100% Renewable Energy: Concepts and Progresses

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Contributor: Joseph Akpan, Oludolapo Olanrewaju

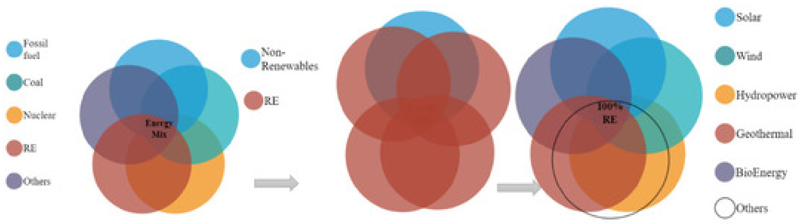
Some advanced countries' rapid population, economic growth, and energy consumption expansion contribute significantly to global CO_2 emissions. And while developed countries have achieved 100% universal access to electricity, mainly from non-renewable sources, many developing countries still lack it. This presents challenges and opportunities for achieving the United Nations' Sustainable Development Goals (SDGs) 7 and 13 of generating all energy from cleaner or low-carbon sources to reduce CO_2 emissions in all countries and combating climate change consequences. Renewable energies have been widely acknowledged to greatly advance this endeavour, resulting in many studies and about 30 countries already with over 70% of their national electricity mix from RE. It has birthed a new paradigm and an emerging field of 100% RE for all purposes, receiving much attention from academia and in public discourse.

Keywords: 100% renewable energy ; climate change ; sustainable development

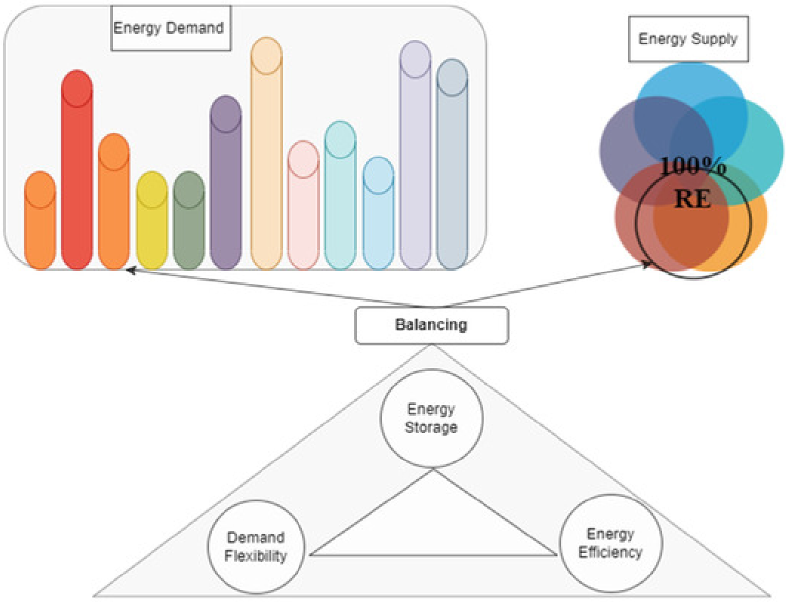
1. Concept Background

Alongside the main renewable energy sources generally in use, fuel cells, solid waste, and hydrogen energy technologies help meet rising worldwide electricity demand [1]. They increase the promising opinion that all energy usage can come from renewables. Energy storage integration, size, energy flow management, and optimisation can now be examined in wind turbines, solar panels, biomass gasifiers, and fuel cell power plants to add to the present discussion of the possibilities. The process of assessment can be done using a series of approaches and evaluation mechanisms, as well as concepts that suit the needs of the case selected for the studies, but with the overall goal of determining the best options that are available towards the transition into a complete net-zero-carbon-free environment, in this case, a society that completely uses renewables for all it purposes. As a result, interest in developing 100% clean energy systems has increased in recent years [2]. Many leading scholarly journals have published studies on the topic, with a bibliometric review done by S. Khalili and C. Breyer in [3] showing most of the studies that have been carried out.

The term "100% renewable energy" entails that all energy used comes from renewable sources that replenish continuously and have no or minimal environmental impact [3][4][5]. One of the foremost 100% RE global studies by Jacobson M. in [6] proposed the possibilities of using only hydro, wind, and solar for all purposes in 139 countries due to the abundance of natural resources already identified. By gradually replacing non-renewable energy sources such as coal, oil, and natural gas with renewable energy, societies can reduce global carbon footprints and other pollutants in the drive to mitigate the health and climate change consequences. The transition to 100% renewable energy represents a substantial transition in the global energy sector, seeking to substitute all fossil fuels and other non-renewables with sustainable alternatives, as depicted in **Figure 1**.



