Energy and Built Environment xxx (xxxx) xxx

Contents lists available at ScienceDirect

Energy and Built Environment

journal homepage: http://www.keaipublishing.com/en/journals/energy-and-built-environment/

Review

A comprehensive review of international renewable energy growth

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ARTICLE INFO

Keywords:
Global renewable energy trends
Policy and technological assessment
Climate change and sustainability
Renewable energy adoption challenges
Future growth trajectories

ABSTRACT

The study meticulously reviews international growth trends in renewable energy from 2010 to 2022, across various global regions. Utilizing a comprehensive methodology, the study systematically analyzes academic articles, policy documents, and industry reports to offer a holistic understanding of the progression and distribution of renewable energy practices. It scrutinizes the principal drivers propelling the adoption of renewable resources and identifies the prevalent challenges that impede their maximization. The study critically evaluates existing policies, infrastructural advancements, and technological innovations, assessing their effectiveness across diverse socio-economic landscapes. It delves into the environmental and economic impacts of transitioning to renewable energy, underlining the intricate balance between sustainable development and ecological conservation. The role of renewable energy as a pivotal player in climate change mitigation is explored, providing a balanced perspective of its potential to transform energy systems while recognizing the complexities in its widespread adoption. Additionally, the study outlines potential future trajectories for renewable energy growth, offering invaluable insights for policymakers, researchers, and investors. It underscores the necessity of evidence-based decision-making to navigate the intricacies of renewable energy adoption and capitalize on its opportunities. In essence, the research encourages an active and informed approach, guiding the international community towards a more sustainable and environmentally responsible energy future.

1. Introduction

The escalation of renewable energy adoption on a global scale over recent decades represents a transformative shift in power generation, highlighting a concerted move toward more sustainable energy sources. This trend is substantiated by data from the International Renewable Energy Agency (IRENA), which indicates that renewable energy capacity has surged, doubling since 2010 a clear testament to its increasing viability and acceptance [1]. This phenomenal growth transcends a variety of renewable energy types, including the core sectors of solar, wind, hydro, and bioenergy. Each of these sectors has been a beneficiary of relentless advancements in technology, operational efficiency, and cost-competitiveness, making renewable energy an increasingly attractive option on the international stage.

Solar and wind energy have particularly stood out as exemplars of rapid progression. The cost of solar photovoltaic (PV) energy, for instance, has experienced a precipitous drop, attributed to technological breakthroughs and the advantages reaped from economies of scale [2]. This has positioned solar energy as a competitive contender against traditional fossil fuel-based power in numerous global regions. Similarly, wind energy, inclusive of both onshore and offshore varieties, has seen marked improvements in efficiency and cost-effectiveness [3]. These positive trends are anticipated to continue unabated, laying down a strong foundation for augmented penetration of renewable energy into the global energy mix. Hydropower, a seasoned and mature renewable energy form, continues to play a crucial role, especially in geographies blessed with plentiful water resources [4]. The sector has benefited from technological innovations and a deepened understanding of potential environmental impacts, leading to the development of more sustainable hydropower practices. Bioenergy, which includes biofuels and biomass, stands as an indispensable pillar in the renewable energy spectrum, catering to sectors that pose challenges for electrification such as avia-

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https://doi.org/10.1016/j.enbenv.2023.12.002
Received 4 September 2023; Received in revised form 22 December 2023; Accepted 22 December 2023
Available online xxx

Please cite this article as: Q. Hassan, S. Algburi, A.Z. Sameen et al., A comprehensive review of international renewable energy growth, Energy and Built Environment, https://doi.org/10.1016/j.enbenv.2023.12.002

tion, shipping, and heavy industries [5]. The growth of bioenergy has attracted considerable attention, aiming to balance its expansion with the imperative need to safeguard food security and prevent deforestation.

The global proliferation of renewable energy has been fueled by a combination of factors, spearheaded by proactive government policies. These include the implementation of renewable portfolio standards, the provision of feed-in tariffs, auction mechanisms, and the availability of tax credits [6]. Such policies, along with dedicated initiatives to foster research and development, have cultivated a fertile ground for the thriving of renewable energy sectors. Concurrently, the looming threat of climate change, coupled with an acute awareness of the detrimental impacts of fossil fuel consumption, has amplified the appeal of renewable energy [7]. Society increasing environmental consciousness has translated into a robust demand for cleaner, sustainable energy alternatives, marking a paradigm shift in energy preferences [8].

Yet, despite the commendable strides made in the renewable energy domain, the journey is not without its obstacles. There are pressing challenges that necessitate urgent attention and resolution to pave the way for seamless expansion of renewable energy. These challenges encompass issues related to grid integration, the intermittency of certain renewable energy sources, the imperative need for robust energy storage solutions, navigating regulatory landscapes, and cultivating public acceptance [9]. Nonetheless, with the momentum of ongoing technological advancements and a growing political resolve, there is a clear pathway to surmount these challenges. The international growth trajectory of renewable energy is poised to maintain its upward trend as the global community gravitates towards solutions that address climate change, bolster energy security, and stimulate sustainable economic growth. Renewable energy stands at the epicenter of this transformation, poised to play an indispensable role in shaping the future global energy landscape [10,11]. As we witness continuous evolution in technology, underpinned by supportive policies and societal endorsement, renewable energy is set to solidify its position as a major contributor to the global energy matrix, heralding a new era of sustainable and responsible energy use.

The research gap addressed stems from the existing literature fragmented and region-specific analyses of renewable energy trends, which lack a comprehensive and systematic global overview. Prior to this study, there was a significant void in terms of a holistic examination that integrates various renewable energy sources, including solar, wind, hydro, and bioenergy, across diverse global contexts. Most available research tended to focus on individual sectors or specific geographic areas, without providing an exhaustive analysis that considers the multifaceted drivers, challenges, and impacts of renewable energy adoption. Additionally, there was a shortage of studies that critically evaluated the effectiveness of existing policies, technological innovations, and infrastructural advancements in facilitating the transition to renewable energy across different socio-economic landscapes. By addressing these gaps, this research offers a unique contribution, providing a balanced and in-depth perspective of the international renewable energy scenario, its progress from 2010 to 2022, and the intricate interplay between sustainable development, ecological conservation, and energy transformation.

The research paper structured framework to provide a holistic analysis of the subject matter. It begins with a well-defined Introduction that sets the stage and highlights the significance of the study. The Methodology section elucidates the approach taken in conducting the research. Moving forward, the paper delves into the Global Energy Situation and Transition Strategies, offering a comprehensive overview of the current state of global energy and the strategies employed to transition towards renewable sources. The subsequent section, "Trend in renewable energy industry development," explores the evolution and progress of the renewable energy sector. The paper then scrutinizes the challenges and future outlook, shedding light on the obstacles faced and prospects for the future. This structured approach allows readers to navigate through the paper seamlessly, from the initial context setting to the in-depth analysis of the renewable energy growth landscape, ultimately providing a comprehensive understanding of the subject matter.

1.1. Study objective

The study objective is to conduct an exhaustive investigation into the expansion patterns and trajectories in the global renewable energy sector. It aims to undertake a detailed analysis of the rate of growth and adoption of diverse renewable energy forms across different geographical locations. In addition to explore the principal driving factors behind the international growth of renewable energy, encompassing technological advancements, policy support, environmental considerations, and economic factors. The study also aspires to pinpoint the major challenges encountered by the renewable energy industry in its course towards wider expansion and the strategies being implemented to navigate these challenges. Furthermore, an integral part of this study is to evaluate the influence of the expansion of renewable energy on climate change globally.

1.2. Study novelty

The study introduces a novel approach to understanding the global landscape of renewable energy, showcasing an unparalleled depth of analysis across a diverse array of energy sources and geographical contexts from 2010 to 2022. Unlike previous research, which often segmented renewable energy evaluations based on either specific sectors or localized regions, this study amalgamates insights from solar, wind, hydro, and bioenergy sectors, offering a holistic and comprehensive view. The methodology is meticulous, integrating systematic analyses of academic articles, policy documents, and industry reports to unravel the nuanced progression, distribution, and intricacies of renewable energy practices worldwide. This study breaks new ground by critically evaluating the efficacy of existing policies, technological advancements, and infrastructural developments, assessing their impacts across various socio-economic landscapes. It uniquely addresses the delicate balance between sustainable growth and ecological preservation, while also scrutinizing the role of renewable energy in climate change mitigation.

2. Methodology

The study has laid down a multi-faceted methodology to critically analyze the trends, drivers, and impacts of renewable energy growth from 2010 to 2022. A deeper look into how the theoretical foundations of the current study were laid and how the authors have utilized this information to curate their sampled dataset.

1. **Systematic literature review:**
   - **Theoretical Foundations**: The study leverages a vast array of literature, grounding its analysis in the robust theoretical underpinnings provided by previous research, industry reports, and global energy databases. The authors meticulously review peer-reviewed articles, publications from international energy organizations, and industry-specific reports.
   - **Application to Dataset**: The gleaned information offers a historical and contextual background, ensuring the dataset is comprehensive and rooted in established knowledge. This step is crucial for understanding the progression of renewable energy technologies, policy evolution, and recognizing the challenges that have historically impeded or facilitated growth.
2. **Quantitative analysis of growth rates and adoption patterns:**
   - Theoretical foundations: the quantitative dimension of the methodology is underpinned by statistical theories and econometric models, which are essential for analyzing growth rates and identifying patterns in renewable energy adoption.

- Application to dataset: by gathering data on renewable energy production, capacity, and consumption from trustworthy databases and statistical reports, the authors ensure their dataset is both robust and reliable. This data is then meticulously analyzed to extrapolate trends and derive insights on global renewable energy growth. Data sourced from peer-reviewed articles, industry reports, government publications, and documents from international energy organizations such as the International Energy Agency (IEA), IRENA and British Petroleum (BP) statistical reviews [11].

3. **Qualitative analysis of driving factors and challenges:**
   - Theoretical foundations: the qualitative analysis is grounded in social science theories and case study methodologies, providing a framework for understanding the complex socio-political and economic factors that influence renewable energy growth.
   - Application to dataset: through the examination of case studies from countries with notable renewable energy development, the authors are able to dissect the policies, initiatives, and challenges pertinent to each context. This approach enriches the dataset with qualitative insights, ensuring a holistic understanding of the drivers and barriers of renewable energy adoption.
4. **Evaluation of renewable energy impact on climate change:**
   - Theoretical foundations: the evaluation of renewable energy impact on climate change is anchored in environmental science theories and climate modeling. The authors draw upon existing research and data on greenhouse gas emissions and the potential of renewable energy to mitigate climate change [12].
   - Application to dataset: by analyzing data related to emissions and renewable energy role in reducing them, alongside reviewing studies on projected impacts of increased renewable energy adoption, the authors ensure their dataset is not only comprehensive but also directly relevant to one of the most pressing issues of our time climate change.

3. Global energy situation and transition strategies

3.1. Global energy situation

The global energy situation was characterized by a significant shift towards cleaner, renewable sources of energy and efforts to transition away from fossil fuels. This shift is primarily driven by two key factors:

Climate Change: The burning of fossil fuels for energy is a major contributor to greenhouse gas emissions, which drive global warming and climate change. As a result, there is an urgent global need to reduce these emissions, and transitioning to renewable energy is a key part of the solution.

Economic Viability: Technological advancements and economies of scale have significantly reduced the cost of renewable energy. In many parts of the world, it is now cheaper to generate electricity from new solar and wind projects than from new fossil fuel plants.

However, while the growth in renewable energy has been promising, as of 2022 (see Fig. 1), fossil fuels such as oil, natural gas, and coal still made up a significant portion of the world energy mix. This is due to a variety of factors, including existing infrastructure, policy and regulatory environments, and energy storage and grid challenges associated with the intermittent nature of some renewable energy sources [12]. In response to the COVID-19 pandemic, many countries have proposed "green recovery" plans to stimulate their economies and invest in renewable energy and energy efficiency. The long-term impact of these plans will be important to watch in the coming years.

The contemporary global energy landscape is markedly delineated by disparities in energy accessibility, creating a situation of pronounced energy inequality. A substantial portion of the population, particularly those residing in low- and middle-income nations, find themselves grappling with the unavailability of dependable and economically viable energy solutions. Energy is a critical driver for economic advancement and the enhancement of living conditions, making this lack of access a formidable barrier to progress. The dual challenge then arises of not only addressing this issue of energy poverty but also ensuring that the solutions put forth are aligned with the global momentum towards cleaner, renewable energy sources. The challenge is complex, requiring nuanced strategies and sustained efforts.

Fig. 2 delineates the trajectory of renewable capacity growth alongside projections extending up to the year 2027, showcasing scenarios under both standard and accelerated conditions of renewable energy adoption [13]. This visual representation serves as a poignant reminder of the potential that exists for rapid transformation in the energy sector, provided there is a concerted push towards accelerating renewable energy initiatives. It underscores the urgency of bridging the energy divide while also adhering to sustainable practices, highlighting the intricate balance that must be maintained between fostering economic development, improving living standards, and safeguarding environmental integrity. Addressing energy inequality in the context of a clean energy transition is a multifaceted challenge, requiring innovative solutions, strategic investments, and an unwavering commitment to equitable and sustainable progress.

The situation of global energy consumption in terms of fossil energy (coal, oil, and natural gas), nuclear energy, and renewable energy has experienced notable changes since 2015. It is important to note that the growth rates and specific energy mix can vary from country to country due to factors such as available resources, infrastructure, policy frameworks, and economic conditions. However, we can provide a general overview based on global trends.

Fossil Energy (Coal, Oil, and Natural Gas):

- **Coal:** The consumption of coal, a highly carbon-intensive fuel, has experienced a slowdown in growth since 2015. This is primarily due to environmental concerns, the increasing availability and competitiveness of renewable energy sources, and efforts to reduce greenhouse gas emissions. While coal still remains a significant energy source, especially in developing countries with abundant coal reserves, its share in the global energy mix has been gradually declining. According to the BP Statistical Review of World Energy 2021, global coal consumption declined by about 4.2 % in 2020 [14].
- **Oil:** Oil continues to be a major source of energy worldwide, particularly in the transportation sector. The growth rate of oil consumption has been relatively stable since 2015, driven by factors such as population growth, economic development, and rising demand for mobility. However, efforts to diversify energy sources and reduce dependence on oil have gained momentum, with a focus on promoting electric vehicles, alternative fuels, and efficiency improvements. However, the pandemic caused a significant drop in 2020, with a reduction of nearly 9 % according to the IEA [13].
- **Natural Gas:** Natural gas has experienced relatively strong growth in global energy consumption since 2015. It is considered a cleaner-burning fossil fuel compared to coal and oil, emitting fewer greenhouse gases and pollutants. Natural gas has been increasingly utilized for power generation, industrial processes, and residential heating. The growth rate of natural gas consumption has been driven by factors such as the abundance of natural gas reserves, its flexibility as a fuel, and efforts to transition away from more carbon-intensive options. According to the BP review, natural gas consumption grew by 2 % in 2019. However, in 2020, consumption was virtually flat (−0.2 %) due to the impacts of the pandemic [14].

