordinated, local, national, and transnational partnerships. Peace-technology systems in the transition, with special proactive consideration needed for women, local communities, and industry workers amidst likely stranded asset devastations, need coordinated responses and interventions. A complete, new, and holistic view-building, caring, sharing, influencing, and responding is required. To focus on the displacement and then the transition focuses of other investments, new investment potentials, stranded assets, and investment opportunities need operationalization.

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