(a) Transitioning into 100% RE



(b) Energy chain balancing with 100% RE

Figure 1. The 100% RE concept.

The transition is increasingly noticeable as societies tackle climate change [7][8][9][10] and reduce reliance on finite resources. Renewable technologies, such as solar photovoltaics, wind turbines, hydroelectric systems, and geothermal power plants, have undergone notable advancements such as green energy storage solutions [11] and smart grid technologies [12] for the management of energy resources and systems [13][14][15][16][17], resulting in the integration of renewable sources into existing energy infrastructure and enhanced balancing of energy efficiency, demand flexibility, and RE intermittency availability issues necessary for a sustained 100% RE to occur.

Nevertheless, it is imperative to overcome obstacles and barriers to attain the full feasibility of 100% renewable energy.

2. History of 100% RE Studies

Supplementary Materials S1 and Table S1 (available at: https://www.mdpi.com/article/10.3390/en16186598/s1) presents an overview of the growth in 100% RE research by tracing it with the historical progress of sustainable energy development. It gives a clearer picture of how these studies have influenced policies directed at global energy transition.

As seen in Table S1, there has been a noticeable growth in 100% RE research and acknowledgement. It can be inferred from the changes in the global energy transition policies that have constantly seen energy as a major driver for sustainable development. The progress and growth in 100% RE also seem to provide guiding assurances to develop policies that drive this endeavour. The number of research papers describing 100% renewable energy (RE) systems is presented in **Figure 2**, according to a bibliometric study by S. Khalili and C. Breyer [3].

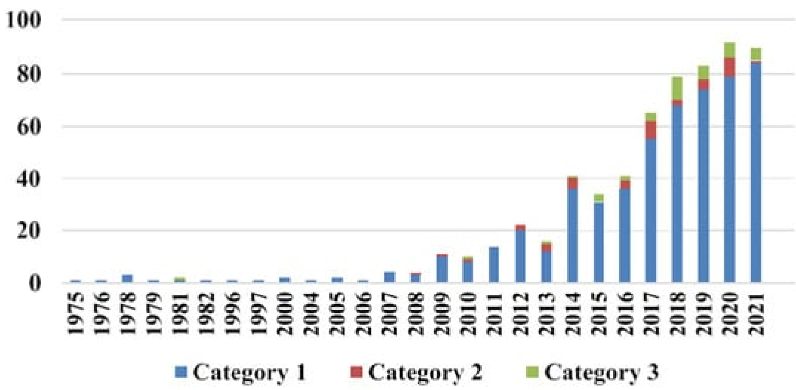


Figure 2. Trend of 100% RE studies according to S. Khalili and C. Breyer [3].

For the categories, S. Khalili and C. Breyer in [3] explain that a particular geographic area is considered in the first category. At the same time, a generic analysis without a specific region's citation falls under category two. The third category is devoted to reviews, which may or may not involve a particular geographic analysis. Since its inception in 1975, Category One has published at least one article annually, on average, according to statistics. Category two was first used in 1996 and has had regular articles since 2008 [3]. **Figure 3** shows the spread of 100% RE studies per country. In contrast, **Figure 4** shows the region distribution, inferring that some countries and regions have had more studies by more publications. In contrast, others have none, or only a few have carried.

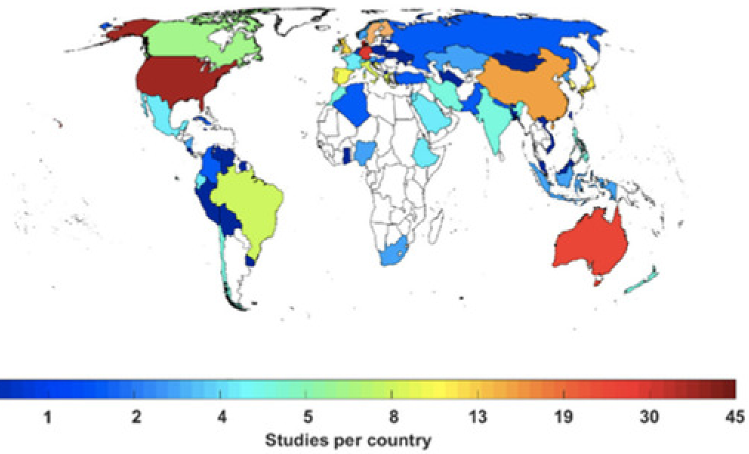


Figure 3. Distribution of 100% RE studies per country as carried out by S. Khalili and C. Breyer in [3].