Nuclear Energy: Nuclear energy, which generates electricity through controlled nuclear reactions, has seen moderate growth since 2015. While some countries have expanded their nuclear power capacities, others have reduced or phased out their reliance on nuclear energy due to safety concerns, high costs, and public sentiment. The growth rate of nuclear energy consumption has varied across regions, with some countries emphasizing nuclear power as a low-carbon option

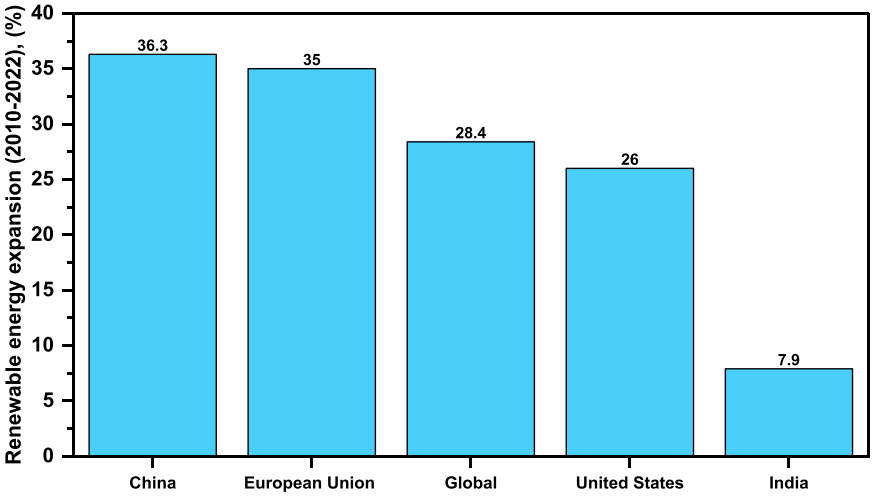

Fig. 1. The forecasts of renewable capacity expansion (2010–2022) [13].

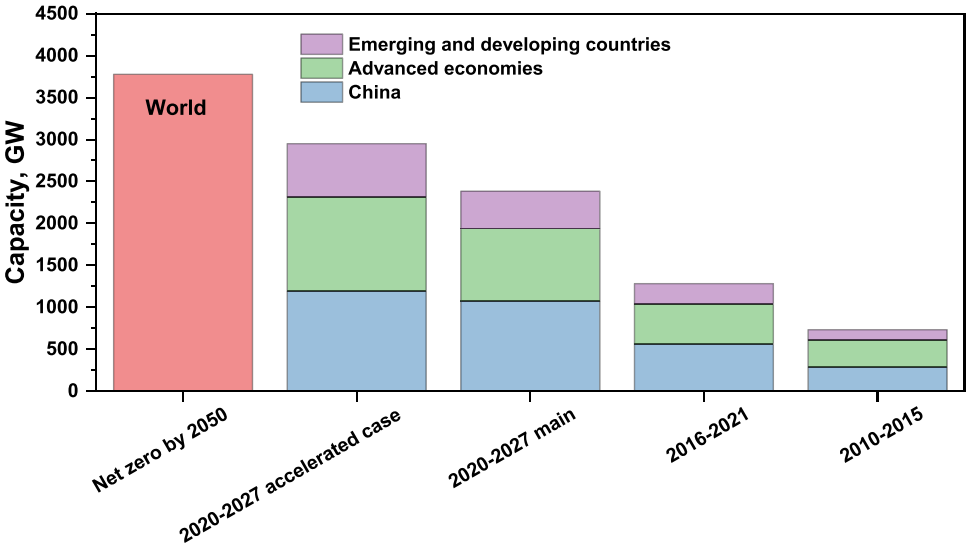

Fig. 2. The renewable capacity growth in the main and accelerated cases, 2010–2050 [13].

to meet their energy needs, while others focus on alternative sources. According to the World Nuclear Association, nuclear electricity generation increased by about 3.6 % from 2015 to 2019. However, growth was stunted by a 4 % decrease in 2020 due to lower electricity demand during the pandemic [16].

Renewable Energy: Renewable energy sources, including solar, wind, hydro, geothermal, and biomass, have experienced remarkable growth since 2015. The push for cleaner and more sustainable energy options, coupled with declining costs and advancements in technology, has propelled the deployment of renewable energy systems worldwide. The growth rates of renewable energy consumption have been particularly high, often outpacing other energy sources. Countries have set ambitious renewable energy targets, implemented supportive policies, and witness substantial investments in renewable projects. The growth rate varies for different renewable sources and regions, with solar and wind power exhibiting the highest growth rates in recent years. According to the IEA, renewable energy capacity grew by almost 50 % from 2015 to 2020. The growth in renewables, particularly wind and solar, was exceptionally strong in 2020, with an increase of nearly 10 % despite the pandemic [13].

The global energy structure has been gradually shifting towards a more diversified and sustainable mix, with varying growth rates for fossil energy, nuclear energy, and renewable energy. The pace of this transition depends on a range of factors specific to each country, including resource availability, technological advancements, policy frameworks, and public awareness. Table 1 show the energy consumption in Exajoules (EJ) based on oil, natural gas, coal, nuclear and renewables for the year 2021.

One key observation is the evident global dependence on fossil fuels, with oil and natural gas being prominent energy sources for numerous countries, highlighting a critical area for decarbonization efforts. Countries such as China and the US showcase a massive energy appetite, dominated by fossil fuels, yet also display significant renewable energy usage, indicating a transition in progress. However, the transition is not uniform, as seen in countries like Norway and New Zealand, where renewable energy comprises a substantial share of their energy mix, showcasing leadership in sustainable energy consumption. On the other hand, nations like the Russian Federation and Saudi Arabia exhibit a massive reliance on fossil fuels, with renewables playing a negligible role. This disparity underscores the uneven progress in the global renewable energy transition, affected by factors like economic capabilities, policy choices, and resource availability. This dataset is crucial for understanding international renewable energy trends, revealing countries making significant strides in integrating renewables into their energy portfolio and those lagging behind. The variance in renewable energy adoption highlights the need for targeted policies, technological support, and investments, particularly in regions heavily reliant on fossil fuels. Such data-driven insights can inform international cooperation and invest-

Table 1
Energy consumption in Exajoules (EJ) for the year 2021 for several regions [1,12,13].

Country	Oil	Natural Gas	Coal	Nuclear	Renewables
Algeria	1.13	0.44	0.19	0	0.56
Argentina	0.53	1.12	0.04	0.01	0.31
Australia	0.69	1.51	0.29	0	1.7
Austria	0.2	1	0.03	0	0.3
Belarus	0.38	0.2	0.15	0.01	0.2
Belgium	0.51	1.36	0.09	0.03	0.3
Brazil	2.9	1.19	0.29	0.01	1.42
Canada	2.91	4.39	0.24	0.08	2.54
Chile	0.16	0.53	0.03	0	0.21
China	12.16	8.47	4.95	0.3	2.61
Egypt	1.07	2.28	0.15	0	1.49
Finland	0.22	0.77	0.04	0.02	0.32
France	1.11	1.92	0.16	0.4	1.28
Germany	1.88	3.3	0.97	0.01	2.05
Greece	0.13	0.63	0.02	0	0.24
Hungary	0.2	0.68	0.06	0.01	0.24
India	7.47	3.11	0.6	0.04	2.82
Iran	3.31	1.4	0.34	0	1.45
Iraq	1.71	0.39	0.14	0	0.29
Italy	0.94	1.51	0.15	0	0.52
Japan	3.89	3.19	0.31	0.07	1.79
Jordan	0.12	0.14	0.01	0	0.15
Mexico	1.28	2.4	0.14	0	0.98
Morocco	0.16	0.44	0.06	0	0.22
Netherlands	0.47	1.17	0.05	0	0.42
New Zealand	0.08	0.25	0.01	0	0.12
Norway	0.08	1.35	0.01	0	1.4
Pakistan	0.59	1.17	0.06	0.01	0.37
Peru	0.21	0.5	0.05	0	0.24
Philippines	0.41	0.88	0.05	0	0.28
Poland	1.18	1.25	0.46	0.01	0.39
Portugal	0.15	0.44	0.02	0	0.17
Qatar	0.49	2.02	0.01	0	0.06
Romania	0.4	0.66	0.19	0.01	0.32
Russian Federation	5.55	19.83	0.95	0.2	2.45
Saudi Arabia	2.53	4.8	0.09	0	0.38
Singapore	0.23	0.31	0.01	0	0.03
South Africa	1	2.02	0.29	0.01	0.39
South Korea	2.62	2.7	0.63	0.1	1.28
Spain	0.87	1.4	0.15	0.02	1.07
Sweden	0.31	1.37	0.12	0.07	1.27
Switzerland	0.24	0.78	0.05	0.01	0.37
Thailand	1.14	1.66	0.2	0	0.77
Turkey	1.22	2.34	0.36	0	1.31
UAE	1.85	3.05	0.03	0	0.26
Ukraine	0.42	1.2	0.22	0.02	0.22
United Kingdom	1.67	3.11	0.28	0.02	1.68
US	21.86	9.89	9.24	0.8	6.67
Vietnam	0.29	1.07	0.16	0	0.49

ment strategies to bolster renewable energy adoption globally, fostering a sustainable and resilient global energy landscape.

3.2. China

China witnessed significant developments in its energy sector, characterized by changes in energy consumption and production, a shift towards renewable energy sources, and the implementation of policies to support sustainable energy development.

The country energy consumption increased at an average annual rate of around 5 %. In 2010, China total energy consumption was approximately 3.47 billion tonnes of standard coal equivalent, which rose to about 4.24 billion tonnes in 2022 [14,15]. In terms of energy production, China continued to be a major global player. The growth rate varied across different energy sources, with coal consumption growing at a slower pace, natural gas and petroleum consumption growing steadily, nuclear energy experiencing significant growth, and renewables showing the most remarkable progress. Fig. 3 show the energy consumption and production of China for the period from 2010 to 2022.

China energy consumption from renewables increased: renewable energy consumption witnessed an average annual growth rate of around 14 % [16]. By 2022, renewables accounted for a substantial share of China energy mix. However, coal remained the dominant energy source, although its growth rate was relatively low, at around 1 % annually [17]. Natural gas consumption grew by approximately 10 % annually, petroleum consumption by around 6 %, and nuclear energy consumption by roughly 15 % annually (see Fig. 4) [17].

Renewable energy production and capacity in China experienced remarkable growth: the country expanded its installed renewable energy capacity across various sources. By 2022, China total installed renewable energy capacity exceeded 900 GW, with wind power, solar energy, and hydropower leading the way [18]. The growth rate of renewable electricity production in China averaged around 20 % annually during this period, reaching over 2000 TWh by 2022 as shown in Fig. 5 [18].

China policies towards renewable energy growth and carbon neutrality by 2060: the country has demonstrated a strong commitment to renewable energy development and sustainability. Looking towards the future, the country has implemented policies and set ambitious targets to support renewable energy growth. China aims to achieve carbon neutrality by 2060, necessitating a significant increase in the share of renewables in the energy mix. The government has set targets to reach an installed capacity of 1200 GW for wind and solar power combined by 2030 [19]. In addition, China plans to enhance the role of other renewable energy sources, such as hydropower, biomass, and geothermal energy. To support these targets, China has implemented various policies and incentives. These include feed-in tariff (FIT) programs, subsidies, tax incentives, and the establishment of renewable energy quotas [20]. The government also encourages the development of offshore wind power and the adoption of energy storage technologies to address the intermittency challenges associated with renewable energy sources.

China witnessed significant developments in its energy sector, characterized by a shift towards renewable energy sources and efforts to reduce reliance on coal. The country experienced substantial growth in renewable energy consumption, production, and capacity, with wind power, solar energy, and hydropower leading the way. China future policy towards renewable energy support aims to further accelerate the transition to a sustainable and low-carbon energy system, with ambitious targets and supportive policies in place.

3.3. The united states

The United States (US) experienced significant changes in its energy landscape, characterized by shifts in energy consumption and production, a growing focus on renewable energy sources, and the implementation of policies to support sustainable energy development.

Energy consumption in the US showed a relatively stable trend, with an average annual growth rate of around 0.3 % [21]. In 2010, the country total energy consumption was approximately 97 quadrillion British thermal units (Btu), which increased to about 100 quadrillion Btu by 2021 [22]. On the production side, the US experienced a significant boost in energy production due to advancements in shale gas extraction techniques and renewable energy deployment. Fig. 6 show the US energy consumption and production for the period from 2010 to 2022 [23,24].

The country underwent a notable shift in its energy mix: consumption of petroleum and coal showed relatively stable growth rates, with petroleum consumption growing at an average rate of 0.3 % per year and coal consumption declining at an average rate of 4.6 % per year [25,26]. However, natural gas consumption experienced substantial growth, with an average annual growth rate of around 3.6 %. Nuclear energy consumption remained relatively stable. Renewable energy consumption increased at an average annual growth rate of approximately 5.8 %, showcasing the increasing importance of clean energy

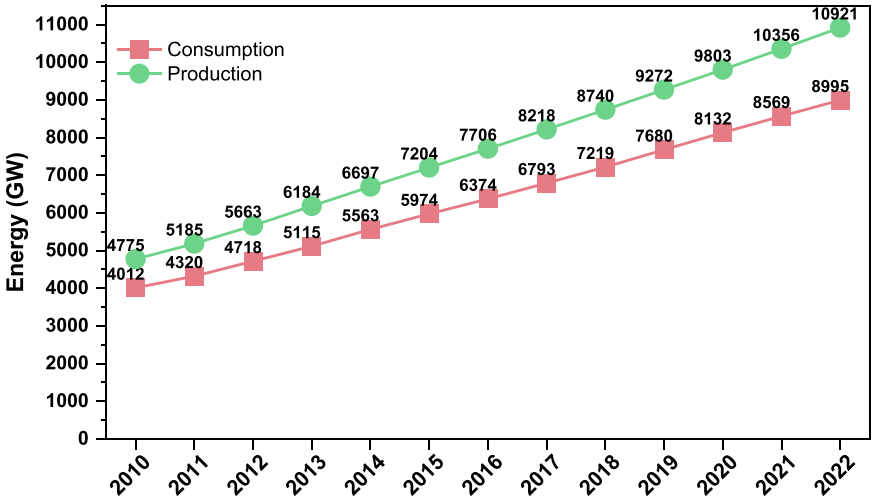

Fig. 3. The energy consumption and production of China (2010 - 2022) [14,15].