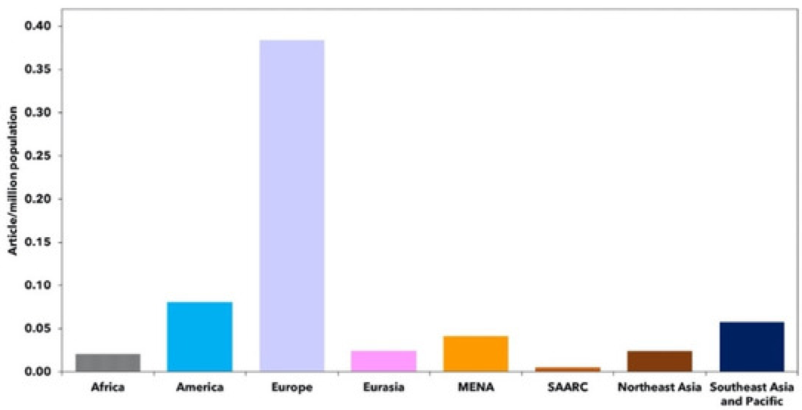


Figure 4. Distribution of 100% RE studies per region by A. S. Oyewo et al. in [18].

Regions such as Africa, Eurasia, SAARC, and North Asia have had very little attention to 100% RE research. Yet, they constitute some of the major CO_2 emitters globally [19], and with the envisaged highest population rate now and in the coming year, even beyond 2070, the population of several countries will either peak or already be on a decline [20][21]. It might infer that there will be an increasing energy demand in these regions/countries and increased CO_2 should energy resources in use not be made from renewables.

It is important to note that these 100% RE studies are very useful in providing pragmatic assurances to national/regional policymakers, even though it can be inferred from **Table 1** that the perception of the 100% RE possibilities at low cost across the globe has not yet been fully acknowledged. For instance, despite the publication of an initial national pathway in 2012 [22], outlining a goal of achieving 100% renewable energy (RE) by 2060, subsequent scenarios proposing similar objectives or near-complete reliance on RE in several countries [5][23][24][25][26][27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45] have had limited influence on the political discourse [46]. Achieving 100% renewable energy is only gaining traction; however, challenges persist in its integration into global energy transition policies. The complexity of the transition requires significant infrastructure modifications and may incur significant expenses. Additionally, some nations heavily rely on non-renewable energy sources, making a comprehensive and expeditious transition challenging. At the same time, many countries are deliberating on the strategies to achieve the nation's newly established objective of attaining 100% renewable energy for power generation, prompted by the recent acts of the Russian–Ukraine war. It can be seen that a few countries have already or are close to achieving that, as can be seen in **Figure 5** for 30 countries with nearly or 100% RE production from their national mix for RE % in national electricity mix and electricity access by % population and population data (2022), respectively. The latter is represented in **Figure 6**.

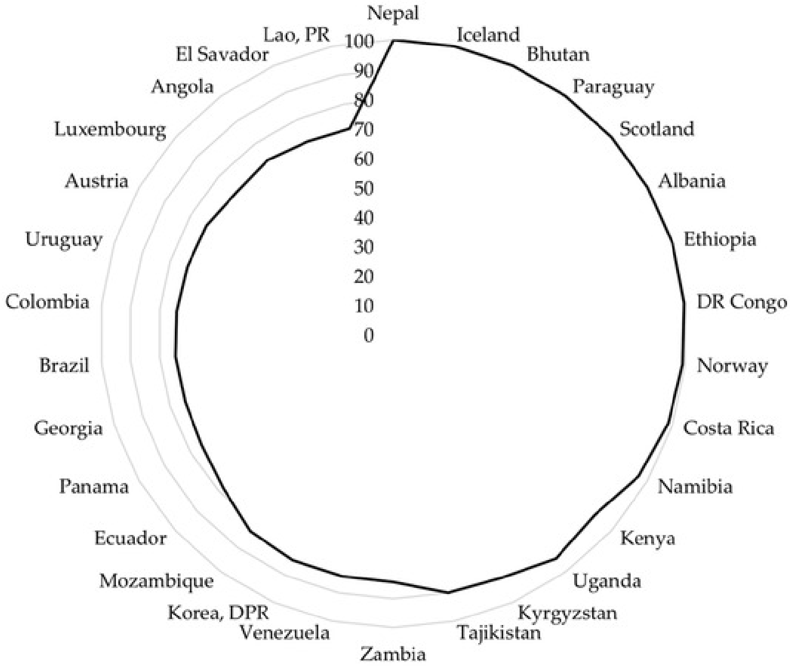


Figure 5. Countries with near or 100% RE in national electricity mix (70% and above) (data only for RE composition are only from solar, hydro, geothermal, and wind) data from [47][48].