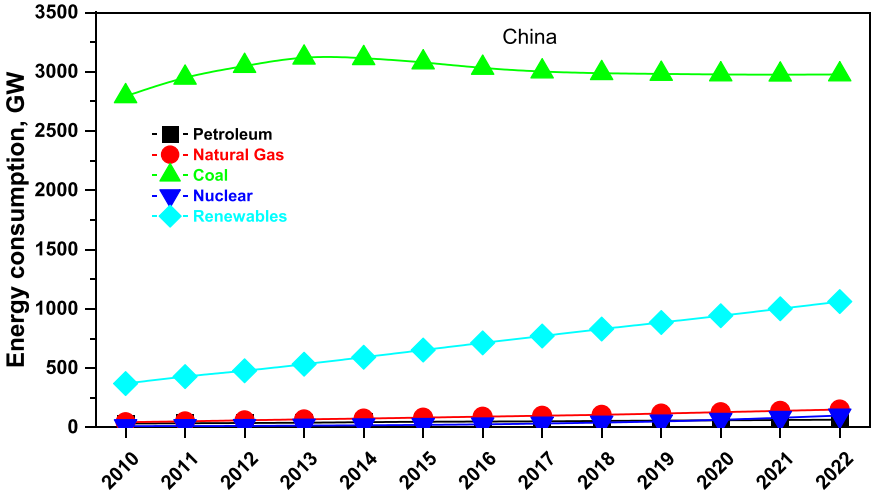

Fig. 4. The energy consumption by form of China (2010 - 2022) [15,17].

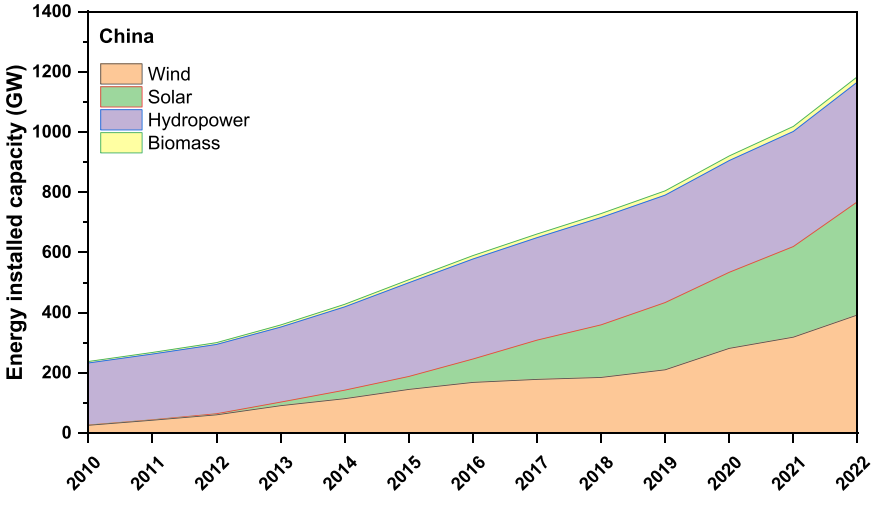

Fig. 5. The renewable energy installed capacity of China (2010 - 2022) [15,17].

sources in the US [27]. Fig. 7 show the energy consumption by form of the US.

Renewable energy production and capacity increases: the country expanded its installed renewable energy capacity across various sources. By 2021, the total installed renewable energy capacity exceeded 295 GW, with wind power and solar energy leading the way [26]. The growth rate of renewable electricity production averaged around 7.4 % annually, reaching over 870 terawatt-hours (TWh) by 2021 [26]. This increase was fueled by the significant expansion of both utility-scale and distributed renewable energy projects throughout the country. Fig. 8 show the US renewable energy capacity increases for the period of 2010–2022.

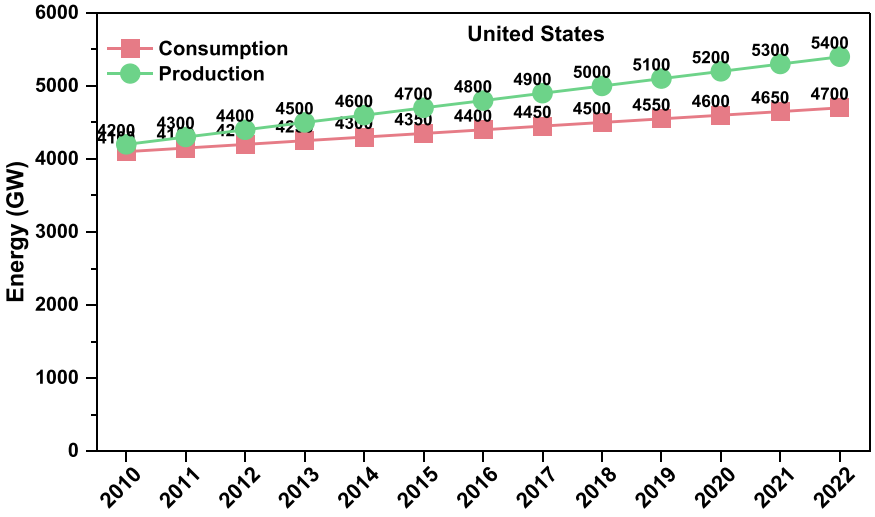

Fig. 6. The US energy consumption and production (2010 - 2022) [23,24].

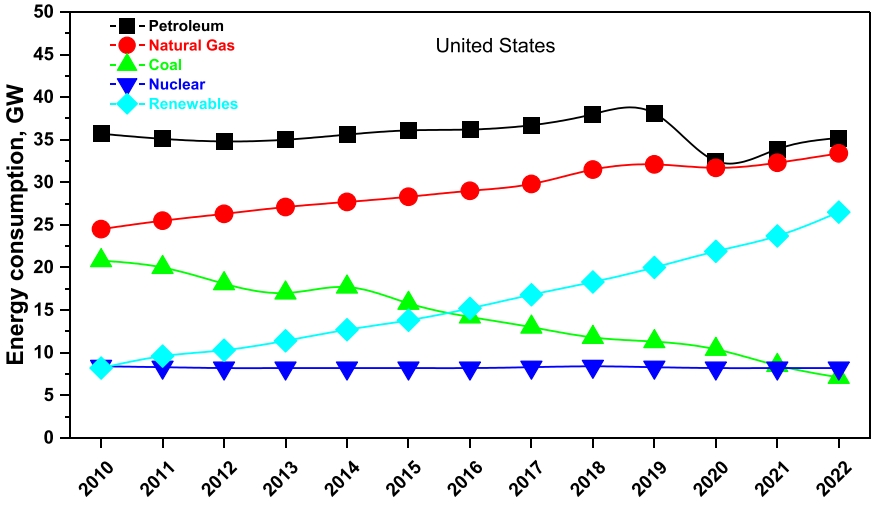

Fig. 7. The energy consumption by form of the US (2010 - 2022) [25].

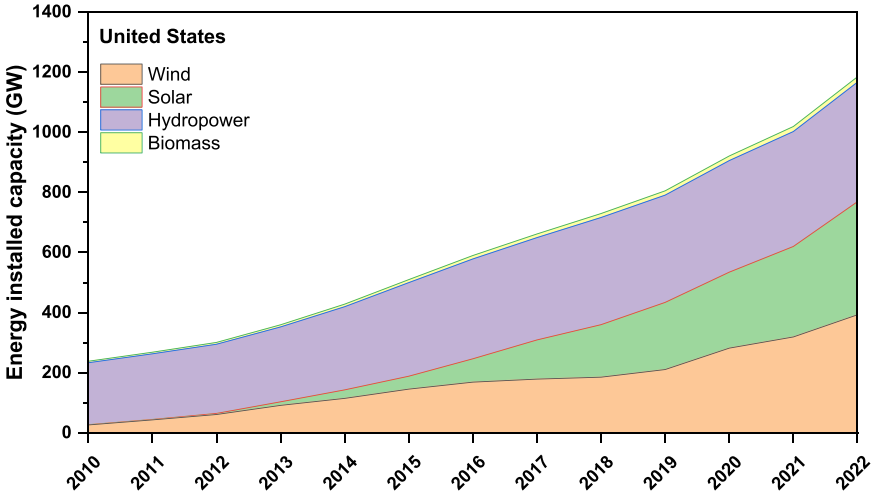

Fig. 8. The renewable energy installed capacity of the US (2010 - 2022) [26].

Renewable electricity production raised: wind and solar power have witnessed substantial growth as viable sources of renewable electricity. According to the EIA, net generation of renewable electricity increased from 534 billion kilowatt-hours in 2015 to 720 billion kilowatt-hours in 2021 [27]. Fig. 9 show the renewable electricy production of the US (2010 - 2022).

Current status of renewable energy development: the US continues to expand its renewable energy capacity. The country has set ambitious targets for renewable energy deployment and carbon reduction. The current status of renewable energy development can be assessed by referring to recent reports and studies from organizations like the EIA, the National Renewable Energy Laboratory (NREL), and industry asso-

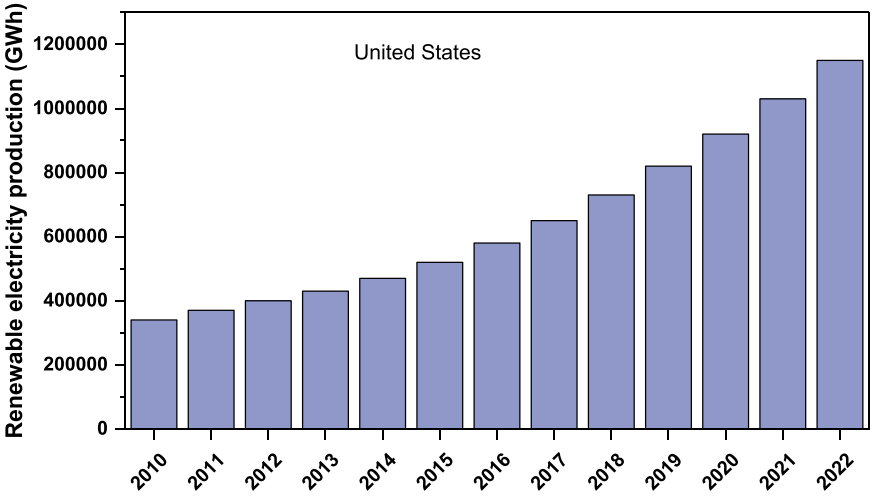

Fig. 9. The renewable electricy production of the US (2010 - 2022) [27].

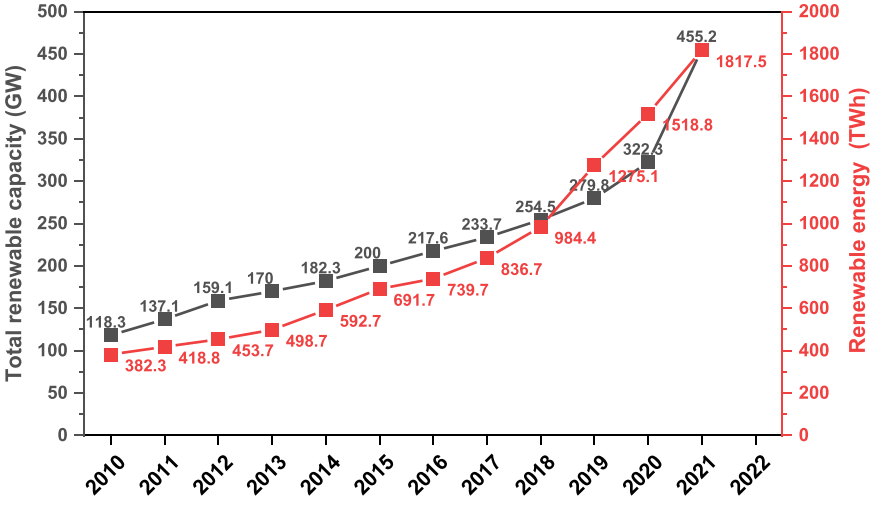

Fig. 10. The US status of renewable of the (2010 - 2022) [28].

ciations such as the American Wind Energy Association (AWEA) and the Solar Energy Industries Association (SEIA). Renewable energy accounted for approximately 20 % of total U.S. electricity generation in 2020, with wind and solar making up the majority of this share [28]. The growth trends of these renewable sources suggest that their contribution to the energy mix will continue to increase in the coming years Fig. 10 show the country status of renewable energy.

The US policies for expediting the development of renewable energy specifically for 2050: the country has outlined policies and targets to further support renewable energy development and transition towards a cleaner energy system. The Biden administration has set a goal of achieving a carbon-free power sector by 2035 and net-zero emissions across the economy by 2050 [29,30]. To support these goals, the U.S. government has proposed initiatives such as the Clean Energy Standard and the investment in clean energy research, development, and deployment. The emphasis is on increasing renewable energy capacity, improving energy efficiency, promoting electric vehicle adoption, and investing in grid modernization and energy storage technologies.

3.4. European union

The European Union (EU) experienced significant changes in its energy landscape, with a particular emphasis on transitioning towards renewable energy sources and reducing greenhouse gas emissions. During this period, there were notable developments in energy consumption, production, growth rates, and capacity in various sectors.

Energy consumption and production: within the EU exhibited a gradual decline between 2010 and 2022, primarily due to increased energy efficiency measures and a shift towards sustainable practices [31]. The growth rate of energy consumption during this period ranged between −1 % and 1 % as showed in Fig. 11.

Sources of energy consumption: petroleum consumption in the EU experienced a gradual decline during the period, reflecting efforts to reduce dependence on fossil fuels. The growth rate of petroleum consumption ranged between −2 % and −4 %. Natural gas consumption remained relatively stable, with a growth rate ranging from 0 % to 2 % [31]. Coal consumption witnessed a significant decrease, indicating a shift towards cleaner energy sources. The growth rate of coal consumption ranged declined between −5 % and −8 %. Nuclear energy consumption remained relatively constant, with a growth declined rate ranging from −1 % to 1 %. Renewable energy consumption showed substantial growth, driven by supportive policies and investments. The growth rate of renewable energy consumption ranged between 6 % and 10 % as presented in Fig. 12.

Renewable energy production: there was a notable increase in renewable energy sources, while the production of fossil fuels remained relatively stable or decreased. The growth rate of energy production from renewables ranged between 4 % and 7 %, whereas fossil fuel production exhibited a growth rate of −1 % to 2 % [32]. The capacity for different energy sources in 2022 was as follows: petroleum by about

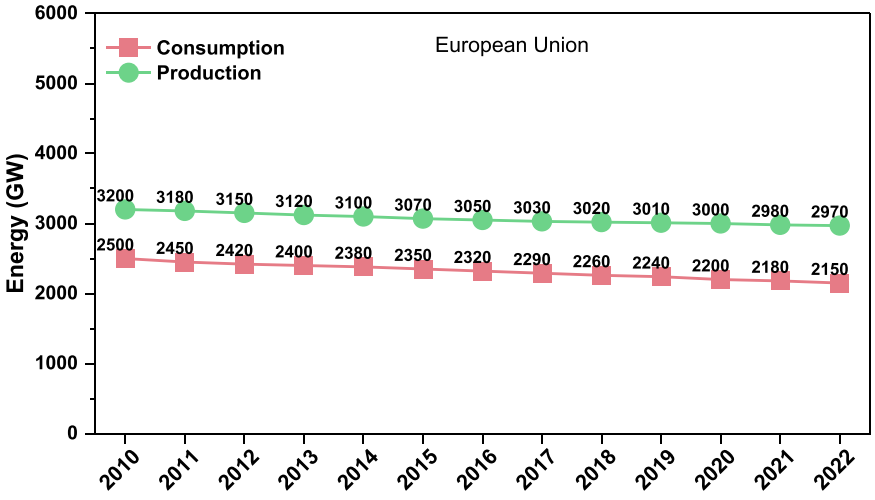

Fig. 11. The EU energy consumption and production (2010 - 2022) [31].

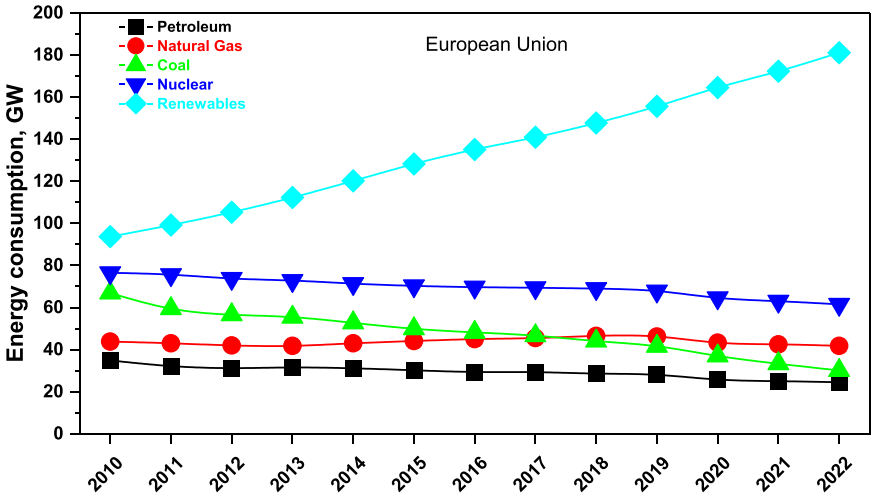

Fig. 12. The energy consumption by form of the EU (2010 - 2022) [31,31].

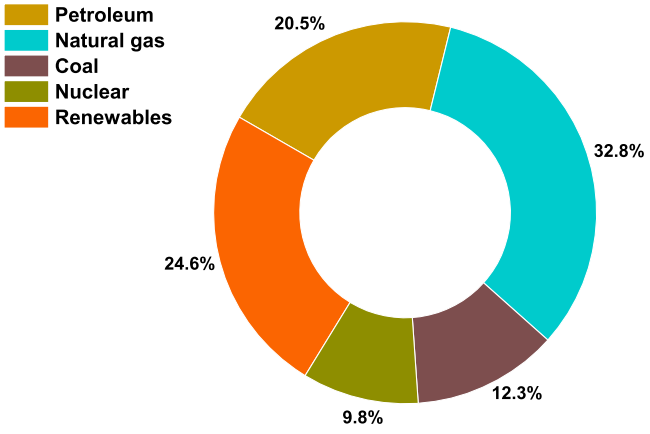

Fig. 13. The capacity for different energy sources of EU for 2022 [32].

250 GW, natural gas by about 400 GW, coal by about 150 GW, nuclear by about 120 GW, and renewables by about 300 GW, as presented in Fig. 13.

Renewable electricity production also witnessed substantial growth in the EU during this period, primarily driven by investments in wind and solar power. The growth rate of renewable electricity production ranged between 5 % and 8 %. The capacity of renewable electricity generation, mainly from wind and solar, reached a cumulative total of 1030 TWh in 2022 as presented in Fig. 14 [33].

Increased installed renewable energy capacity: the installed capacity of renewable energy sources, encompassing wind, solar, biomass, and hydroelectric power, reached 300 GW by 2022 as showed in Fig. 15 [34,35]. This marked capacity expansion resulted from increased investments and supportive policies promoting renewable energy development.

Future policy towards renewable energy support: looking ahead to 2050, the EU is committed to further strengthening its support for renewable energy. The future policy landscape includes an increased share of renewable energy in the overall energy mix, enhanced energy efficiency measures, and a substantial reduction in greenhouse gas emissions. The EU has set a target of achieving climate neutrality by 2040, necessitating a significant increase in renewable energy production and a gradual phasing out of fossil fuel-based energy sources [37]. To facilitate this transition, policies such as feed-in tariffs, renewable energy subsidies, and financial incentives will be implemented to encourage investment in renewable energy projects. Furthermore, the EU will focus on improving interconnections between member states, promoting energy storage technologies, and investing in research and development to advance renewable energy technologies. By 2050, it is envisioned that the EU will possess a highly diversified energy mix, with a substantial share of renewable energy sources such as wind, solar, biomass, and hydroelectric power [38].

The EU has made significant progress in renewable energy consumption, production, and capacity in the last decade. The EU has seen a de-

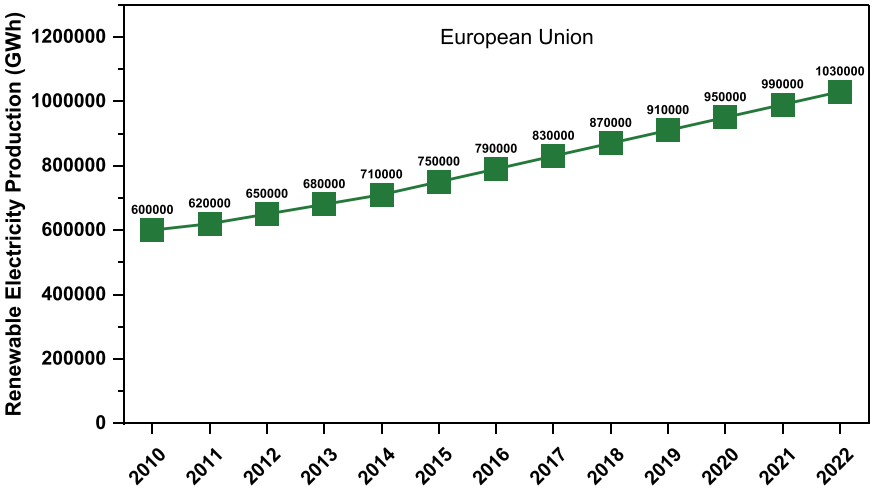

Fig. 14. The renewable electricy production of the EU (2010 - 2022) [33].

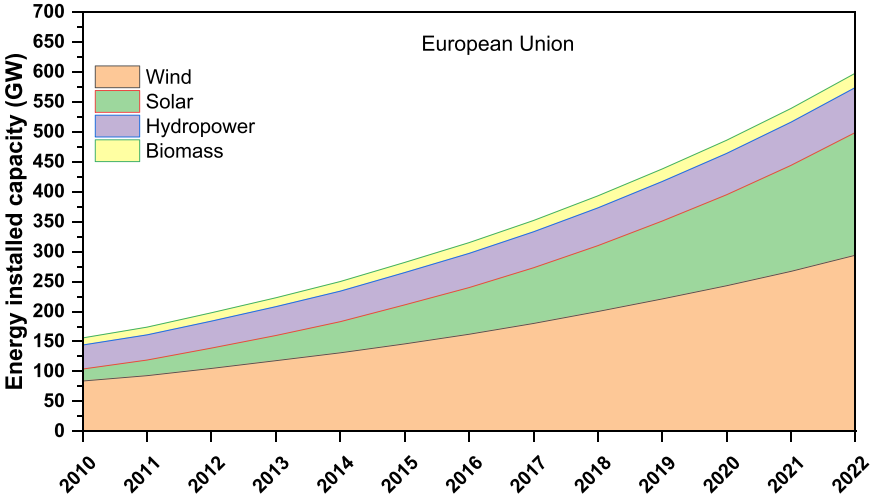

Fig. 15. The renewable energy installed capacity of the EU (2010 - 2022) [35,36].

cline in fossil fuel consumption, stable nuclear energy consumption, and substantial growth in renewable energy consumption and production. Wind and solar power have played a significant role in the EU renewable energy transition (see Fig. 15). Looking ahead, the EU is committed to further supporting renewable energy through ambitious targets, policies, and incentives as part of its long-term strategy to achieve climate neutrality by 2050.

3.5. Brazil

Brazil has a diverse energy mix that includes various sources such as fossil fuels, hydroelectric power, biomass, wind energy, solar energy, and a small contribution from nuclear power. Energy production and consumption in Brazil are influenced by the country geographic and natural resource characteristics, as well as its commitment to renewable energy development.

Energy consumption and production: Brazil experienced a steady increase in energy consumption during this period. According to data from the Brazilian Energy Balance, energy consumption in Brazil grew by approximately 33 % between 2010 and 2021 (see Fig. 16) [39]. This growth can be attributed to factors such as population growth, economic development, and improved energy access. Brazil has a diverse energy mix. Energy production increased by around 24 % during this period, driven by the expansion of renewable energy sources [40].

Brazil energy consumption is characterized by a significant reliance on renewable energy sources. Petroleum consumption saw modest growth, and the country has made efforts to reduce dependence on petroleum through the promotion of alternative fuels, such as ethanol derived from sugarcane. Natural gas consumption also increased steadily as Brazil diversified its energy matrix. Coal consumption remained relatively low compared to other sources, while nuclear energy accounted for a small fraction of the energy consumption [42]. Renewables played a crucial role, particularly hydroelectric power and bioenergy derived from sugarcane as showed in Fig. 17.

Renewable electricity production: Brazil demonstrated remarkable progress in wind, solar, hydropower, and biomass energy generation were presented in Fig. 18. Hydropower has long been a prominent renewable energy source in Brazil, and it continued to play a crucial role in the country electricity production. With its abundance of rivers and favorable geography, Brazil generated a substantial amount of hydropower, reaching 378,261 GWh in 2010 and steadily increasing to 579,305 GWh by 2022. Solar energy witnessed remarkable growth during this period, driven by declining costs and government incentives. Brazil tapped into its solar potential, increasing solar electricity production from 5496 GWh in 2010 to an impressive 8269,860 GWh in 2022 [44]. This surge can be attributed to the country efforts to promote solar installations and develop large-scale solar projects. Wind power also experienced a significant expansion as Brazil focused on diversifying its renewable energy portfolio. The country harnessed its windy regions, particularly in the northeast, and increased wind energy generation from 7991 GWh in 2010 to 244,613 GWh in 2022. This growth was propelled by substantial investments in wind farms

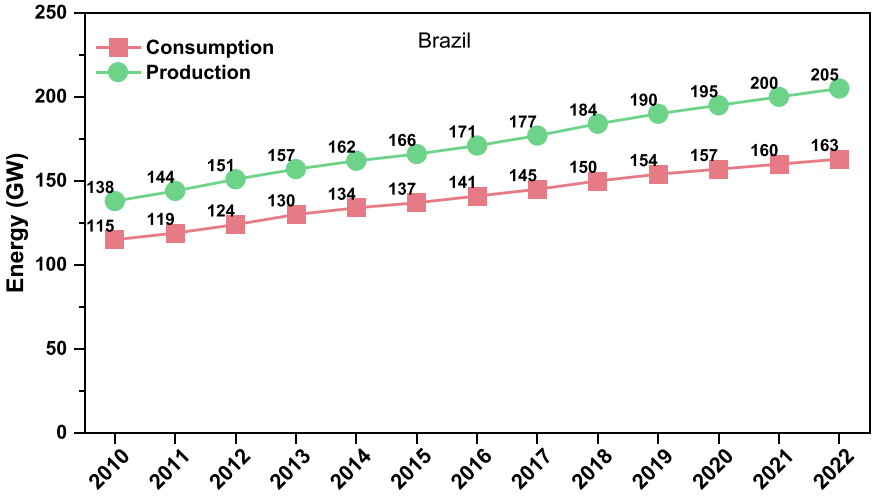

Fig. 16. Brazil energy consumption and production (2010 - 2022) [41].

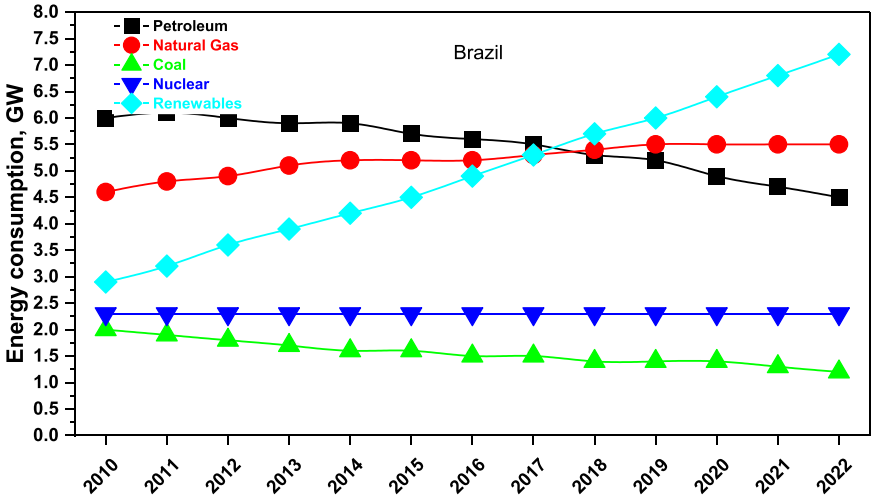

Fig. 17. The energy consumption by form of Brazil (2010 - 2022) [42,43].