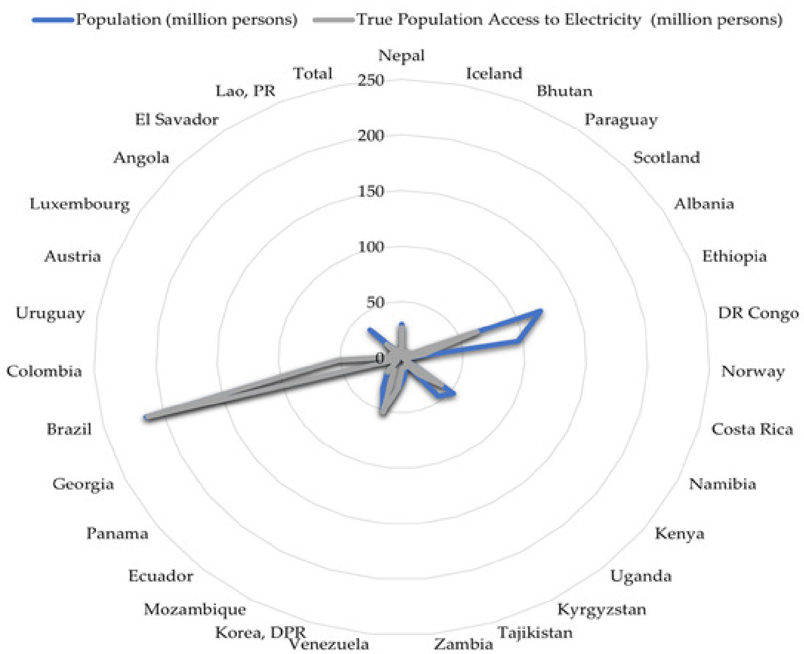


Figure 6. Population access to electricity in countries with near or 100% RE (70% and above) data from [47][48].

Table 1. Significant approaches helping some of the countries achieve near-or-complete RE successes.

Country	Highlights
Iceland, Kenya	***Geothermal utilisation*** **With abundant geothermal resources from volcanic activities, Iceland has harnessed geothermal energy for heating and electricity. It has enabled the country to achieve high levels of renewable energy utilisation.** ***New energy technologies integration*** **With ample renewable energy sources such as geothermal and hydroelectric, Iceland focuses on energy storage technologies such as pumped-hydro storage to store extra energy during high-generation and release during low-generation times with high demands.**

Country	Highlights
Norway	***Hydropower dominance*** **An abundance of hydropower resources generates a significant portion of its electricity.** ***Excess electricity for hydrogen production*** **They also utilise their excess renewable energy to produce hydrogen for other sectors such as transportation.** **Taking the global frontier in electric vehicle (EV) utilisation** **It is a global leader in EV adoption, reducing its dependency on fossil fuels for transportation.**
Iceland/Norway	***Regional collaboration and grid interconnections*** **Nordic countries such as Norway and Iceland, including Sweden, Denmark, and Finland, have collaborated on energy interconnections, enabling them to share excess renewable energy and balance out variations in generation.**
Costa Rica	***Local community initiatives*** **They have made significant strides toward renewable energy by involving local communities and focusing on decentralised energy production through solar, wind, and hydropower energy.** ***Hydropower and geothermal utilisation*** **They capitalised on their unique geography to harness hydropower and geothermal energy.**
Uruguay	***Supporting policy regulatory environment*** **Uruguay's success in renewable energy can be attributed to its stable regulatory environment, enabling the growth of wind and solar energy projects.**
Ethiopia, Zambia, DR. Congo, Uganda, Kyrgyzstan, Tajikistan, Venezuela, Korea DPR, Angola, Mozambique, Ecuador, Kenya, Columbia, Lao PR	***Hydropower dominance*** **Hydropower resources are abundant, helping to generate a significant portion of its electricity from this source.**
Scotland	***Wind power dominance and supporting policy regulatory environment*** **Scotland has made progress in using wind power in its grid. Offshore wind farms are a major cause for its renewable energy success. It has invested much in wind power and passed advantageous legislation to promote renewable energy.**

Countries such as Iceland have already reached their goal of 100% energy production, with about 87% of its primary energy from renewables. Conversely, countries such as Costa Rica (setting most consecutive days for 99% electricity from RE) and Uruguay (about 100% electricity from RE, mainly hydropower) are close to reaching the 100% RE target [47].