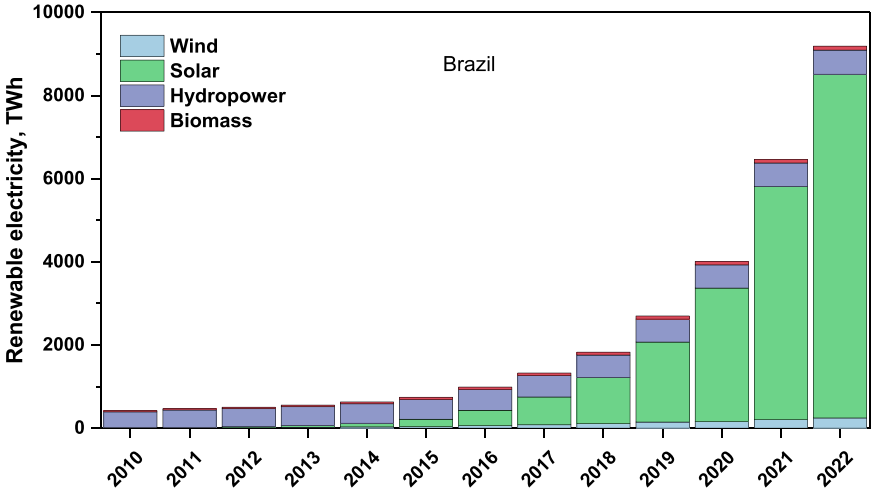

Fig. 18. The renewable electricy production of Brazil (2010 - 2022) [44,45].

and technological advancements in wind turbine technology. Biomass energy, derived from organic waste, agricultural byproducts, and dedicated energy crops, also contributed to Brazil renewable electricity production. Biomass generation steadily increased from 28,405 GWh in 2010 to 96,340 GWh in 2022 [45]. The country utilized biomass resources efficiently to generate electricity and reduce greenhouse gas emissions.

Installed renewable energy capacity: the country made remarkable progress in harnessing a diverse range of renewable energy technologies, including wind, solar, hydropower, and biomass as presented in Fig. 19. Hydropower is continued to play a vital role during this period. In 2010, Brazil had an installed hydropower capacity of 75.09 GW which increased to 107.07 GW by 2022 [46]. This growth was facilitated by the construction of large-scale hydropower plants, tapping into the

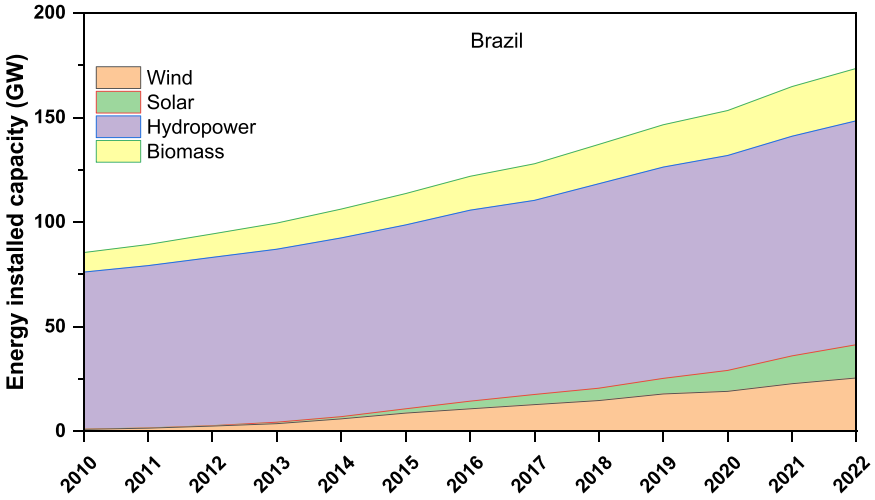

Fig. 19. The renewable energy installed capacity of the Brazil (2010 - 2022) [46–49].

country abundant water resources. The installed wind capacity skyrocketed from 0.93 GW in 2010 to 25.48 GW in 2022 [47]. This remarkable expansion was driven by favorable wind conditions in certain regions, supportive government policies, and investments in wind farm installations. The installed solar capacity increased from a modest 0.06 GW in 2010 to 15.92 GW in 2022 [48]. This surge can be attributed to declining costs of solar technology, supportive government initiatives, and the implementation of large-scale solar projects across the country. The installed biomass capacity rose from 9.35 GW in 2010 to 25.04 GW in 2022 [49]. Brazil effectively utilized its vast agricultural resources to generate electricity from biomass, further diversifying its renewable energy mix. The remarkable growth in Brazil installed renewable energy capacity over this period reflects the country commitment to sustainable development and reducing greenhouse gas emissions. The expansion of renewable energy technologies not only contributes to energy security but also positions Brazil as a global leader in clean energy transition. The combination of wind, solar, hydropower, and biomass has paved the way for a more sustainable and environmentally friendly energy future for Brazil.

Future policy towards renewable energy support: the country has set ambitious targets to increase the share of renewable energy in its energy mix and reduce greenhouse gas emissions. One significant policy framework in Brazil is the National Renewable Energy Plan (PNE 2050) [50]. The PNE 2050 aims to guide the country energy development and transition towards a more sustainable future. It sets long-term goals, including the expansion of renewable energy sources, energy efficiency improvements, and the reduction of greenhouse gas emissions. Additionally, Brazil has implemented specific policies and incentives to promote renewable energy deployment. These include auctions for the procurement of renewable energy projects, such as wind and solar, which provide long-term contracts and financial support to project developers. These auctions have been successful in attracting private investments and driving the growth of renewable energy capacity in the country. Another important policy instrument is the RenovaBio program, which aims to increase the use of biofuels in Brazil transportation sector. RenovaBio establishes targets for the decarbonization of the transportation sector, promoting the production and consumption of biofuels, particularly ethanol and biodiesel [51]. These efforts are essential for the country to achieve its sustainable development goals, mitigate climate change, and ensure a resilient and clean energy future for Brazil.

3.6. India

India experienced significant developments in its energy sector, characterized by changes in energy consumption and production, growth rates, and capacity.

Energy consumption and production: India energy consumption showed a consistent upward trend from 2010 to 2022. The consumption of petroleum grew at an average annual rate of around 4.2 %, reaching 229 million metric tons in 2022 [52]. Natural gas consumption also witnessed steady growth, with an average yearly increase of approximately 4.8 %, reaching 67 billion cubic meters in 2022 [53]. Coal consumption, being a dominant energy source, experienced an average annual growth rate of 4.4 %, reaching 1165 million metric tons in 2022. Nuclear energy consumption showed relatively modest growth, with an average yearly increase of about 1.7 %, reaching 32.4 billion kilowatt-hours (kWh) in 2022. On the other hand, renewable energy consumption experienced significant progress, growing at an average annual rate of 16.7 %, reaching 205 billion kWh in 2022 [54]. Fig. 20 show the India energy consumption and production (2010 - 2022).

Energy production, petroleum production remained relatively stable during this period. Natural gas production witnessed a slight decline, reaching 31 billion cubic meters in 2022 [55]. Coal production, however, showed substantial growth, with an average annual growth rate of around 4.5 %, reaching 746 million metric tons in 2022. Nuclear energy production remained consistent, with 36.4 billion kWh generated in 2022. The most notable progress was observed in renewable energy production, which grew at an average rate of approximately 19.3 % per year, reaching 189 billion kWh in 2022 as showed in Fig. 21.

Renewable energy capacity: India has been actively promoting renewable energy sources as part of its energy transition. The installed renewable energy capacity in the country significant growth during the period from 2010 to 2022 (see Fig. 22). The total installed renewable energy capacity increased from around 25 GW in 2010 to over 100 GW by 2022, representing a remarkable growth rate of about 300 %. [56] This expansion was mainly driven by the installation of solar and wind power projects across the country.

Renewable electricity production: renewable electricity production also experienced substantial growth in India. The growth rate for renewable electricity generation averaged approximately 18.2 % per year, indicating the country commitment to clean energy. By 2022, India renewable electricity capacity reached around 530 TWh, a significant increase from about 175 TWh in 2010 (see Fig. 23).

Policy towards future energy: India has outlined ambitious plans and policies to further support renewable energy development until 2040. The country aims to achieve a total renewable energy capacity of 450 GW by 2030, which includes 280 GW of solar power, 140 GW of wind power, and 30 GW of other renewable sources [58]. These targets reflect India commitment to the Paris Agreement and its sustainable development goals. The Indian government has implemented various measures to facilitate this growth, including financial incentives, tax benefits, and streamlined approval processes for renewable energy projects.

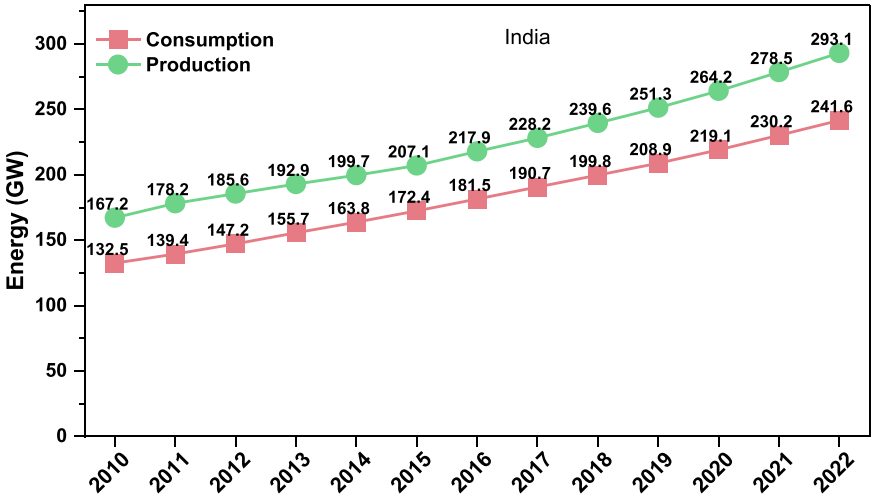

Fig. 20. India energy consumption and production (2010 - 2022) [53,54].

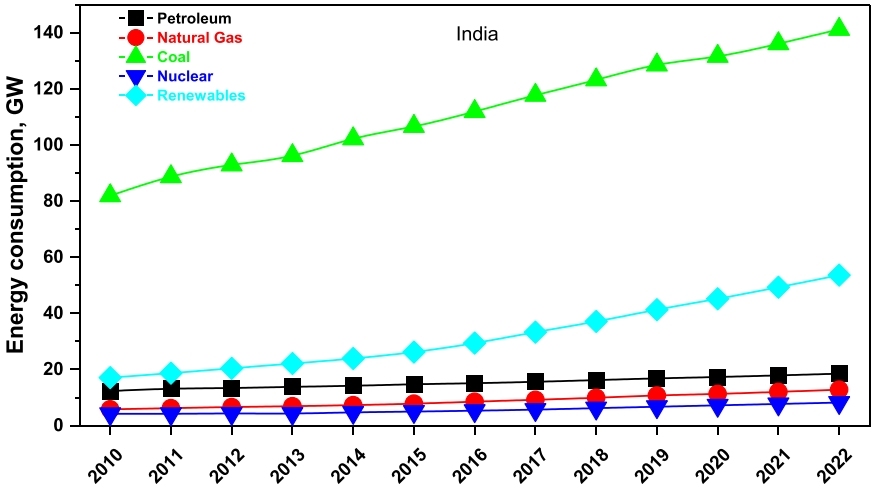

Fig. 21. The energy consumption by form of India (2010 - 2022) [55,56].

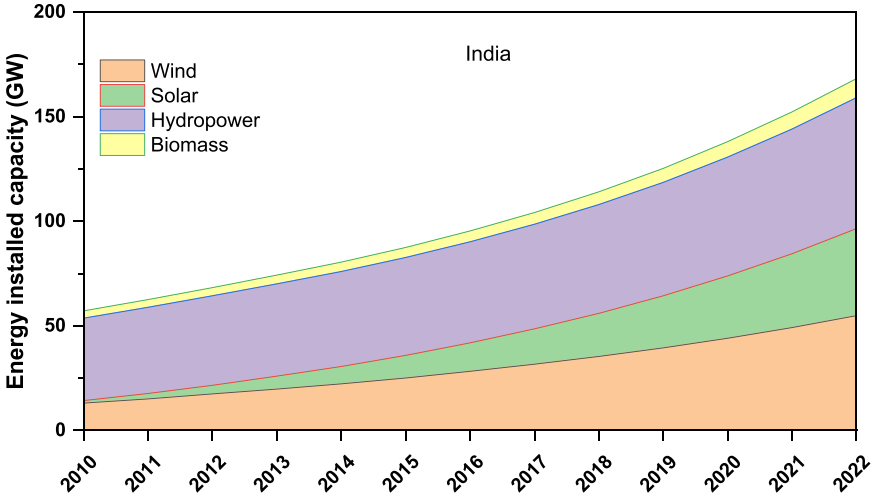

Fig. 22. The renewable energy installed capacity of the India (2010 - 2022) [56].

Additionally, there is a focus on technological advancements, grid integration, and energy storage solutions to ensure the efficient utilization of renewable energy sources.

3.7. Canada

Canada is a country with diverse energy resources. It has abundant natural resources, including oil, natural gas, hydroelectric power, uranium, and biomass. Canada experienced significant developments in its energy sector, with a particular focus on renewable energy. Energy consumption and production in the country saw notable changes, as did the growth rates and capacities across different energy sources.

The overall energy consumption, Canada steady increase during this period. Petroleum remained the dominant source of energy, with consumption growing at an average annual rate of 1.1 % and capacity reaching approximately 1.9 GW in 2022 [59]. Fig. 24 show the per-

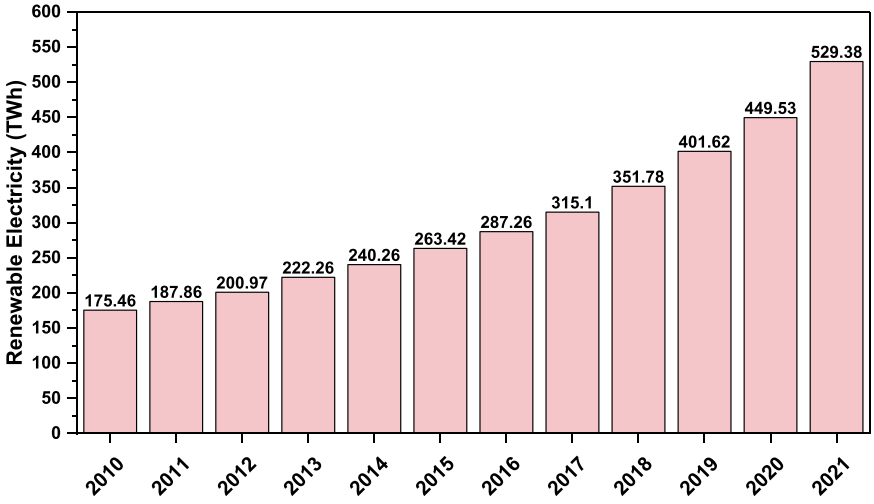

Fig. 23. The renewable electricy production of India (2010 - 2022) [57].