Despite the progress by several countries, as mentioned in **Figure 5**, challenges persist from key observations, some of which are that they are either nations with very little population or that the population do not have 100% access to electricity (highlighted in **Figure 6**) or there is an intermittent electricity supply. The countries that emit the highest amount of greenhouse gases through their energy processes are not in any way represented in either **Figure 5** or **Figure 6**, except for Ethiopia, which is among the top 10 CO_2 emitters in Africa. However, numerous nations and institutions have continuously driven to promote renewable energy adoption through policies, research and development, and advocacy.

With the EU RE target highlighted by the IEA report in [49], the Portuguese government has set a four-year goal of increasing renewable energy consumption from 60% in 2021 to 80% in 2026. Natural gas imports have switched from Russia to Nigeria and the United States. EDP, the largest power provider on the Iberian Peninsula, plans to switch to renewable energy by the decade's end. Due to these developments, Portugal will no longer depend on fossil fuels. Offshore wind power generation in the Netherlands is predicted to increase by a factor of two by the end of this decade, making it a leader in Europe's energy revolution. By 2050, the North Sea area hopes to have the capability to generate 150 gigawatts (GW) of power. The United States is still far from its goal of using only clean energy, but it may reap benefits from renewable energy such as wind and solar. By increasing its clean energy production, Denmark hopes to become a top exporter of renewable power. The EAG in Austria plans to invest EUR 1 billion annually and set aside special money for clean technology to achieve its goal of producing 100% electricity from renewable resources by 2030.

Research and policy implementation have led to technological advancements resulting in improved efficiency and cost-effectiveness of renewable energy solutions, making them increasingly appealing. At a critical juncture in the transition, ongoing scholarly inquiry, innovative thinking, and cooperative efforts can make significant strides towards a complete reliance on renewable energy. The discourse among the general populace is particularly intense regarding the non-homogenous global population growth changes in countries, increasing energy developments in developing countries, economic ramifications, and advantages associated with the transition process. The public and political discourse regarding the implications of the ratified Paris Agreement remained relatively limited until additional political pressure was exerted, notably through initiatives such as the Fridays for Future movement (FFF), supported by Scientists for Future [50]. In line with the FFF, additional scholarly investigations have been disseminated, which expand upon preceding research endeavours such as the regional collaborative studies as in [5][6][29][41][51] and studies in the major global emitters of CO_2 such as China [30][52][53], the USA [36][40], India [38], Japan [27][37], Iran [42], Germany [35][41][54], Indonesia [33], Canada [55][56], South Korea [57], and Saudi Arabia [44][45]. Similarly, the same studies have also been investigated in Africa's major emitters of CO_2 as in South Africa [31], Egypt [58], Algeria [59], and Nigeria [25][28][60].

3. Notable Approaches Facilitating near or 100% RE Successes in Countries

Several countries have made substantial progress towards near or 100% renewable energy (RE) through diverse measures. **Table 1** highlights how countries have used different approaches to reach near or 100% renewable energy. It involves a combination of policy frameworks and supportive regulations, technologies, market processes, renewable energy investment, energy storage integration, geographical advantages, investments in research and technology development, and strong political commitment and innovative solutions.

As renewable energy evolves, new approaches and successes may arise. It is also vital to highlight that countries' natural resources, technological capability, political context, and socio-economic aspects determine the optimal options. Reaching close or 100% renewable energy success requires a holistic approach that includes several of these tactics, and each country's strategy is unique, so what works for one may not work for another.

Other countries aiming towards 100% RE have used comparable and separate significant measures in addition to the support mechanisms described in **Table 1** above. These countries include Sweden, Portugal, Finland, Germany, Denmark, and New Zealand.

Sweden has worked hard to combine renewable energy and cutting-edge energy storage devices. This strategy helps ensure a stable supply of goods and services, especially when renewable energy sources are intermittent. With renewable energy growth, demand-side management and energy efficiency have been introduced in Portugal. The government has successfully used renewable energy with this comprehensive policy. Better grid integration of intermittent renewable sources is achievable with smart grids and demand response systems. After enhancing grid functioning, Portugal ran on renewable energy for 6 days in 2016.

Sweden's politicians have set ambitious renewable energy goals and funded research and development. Biofuels and wave energy converters have received significant R&D funding from Finland. Technological advances such as solar panels and wind turbine efficiency have reduced the cost of renewable energy generation. Energy-efficient technology and practises can help countries satisfy their energy needs with renewables by cutting demand.