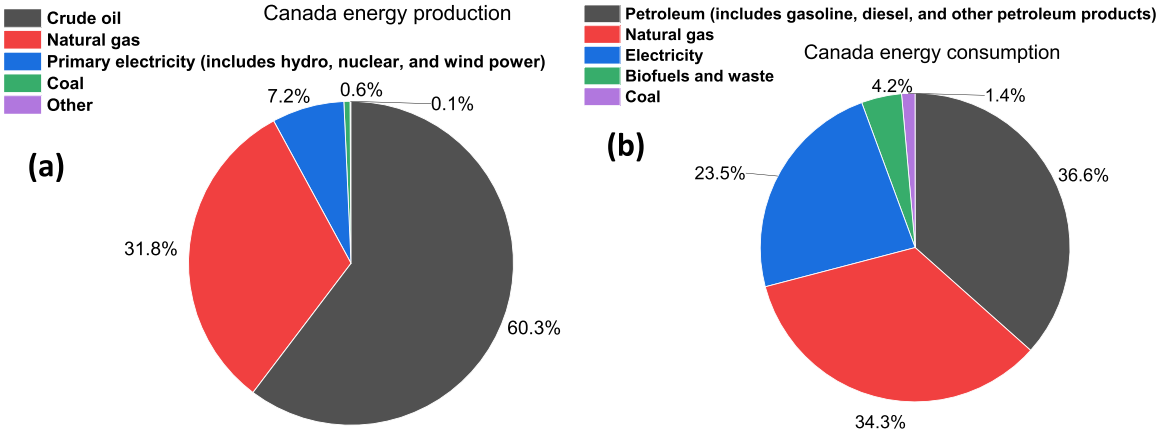

Fig. 24. energy production in (a) and consumption in (b) in percentage of Canada for the year of 2022 [59].

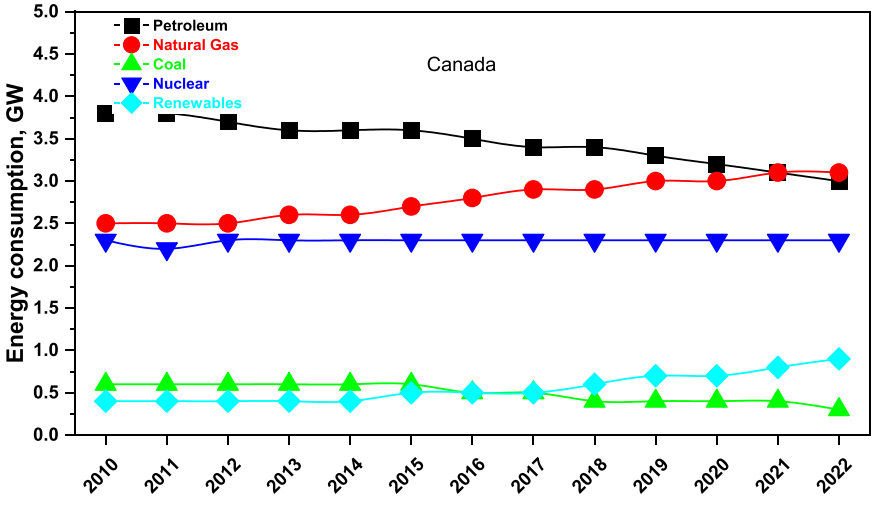

Fig. 25. The energy consumption by form of Canada (2010 - 2022) [59,60].

centage of energy production in (a) and consumption in (b) for the year of 2022.

Natural gas consumption also expanded, with an average growth rate of 1.7 % and capacity reaching around 3.8 GW. However, coal consumption experienced a decline, with an average annual reduction of 2.4 % [60]. Nuclear energy consumption remained relatively stable, with a slight growth rate of 0.4 %. Renewable energy consumption witnessed a substantial increase, with an average annual growth rate of 7.2 % as presented in Fig. 25.

Increase in the renewable energy: Canada made significant progress in expanding its renewable energy production and capacity. The growth rate of renewable energy production between 2010 and 2022 averaged around 7.6 % annually [61,62]. By 2022, Canada had achieved a total renewable energy capacity of approximately 97 GW,

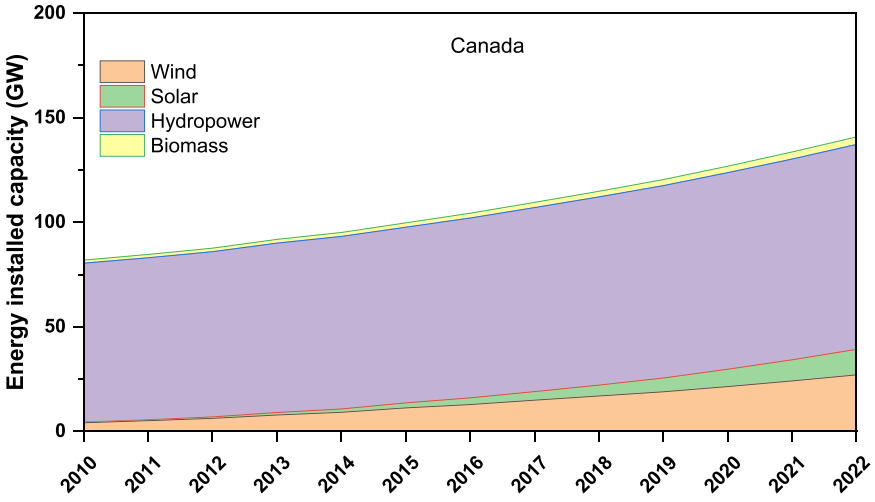

Fig. 26. The renewable energy installed capacity of Canada (2010 - 2022) [62,4].

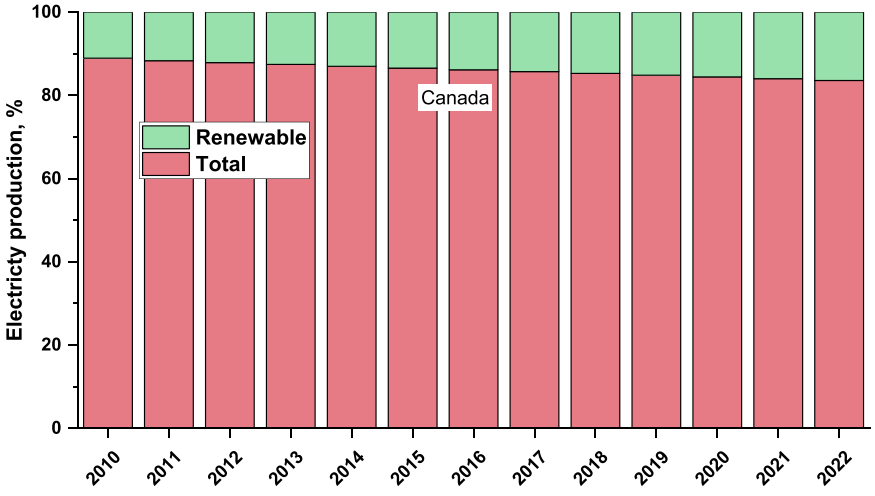

Fig. 27. The renewable electricy production of Canada (2010 - 2022) [59,63].

with wind energy accounting for the largest share, followed by hydroelectric power and biomass as showed in Fig. 26.

Renewable electricity production also experienced remarkable growth during this period, with an average annual growth rate of 8.4 % (see Fig. 27). By 2022, Canada renewable electricity capacity reached around 84 GW, representing a significant increase. Hydroelectric power contributed the most to renewable electricity production, followed by wind and solar energy.

Canada commitment to renewable energy was evident in its efforts to increase installed renewable energy capacity. By 2022, Canada had installed approximately 97 GW of renewable energy capacity, demonstrating substantial progress in transitioning towards a more sustainable energy mix.

Canada future policy towards renewable energy: Canada has set ambitious goals, including achieving net-zero emissions by 2030–2050. These may include strengthened renewable energy targets, with a focus on increasing the share of renewable energy in the overall energy mix. The policy framework is expected to provide financial incentives, such as subsidies and tax credits, to encourage renewable energy development and attract investments [64,65]. Furthermore, the government is likely to enhance regulatory frameworks to facilitate the integration of renewable energy into the grid, streamline permitting processes, and ensure fair market access. The country is also expected to invest in research and development to improve the efficiency and cost-effectiveness of renewable energy technologies, as well as explore energy storage solutions to address intermittency challenges. Collaboration and partnerships, both domestically and internationally, will play a crucial role in knowledge-sharing, technology transfer, and fostering innovation.

3.8. Australia

Between 2010 and 2022, Australia experienced significant changes in its energy sector, marked by a growing emphasis on renewable energy and a shift away from traditional fossil fuels. In terms of energy consumption and production, the country witnessed overall growth during this period, although the rate varied across different energy sources. According to the Australian Bureau of Statistics (ABS) and the Department of Industry, Science, Energy, and Resources, Australia total energy consumption increased at an average annual rate of 0.9 % from 2010 to 2022 (see Fig. 28) [66].

When examining specific energy sources, Australia consumption of petroleum remained relatively stable, with a modest growth rate. Natural gas consumption, however, showed a notable increase, growing at an average annual rate of 4.5 % between 2010 and 2022 [67]. Coal consumption experienced a decline over the years due to various factors, including economic shifts, climate concerns, and the growth of renewable alternatives (see Fig. 29).

Australia nuclear energy sector remains undeveloped, as the country does not have any operational nuclear power plants. As such, nuclear energy does not contribute significantly to the country energy consumption or capacity.

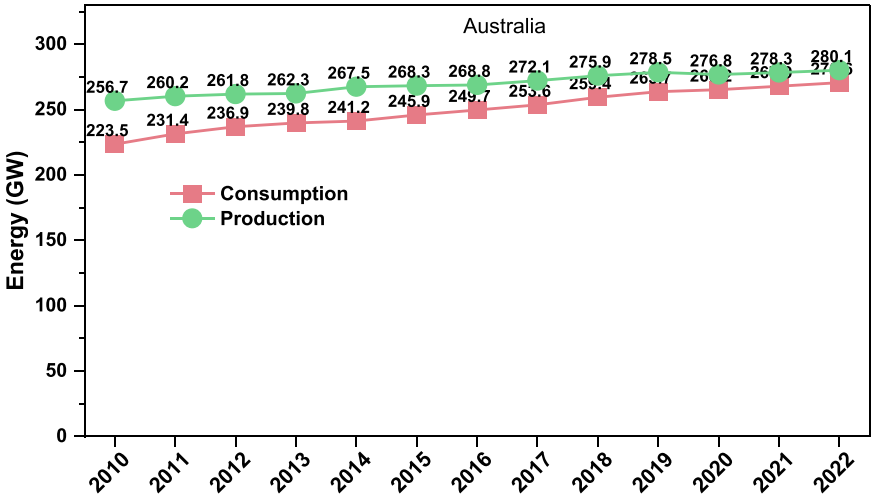

Fig. 28. Australia energy consumption and production (2010 - 2022) [66,67].

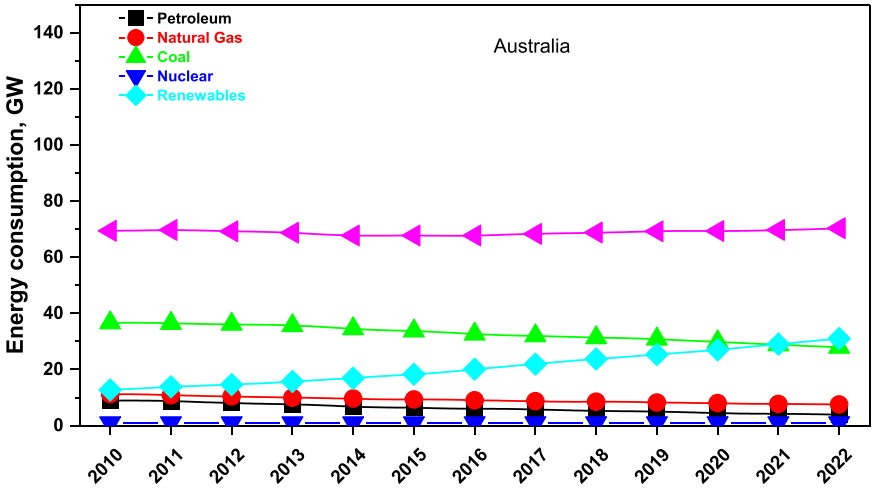

Fig. 29. The energy consumption by form of Australia (2010 - 2022) [59,60].

The most significant transformation occurred in the renewable energy sector, where Australia experienced substantial growth in both production and capacity. Renewable energy consumption grew at an average annual rate of 14.1 % between 2010 and 2022, indicating a considerable shift towards cleaner energy sources [68]. This growth was driven by various renewable energy technologies, including solar, wind, hydro, and bioenergy. Solar energy production witnessed exponential growth during this period. The capacity of installed solar energy in Australia increased from approximately 2.6 GW in 2010 to over 17.3 GW in 2022, representing an average annual growth rate of 39.1 %. Similarly, wind energy production expanded significantly, with installed capacity rising from around 2.5 GW in 2010 to over 9.9 GW in 2022, exhibiting an average annual growth rate of 19.7 % (see Fig. 30) [69,70].

Renewable electricity production in Australia also experienced remarkable growth. The average annual growth rate of renewable electricity generation from 2010 to 2020 was approximately 13.8 %. By 2020, the total renewable electricity capacity reached around 25.3 GW, reflecting the increasing contribution of renewable sources to the country electricity mix [71]. Australia commitment to renewable energy is supported by various policies and initiatives. The Renewable Energy Target (RET) was a key policy that aimed to ensure that 20 % of Australia electricity would come from renewable sources by 2022. Additionally, the National Energy Guarantee (NEG) framework sought to provide a reliable and affordable energy system while reducing emissions.