Due to the legislative and regulatory structure that guarantees renewable energy producers' regular compensation for their power, usually through a long-term contract, RE's proportion of national electricity supplies has increased. Germany's "Energiewende" (energy transition) strategy pioneered feed-in tariffs (FiTs) and rapid deployment of renewable energy sources such as solar and wind, resulting in a high share of renewables in the energy mix and a decentralised energy system. A policy such as the Renewable Portfolio Standard/Renewable Energy Standard requires utilities to obtain a certain share of their power from renewables. These standards have helped Denmark and Sweden increase renewable energy utilisation. If the public is educated on the benefits of renewable technology, policy adjustments and widespread adoption may receive more support.

Carbon pricing and strict emission reduction objectives help renewable energy transition. New Zealand and Iceland are already doing this. Island states have used international aid and investment for solar and wind power to switch to renewable energy. Community and municipal initiatives have improved renewable energy consumption in certain places. Danish community-owned wind farms and German solar co-ops are examples.

Figure 7 presents the RE mix of the 30 countries with near or 100% RE in their national mix. It can be observed that a high share of hydropower appears to be dominant across countries, except for Scotland, followed by a higher share of wind in about 10 countries. The margin of contribution from solar is less than wind but higher than geothermal, which is mainly used in 4 out of the 30 countries. For the same **Figure 7**, researchers included the RE mix of four top global CO_2 (China, the USA, India, and the EU). Much difference that can be seen is the seeming proportionate share of solar, wind, and hydro in these locations, except for geothermal energy.

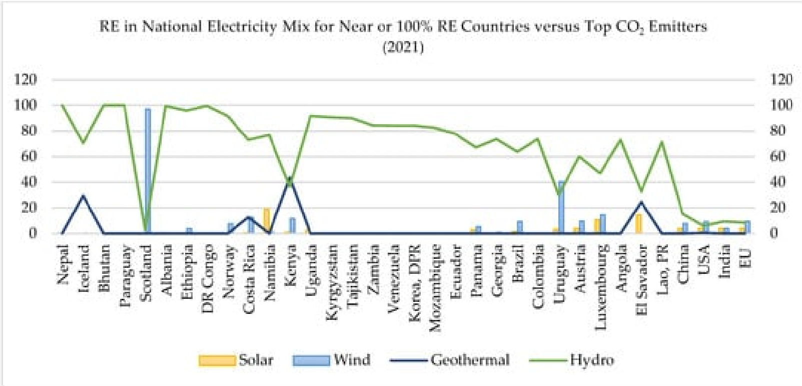


Figure 7. RE electricity mix in countries with high RE (70% and above), data from [47][48].

Table 2 highlights the categories of the renewable energy systems used in 100% RE studies of different countries (herein, researchers considered mainly the top global CO_2 emitters). **Table 3** also summarises the studies with the employed support mechanisms and evaluation approaches.

Table 2. Summary of RE considered in the top global emitters of CO_2 100% RE studies.

Country	RE Technology Covered in the 100% RE Studies							Target Year	Actual RE % in National Mix (2021)	Ref.
	Solar	Wind	Hydropower	Bioenergy	Geothermal	Others	Storage			
China (1)	-	-	-	-	-	G	-	N/D	28.91	[61]
China (2)	✔	✔	-	✔	-	-	-	N/D	28.91	[62]
China (3)	-	-	-	-	-	G	-	2030	28.91	[63]
USA (1)	-	-	-	-	-	S	-	2050	20.74	[40]
USA (2)	✔	✔	-	-	-	-	-	2040–2045	20.74	[36]
India (1)	-	-	✔	-	-	P2X	✔	2050	19.38	[38]
India (2)	-	-	-	-	-	-	-	N/D	19.38	[34]
Europe, Eurasia, and MENA regions	✔	✔	✔	✔	✔	G	-	2030	-	[64]

✔ refers to the inclusion of the particular RE technology in the study referenced G—grid, P2X—power to X, N/D—not defined. RE% data extracted from [48].

Table 3. Summary of key 100% renewable energy studies in top global CO_2 emitters.

Country	Summary of Studies	Support Mechanisms and Evaluation Approaches Used	Target Year for 100% RE	Ref.
China (1)	One of the earliest experimental projects into 100% RE. This study found China's large domestic RE sources promising, suggesting a 100% RE system analysis for China.	• Renewable resource assessment	N/D	[61]

Country	Summary of Studies	Support Mechanisms and Evaluation Approaches Used	Target Year for 100% RE	Ref.
China (2)	Design optimisation is suggested for improving 100% renewable energy systems in low-density areas. Integration and performance of 100% RES were investigated in 30 Chinese cities with payback times under six years, showing that future breakthroughs could shorten the payback period.	• Energy system analysis • Design optimisation • Economic assessment • New technology integration	N/D	[62]
China (3)	This Beijing study used two-phase energy system models to study Beijing's 2030 energy market reaching 100% RE. The reference scenario uses 72% more primary fuel than the RES scenario 2030.	• Reliability and optimisation • Environmental assessment	2030	[63]
USA (1)	100% renewable energy (RE) in US electric power networks were simulated. The least-cost buildout reaches 57% RE penetration in 2050 under base conditions. According to this base scenario, CO_2 abatement costs of 80%, 90%, 95%, and 100% RE are USD 25, USD 33, USD 40, and USD 61/ton, with system costs rising from USD 30 to USD 36/MWh at 95% (achieved in 2040) and USD 39/MWh at 100%.	• Energy system analysis • New technology integration • Economic assessment • Environmental assessment	2050	[40]
USA (2)	New Mexico, a US state with great solar and wind potential, is used in this study. An optimisation problem is proposed to determine the amount of renewable generation and energy storage needed to balance 100% of a utility's hourly electricity demand over several years at a desired cost.	• Energy system analysis • Renewable resource assessment • Design optimisation	2040–2045	[36]
India (1)	The model optimises the least cost combination of RE power plants and storage technologies to create a completely RE-based power system by 2050 based on 2015 installed power plant capacities, lives, and total energy demand. The levelised cost of electricity falls from EUR 58/MWhe to EUR 52/MWhe in 2050, enabling a 100% renewable energy system.	• Energy system analysis • Economic assessment	2050	[38]

Country	Summary of Studies	Support Mechanisms and Evaluation Approaches Used	Target Year for 100% RE	Ref.
India (2)	Delhi's 100% renewable energy system's technological and economic potential is examined in this study. Delhi may promote a regional energy transition by reducing primary energy by 40%, energy costs by 25%, greenhouse gas emissions, air pollution, and health costs.	• Energy system analysis • Renewable resource assessment • Economic assessment • Environmental assessment • Energy–environment–economy development	N/D	[34]
Europe, Eurasia, and MENA regions	This study explored the feasibility of a regional integrated renewable energy-based carbon-neutral power system using existing energy generation, storage, and transmission technologies throughout Europe, Eurasia, the Middle East, and North Africa. With a total LCOE of about EUR 42/MWh, the result showed that the integration could produce an economically viable and sustainable energy system less expensive than coal-CCS or brand-new nuclear options, helping improve stability flexibility and lessen the need for energy storage.	• Economic assessment • Energy system analysis • Renewable resource assessment	2030	[64]
Japan (1)	The research designed and evaluated a renewable energy system for Akita, Japan. Wind power potential is estimated at 35.2 TWh/year, greatly above the 11.3 TWh/year electricity need. Batteries must have 48.4 GWh to meet yearly demand for over 1000 h. Batteries produce hydrogen, cutting electricity costs by 57% and overall costs by 32%.	• Renewable resource assessment • Economic assessment • New technology integration	N/D	[37]
Japan (2)	Akita prefecture's 100% renewable energy system's biomass power cost and availability are examined in a second study [37]. Batteries met demand when other energy sources failed. The "no biomass", "supply shortage", and "baseload" situations were explored. Compared to "no biomass" electricity prices, "baseload" lowered them all.	• New technology integration • Economic assessment		[39]
Japan (3)	Japan's renewable energy future using a 40-year hourly energy balance model was examined. Under restrictions, differential evolution finds the lowest-cost solution. Japan has 14 times more solar and offshore wind resources than needed for 100% renewable electricity, and solar costs USD 86/megawatt-hour and wind USD 110. Japan can be power self-sufficient at competitive prices despite solar photovoltaic and offshore wind deployment constraints.	• Renewable resource assessment	2050	[27]