Australia energy policy: is expected to prioritize the expansion of renewable energy and the reduction of greenhouse gas emissions. The Australian government has set a target to reach net-zero emissions by 2050, indicating a long-term commitment to a sustainable energy transition. The National Hydrogen Strategy and the Technology Investment Roadmap are examples of initiatives aimed at supporting renewable energy development and innovation [72,73].

3.9. Renewable energy growth rate

According to the IRENA: renewable capacity statistics 2022 [74], the renewable energy growth has been increased year per year as: China had a total renewable energy capacity of over 895 GW, with renewable sources contributing to around 28 % of the country total energy consumption by 2022. The US had a total renewable energy capacity of over 292 GW, with wind and solar being the primary contributors. Renewable sources accounted for around 20 % of total electricity generation in the country by 2022. Germany has been a leader in renewable energy adoption, with a strong focus on solar power. By 2020, Germany had a total renewable energy capacity of over 132 GW, primarily from solar, wind, and biomass. Renewable sources accounted for over 50 % of the country electricity generation. India has been actively expanding its renewable energy capacity, with a focus on solar and wind power. By 2020, India had a total renewable energy capacity of over 94 GW, with solar and wind contributing significantly. Renewable sources accounted for around 24 % of India installed power capacity. Japan by 2020, had a total renewable energy capacity of over 100 GW, with solar being the

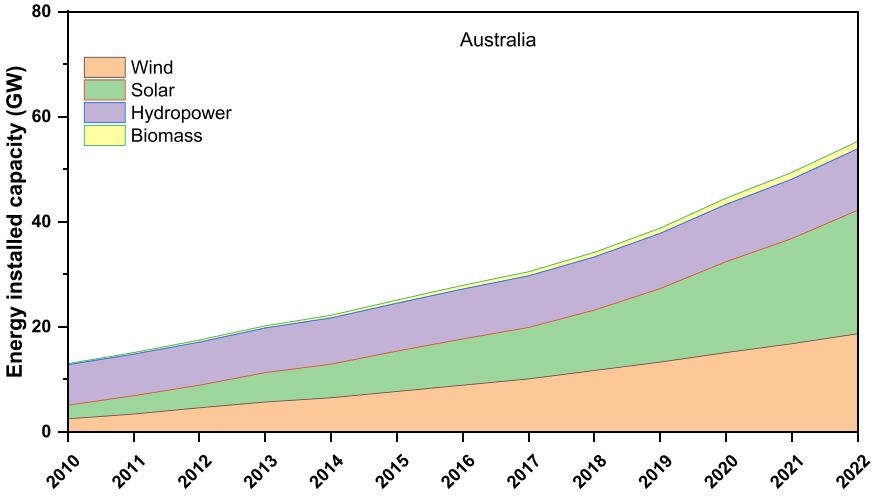

Fig. 30. The renewable energy installed capacity of Australia (2010 - 2022) [69,70].

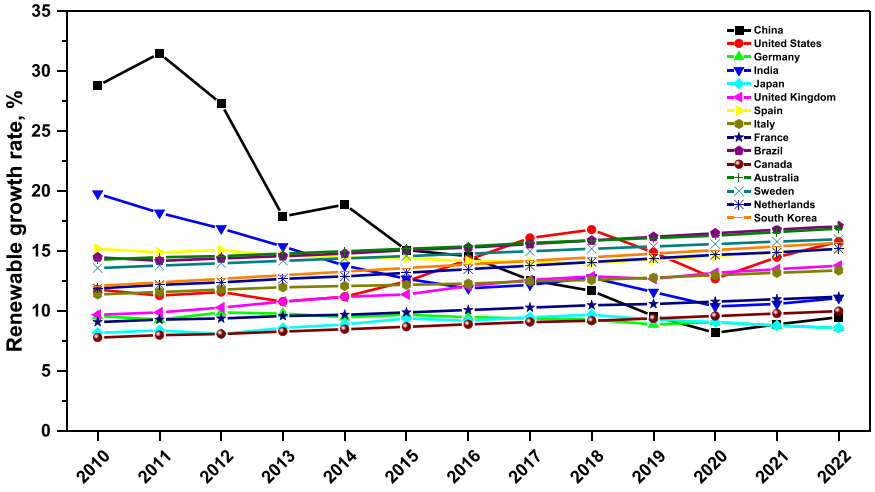

Fig. 31. The renewable energy growth rate for 15 countries of (2010 - 2022) [1].

largest contributor. Renewable sources accounted for around 18 % of the country electricity generation as presented in Fig. 31.

4. Trend in renewable energy industry development

The renewable energy industry encompasses various technologies, including solar, wind, hydropower, biomass, and geothermal, that harness naturally replenishing sources of energy. Unlike fossil fuels, which are finite and contribute to environmental degradation, renewable energy sources offer several significant advantages.

First and foremost, renewable energy is clean and emits significantly lower greenhouse gases compared to fossil fuels. By transitioning to renewable energy, we can reduce our carbon footprint and combat climate change. Greenhouse gas emissions from burning fossil fuels are the primary drivers of global warming, leading to adverse impacts such as rising temperatures, extreme weather events, and sea-level rise. The renewable energy industry provides an alternative pathway to reduce emissions and mitigate the negative effects of climate change.

4.1. Factors driving the development trend

- **Renewable energy production continues to expand quickly.**

The capacity for renewable energy generation has been steadily increasing. For example, in 2019, renewable energy capacity reached around 2537 GW worldwide, accounting for approximately 34 % of the total global electricity capacity. According to the IRENA [74], global wind energy capacity reached 651 GW in 2020, with an increase of 53 GW compared to the previous year. This represents a growth rate of approximately 9 % year-on-year. The global installed PV capacity increased to around 714 GW by the end of 2020, showing an annual growth rate of approximately 18 %. Solar energy has seen significant cost reductions over the years, making it more competitive and attractive for widespread adoption. Hydropower is one of the most widely used sources of renewable energy. While the growth rate has slowed in recent years, hydropower still accounts for a substantial portion of global renewable energy capacity. In 2019, hydropower capacity reached around 1308 GW, contributing to approximately 16 % of the world total electricity production. Apart from wind, solar, and hydropower, other renewable energy sources like biomass, geothermal, and ocean energy also contribute to the overall renewable energy mix. Their individual growth rates vary, but they collectively play a role in expanding renewable energy production as shown in Fig. 32.

- **There are disparities in development across sectors and regions.**

The statement highlights the uneven progress of renewable energy across different sectors and regions. While significant advancements have been made in the field of electricity generation from renewable sources, there is still a need for improvement in sectors such as heating, cooling, and transportation.

Progress in electricity generation: renewable energy has made substantial progress in the electricity sector. Technologies like solar and wind power have seen rapid growth and deployment. They have become more cost-effective and efficient, contributing significantly to

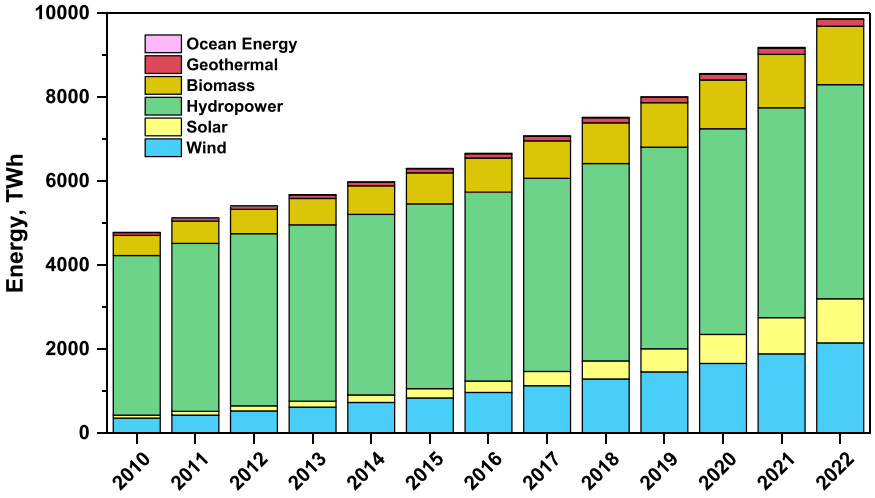

Fig. 32. Global renewable energy generation for the years 2010 to 2022 [74].

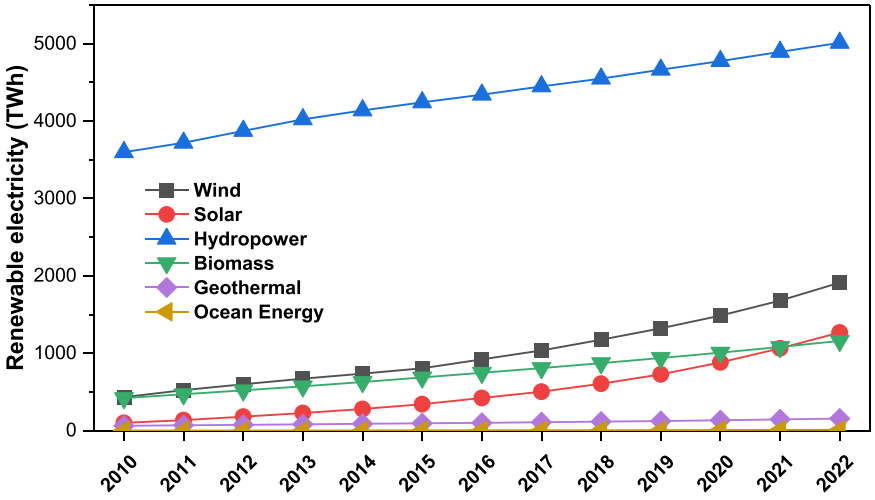

Fig. 33. The global renewable electricy generation by form for the years 2010 to 2022 [75].

the global electricity generation capacity. This progress can be attributed to advancements in technology, declining costs, and supportive policies.

Challenges in heating, cooling, and transportation: in contrast to electricity generation, renewable energy adoption in sectors like heating, cooling, and transportation is still relatively limited. These sectors heavily rely on fossil fuels, posing challenges for the widespread integration of renewable energy sources. Transitioning these sectors to renewable energy requires innovative solutions, such as renewable heating and cooling systems, and the development of sustainable transportation options like electric vehicles.

Maturing intermittent renewable energy sources: solar and wind power, as intermittent renewable energy sources, have witnessed significant growth due to their increasing maturity. However, their intermittent nature presents challenges related to reliability and grid integration. As renewable energy penetration increases, the need for more flexible energy systems becomes essential to balance supply and demand, ensure grid stability, and maintain high reliability.

Integration and system flexibility: to achieve high reliability and cost-effectiveness, it is crucial to integrate renewable energy sources into the existing energy systems in a flexible manner. This requires developing advanced grid management technologies, energy storage solutions, and demand response mechanisms. By enhancing the flexibility and adaptability of the energy system, intermittent renewable energy sources can be effectively integrated, ensuring a reliable and resilient energy supply.

Complex policy measures: as renewable energy transitions progress, the policy landscape needs to evolve accordingly. The shift from electricity generation to encompassing heating, cooling, and transportation sectors requires more comprehensive and complex policy measures. Governments and policymakers need to consider a broader range of incentives, regulations, and supportive frameworks to encourage the adoption of renewable energy in these sectors.

- **Renewable electricity dominates renewable energy investment.**

According to the IEA, renewable electricity report [75], renewable electricity investments have consistently represented a substantial majority of total renewable energy investments. In 2020, renewable electricity accounted for approximately 85 % of global investments in renewable energy. This means that out of the total investment made in renewable energy technologies, around 85 % was directed towards the electricity sector, including technologies such as solar, wind, hydropower, and geothermal. The global investment in renewable energy reached a record-breaking total of around $303.5 billion, approximately (85 % of $303.5 billion) would have been invested in renewable electricity [76,77].

It is worth noting that this dominance of renewable electricity in investment is driven by several factors. Firstly, the electricity sector offers significant opportunities for renewable energy deployment due to its high energy demand and the ability to integrate renewable sources into existing grids. Additionally, technologies like solar and wind power have witnessed rapid cost reductions, making them attractive investment op-

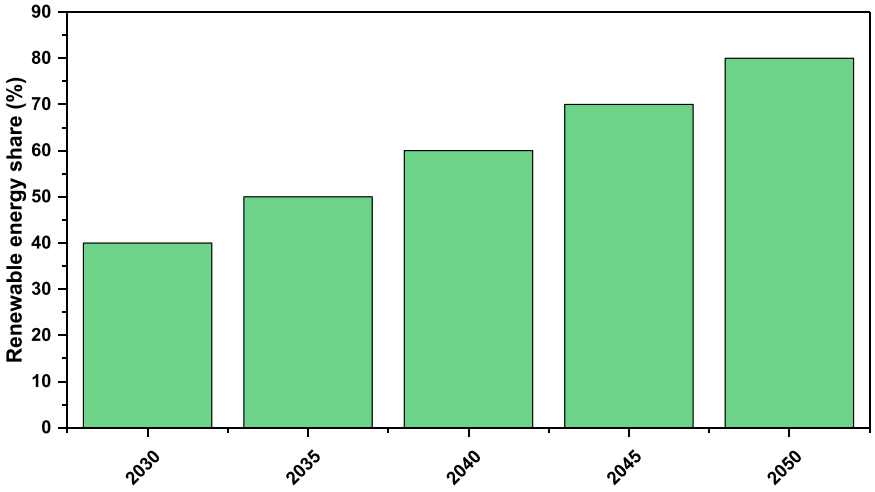

Fig. 34. The global renewable energy share projection to 2050 [79,80].

tions for electricity generation. While renewable electricity investment is dominant, other sectors such as heating, cooling, and transportation are also receiving attention, albeit to a lesser extent.

- **Renewable energy has expanded rapidly and become increasingly competitive.**

Based on the IEA forecast [78], it is projected that renewable energy will contribute to nearly 40 % of global electricity generation by 2027. Among the various renewable energy sources, hydropower is expected to account for 17 %, followed by wind power at 7 %, solar power at 5 %, and biomass at 4 %. These Fig. 34 highlight the growing significance of renewable energy in the global electricity sector [79].

To meet the goals outlined in the Paris Agreement, there is a need to significantly expand the deployment of renewable energy. The expansion required is estimated to be at least six times the current capacity. Achieving this level of growth is essential to accelerate the transition towards a low-carbon and sustainable energy system.