Country	Summary of Studies	Support Mechanisms and Evaluation Approaches Used	Target Year for 100% RE	Ref.
Germany (1)	**The study tried to clarify the possibility of Germany's 100% renewable energy transition in 2050. Consumption changes to Germany's heating, industrial, transport, and power sectors' energy systems were made using renewable resource potential, energy system costs, and primary energy supply. This change is feasible technically and economically, but it requires action to implement it efficiently and affordably.**	• Energy system analysis • Renewable resource assessment	**2050**	[35]
Germany (2)	**This research examines Germany's 100% renewable and sector-coupled energy system's viability. OSeEM-DE, an hourly optimisation tool, uses open energy modelling to study the German energy system. Volatile generators cost EUR 17.6–26.6 billion annually, and heat generators cost EUR 23.7–28.8 billion annually. Parametric scenarios affect investment capacities and component costs. The model recommends EUR 2.7–3.9 bn/yr for power and heat storage. According to sensitivity analysis, storage and grid expansion maximise system flexibility and lower investment costs.**	• Energy system analysis • Economic assessment • New technology integration • Energy financing • Reliability and optimisation	**N/D**	[54]
Iran	**The report forecasts the possibility of 100% renewable in Iran by 2050. Iranian electricity capacity demands from 2015 to 2050 were simulated hourly. It estimates that renewable energy (RE) will supply 100% of the world's power at EUR 41–47/MWhe by 2050, while EUR 32–40/MWhe is unfeasible unless the target time is extended.**	• Energy system analysis • Economic assessment • New technology integration	**2050**	[42]
Canada	**This article evaluates the infrastructure costs for transitioning to carbon neutrality for Canada's 10 provinces until 2060. It finds that most of Canada's provinces stand to benefit from a pan-Canadian energy transition by capturing fossil fuel savings.**	• Energy system analysis • Economic assessment • New technology integration • Environmental assessment	**2060**	[55]

Country	Summary of Studies	Support Mechanisms and Evaluation Approaches Used	Target Year for 100% RE	Ref.
South Korea	**The research develops a renewable energy forecasting model using Korean energy policy as a case study. It analyses four renewable energy scenarios using deep-learning-based models to anticipate power demand and generation. The lowest economic–environmental costs, steady electricity for demand, and 100% renewable energy come from an integrated gasification combined cycle, onshore and offshore wind farms, solar power plants, and fuel cell facilities.**	• Energy system analysis • Economic assessment • New technology integration • Environmental assessment • Policy and regulatory assessment	**Annual**	[57]
Indonesia	**This study investigates Indonesia's 2050 100% renewable energy power system transition. TIMES' least-cost optimisation analysed 27 power plants and 3 energy storage systems utilising 24 h time slices and hourly demand and supply operational data. It found that nuclear and solar PV utility scale will supply 16% and 70% of electricity output and requires USD 95 billion and 215 million tons of CO_2-eq. Nuclear-free power increases solar PV utility scale and battery capacity, land requirement, supply variability, and energy production cost by 9.7%.**	• Energy system analysis • Economic assessment • New technology integration • Environmental assessment • Energy–environment–economy development • Reliability and optimisation	**2050**	[33]
Saudi Arabia (1)	**This research indicates that by combining the electricity and growing desalination sectors, Saudi Arabia can achieve a 100% renewable energy power grid by 2050. By 2040, solar photovoltaics will account for 79% of power output, bringing the system's LCOE down to EUR 41/MWh. Since the integrated scenario uses less battery storage and power-to-gas plants, it lowers annual levelized costs by 1% to 3%.**	• Energy system analysis • Economic assessment • New technology integration	**2050**	[45]
Saudi Arabia (2)	**As a follow-up to the first Saudi Arabia 100% RE study in [45], the new study presents that a full transition to renewable energy can be possible if single-axis tracking PV and battery storage are the system's primary LCOE drivers. By 2050, if about 79% of all electricity will be produced by PV systems using only single-axis tracking, 441 of power could come from battery storage. Decreasing capital expenditures allows desalination facilities to adapt to changing conditions more quickly.**	• Energy system analysis • Economic assessment • New technology integration	**2040–2050**	[44]

Country	Summary of Studies	Support Mechanisms and Evaluation Approaches Used	Target Year for 100% RE	Ref.
South Africa (1)	**South Africa’s energy transition is simulated hourly until 2050. The findings imply solar PV and wind energy can replace coal in electricity. The Best Policy Scenario raises electricity-levelized costs somewhat, while the Current Policy Scenario raises them dramatically. The Best Policy Scenario has 25% lower electricity bills than the Current Policy Scenario without GHG emissions. The cheapest renewable energy system eliminates new coal and nuclear power plants and steadily reduces fossil fuel capacity.**	• Policy and regulatory assessment • Economic assessment • Environmental assessment	**2050**	[31]
Egypt (1)	**Egypt’s wind energy potential is understudied, so the author examined two 300 MW wind farms for roughness factor and wind power density. Kharga and Dakhla South wind farms can generate 1130 GWh annually with good capacity factors and low electricity costs, lower than the country’s needs. Further investment in these wind farms can help Egypt and Southern Europe completely reduce fossil fuel dependence by exporting.**	• Renewable resource assessment	**Annual**	[65]

N/D—not defined.

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