According to the renewable energy roadmap (Remap) issued by the International Renewable Energy Agency (IRENA), a diverse range of sectors must embrace renewable energy expansion [81,82]. The Remap highlights that renewable energy needs to be integrated into various fields beyond electricity generation. It envisions a substantial increase in the share of renewable energy across all countries by 2050. The transition to a renewable energy future is crucial for mitigating climate change and reducing greenhouse gas emissions. By increasing the share of renewable energy across sectors and countries, we can significantly contribute to achieving a more sustainable and environmentally friendly energy landscape.

- **The** primary sources of renewable energy consumption are wind and photovoltaic.

Both wind and solar energy have become key pillars of the global renewable energy sector due to their vast potential, scalability, and environmental benefits. They offer a sustainable alternative to fossil fuels, reducing greenhouse gas emissions and mitigating climate change. The growth of wind and solar energy deployment has been facilitated by decreasing costs, technological advancements, supportive government policies, and increased awareness of the need for clean energy sources [83,84]. Wind and photovoltaic energy have played a vital role in diversifying the energy mix and reducing reliance on fossil fuels in many countries worldwide. Continued investments in research, development, and infrastructure are expected to further enhance the efficiency and competitiveness of wind and solar energy, driving their continued global expansion in the transition towards a more sustainable energy future. Table 2 show the global leading countries that have highest renewable energy production by solar and wind for the years 2021 and 2022.

Table 2
Renewable energy production by solar and wind [85].

Country	Solar energy (TWh)		Wind energy (TWh)	
	2021	2022	2021	2022
China	287.5	305.7	445	460.5
United States	133	145.2	334	348.8
Germany	56.5	59.2	128.8	134.6
India	55.7	58.9	60.3	64.1
Japan	55	57.8	11.2	12
United Kingdom	30.1	32.2	61.3	65.5
Australia	18.9	20.1	47.5	50.7
France	18	19.1	30.5	32.6
Italy	16.8	17.9	15.7	16.7
Canada	16.6	17.6	35.1	37.2
Spain	15.9	16.8	51.2	54.3
South Korea	13.2	14	1.7	1.9
Netherlands	12.8	13.6	31.6	33.8
Brazil	10.1	10.7	64.3	68.2
Turkey	9.3	9.9	26.7	28.5

4.2. Solar energy

The solar power industry has positive predictions: solar power industry has experienced significant growth and development globally. The adoption of solar PV technology has expanded, driven by factors such as declining costs, technological advancements, supportive policies, and increasing awareness of the need for clean energy sources. The installed capacity, the global solar power capacity has grown substantially over the years. In 2010, the total installed capacity was around 40 GW, and by 2022, it is projected to reach over 1000 GW (or 1 terawatt), representing more than a twenty-five-fold increase [86]. This growth indicates the significant progress made in expanding solar energy generation worldwide. Moreover, the cost of solar PV panels has declined significantly during this period. In 2010, the average cost of solar panels was around $4 per watt, and by 2022, it is projected to decrease to about $0.5 per watt or even lower [87]. This decline in costs has made solar energy increasingly cost-competitive with traditional sources of electricity, driving further adoption and deployment. Policy support and incentives have also played a crucial role in fostering the growth of the solar power industry. Many countries have implemented feed-in tariffs, net metering programs, tax credits, and other supportive measures to encourage the installation of solar PV systems. These policies have incentivized investments in solar energy and accelerated its adoption in various regions.

On the photovoltaic market, the region of Asia and Asia-Pacific regions holds the highest rank: installed PV capacity in the region of

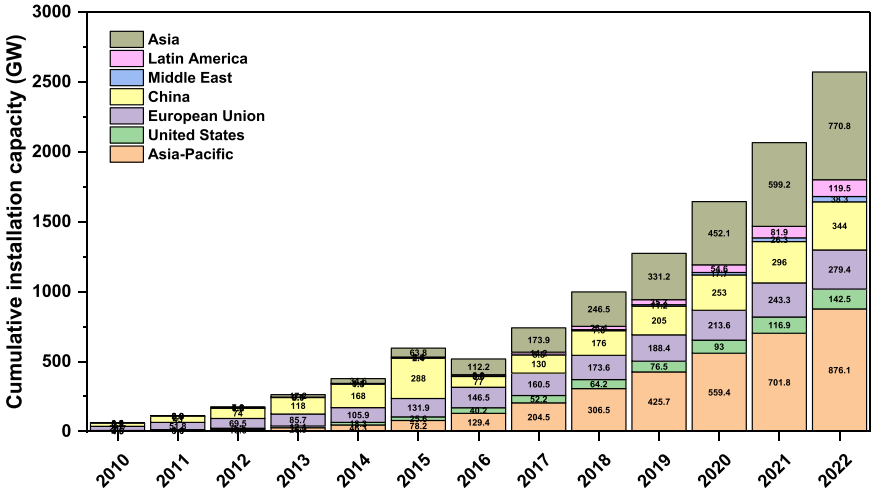

Fig. 35. The global photovoltaic installation accumulative capacities [89].

Asia and Asia-Pacific has experienced remarkable growth. Starting at 4.5 GW in 2010, the capacity has consistently increased each year, reaching 876.1 GW by 2022 (see Fig. 35) [88]. This represents an extraordinary progress and a significant expansion of solar energy installations in the region.

Several countries in the region have been instrumental in driving this growth. China, in particular, has been a key player and has consistently been the largest market for PV installations globally. The country installed PV capacity has shown a remarkable increase from 21 GW in 2010 to 344 GW in 2022, contributing significantly to the overall capacity of the Asia and Asia-Pacific region [89]. Other countries in the region, such as Japan, Australia, India, and South Korea, have also made significant contributions to the growth of the PV market. These countries have implemented supportive policies, incentives, and ambitious renewable energy targets, which have propelled their solar energy installations and contributed to the region overall PV capacity. photovoltaic market,

The growth of the photovoltaic industry: the overall trend of the PV industry positive development is supported by the declining costs of PV technology, the increasing installed capacity, policy support, technological advancements, and the global shift towards renewable energy. These factors collectively indicate a promising future for the photovoltaic industry as it continues to contribute to the global energy transition and sustainable development goals. Since 2010, the cost of PV panels has significantly dropped, making solar energy more affordable and competitive with traditional energy sources. This decline in costs has stimulated greater demand for PV installations, driving the growth of the industry [90]. The global installed capacity of PV systems has witnessed remarkable growth. The PV industry has experienced substantial increases in installed capacity worldwide. For instance, in 2010, the total global installed PV capacity was around 40 GW. By 2022, it had surpassed 770 GW, reflecting a significant expansion of the industry [91].

The outlook for the CSP industry is encouraging, but additional policy support is required: despite its potential, the widespread deployment of CSP systems still requires additional policy support. This support can come in the form of government incentives, regulations, and long-term planning that encourages investment in CSP projects [92]. Policy support is crucial for addressing challenges such as high initial costs, technology development, and grid integration. It can provide financial incentives such as feed-in tariffs or tax credits that make CSP projects more economically viable and attractive to investors. Additionally, clear and consistent regulatory frameworks can help streamline the permitting and approval processes for CSP projects, reducing uncertainties and delays. Furthermore, long-term planning is essential for integrating CSP into the overall energy mix and ensuring grid stability [93,94]. This involves aligning CSP development with energy transition goals, setting renewable energy targets, and implementing effective grid management strategies to accommodate the intermittent nature of solar power. Fig. 36 show the installation of SCP for global several countries.

Increasing deployment of solar PV installations worldwide: The increasing deployment of solar PV installations worldwide refers to the growing trend of installing solar photovoltaic systems across different regions and countries globally. One of the primary drivers behind the increasing deployment of solar PV installations is the declining cost of solar technology. Another important factor is the implementation of supportive policies and incentives by governments worldwide. Many countries have introduced feed-in tariffs, net metering programs, tax credits, and other financial incentives to encourage the adoption of solar PV systems. s a result of these combined factors, the deployment of solar PV installations has seen significant growth worldwide [95,96]. Countries in North America, Europe, Asia, and other regions have experienced a substantial increase in installed solar capacity. This growth includes utility-scale solar projects, commercial and industrial installations, and residential rooftop systems. Fig. 37 show the installation of solar PV for global several regions.

4.3. Wind energy

Expansion and progress of wind energy: The global wind power industry has indeed experienced rapid development over the years (see Fig. 38). The wind power industry rapid development is evident from the significant increase in wind energy production across multiple countries. In 2021, China emerged as the leading country in wind energy production 445.0 TWh. The United States also showcased substantial progress, generating 334.0 TWh of wind energy in 2021. The country has been actively promoting renewable energy development, particularly wind power, across various states. Germany, renowned for its commitment to renewable energy, produced 128.8 TWh of wind energy in 2021. Germany well-established wind power infrastructure and favorable regulatory framework have contributed to its significant wind energy production [97–99].

India demonstrated remarkable growth, generating and 60.3 TWh of wind energy in 2021. The country ambitious renewable energy targets, supportive policies, and large-scale project installations have bolstered its position in the global wind power industry. Other countries, including Japan, the United Kingdom, Australia, France, Italy, Canada, Spain, South Korea, the Netherlands, Brazil, and Turkey, also made substantial contributions to global wind power production in 2021, though to varying degrees. Moving to 2022, the trend of rapid growth in the wind power industry continued. China wind energy production rose to 460.5 TWh, reinforcing its position as the global leader in renewable energy generation [99]. The United States witnessed a modest increase in wind

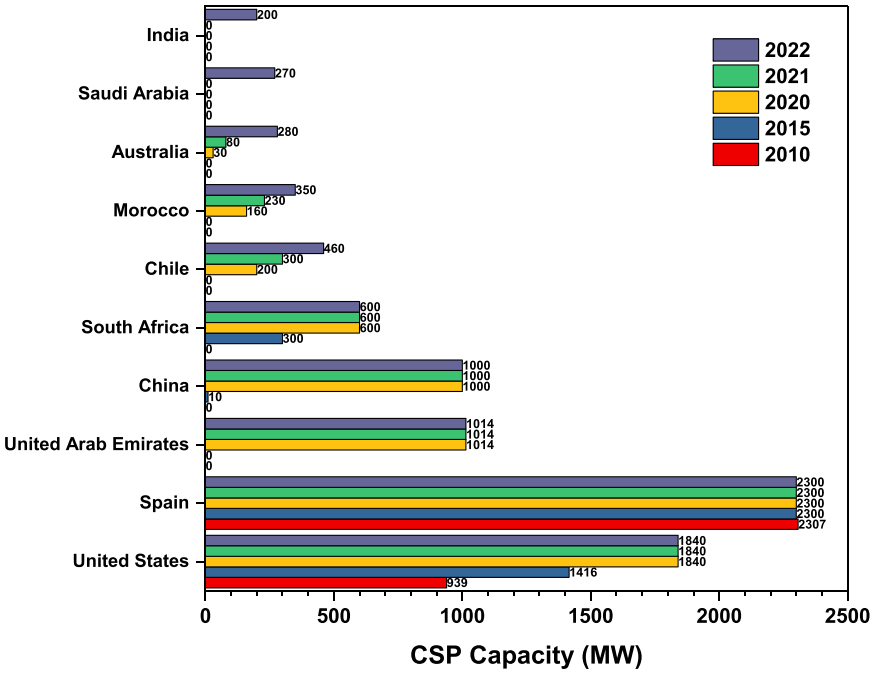

Fig. 36. The global installation of SCP for global several countries [94].

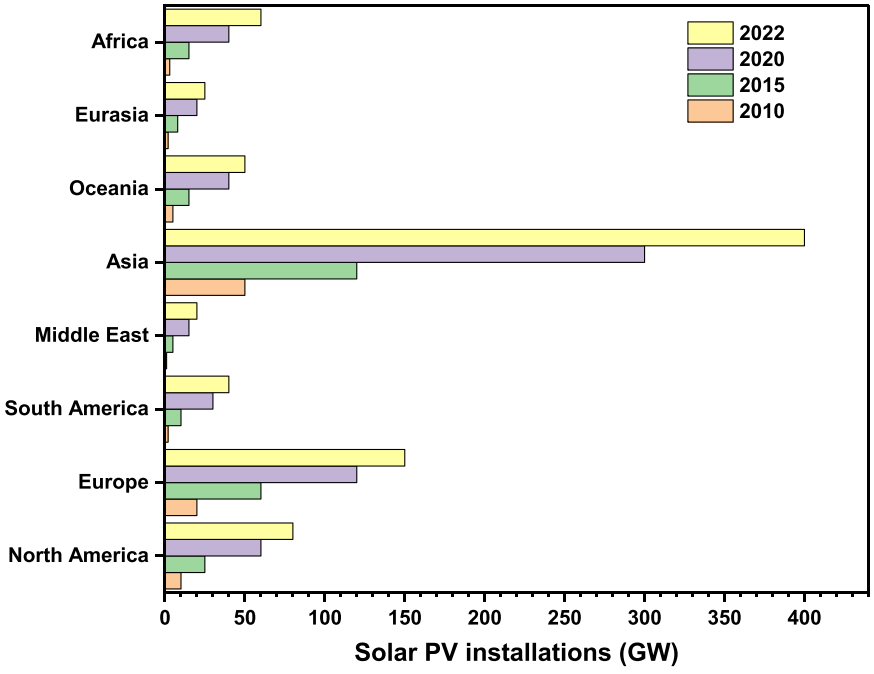

Fig. 37. The global renewable energy share projection to 2050 [96].

energy production to 348.8 TWh, reflecting continued investments in renewable energy projects and policy support (see Fig. 39).

Offshore wind power: has experienced remarkable growth in 2022, reaching record highs in terms of capacity installations. During this period, several countries have played a significant role in driving the expansion of offshore wind energy. One of the pioneering nations in offshore wind power is the United Kingdom. The UK has been at the forefront of offshore wind development, consistently increasing its capacity over the years. By the end of 2022, the UK had installed more than 11 GW of offshore wind power, making it the global leader in offshore wind capacity. By 2022, Germany had an installed offshore wind capacity of over 7 GW, solidifying its position as one of the top countries in offshore wind development. China has emerged as a major player in offshore wind power. With its vast coastline and commitment to renewable energy, China has rapidly expanded its offshore wind capacity. By the end of 2022, China had surpassed 7 GW of installed offshore wind power [100].

The combined efforts of countries like the UK, Germany, Denmark, the Netherlands, Belgium, Sweden, and China have propelled the industry forward, setting new records in capacity installations and driving the transition to clean and sustainable energy sources. The ongoing expansion of offshore wind power demonstrates the increasing global recognition of its potential in meeting energy demands while mitigating climate change [101,102].

Onshore wind power: By the end of 2022, China had installed over 350 GW of onshore wind power, making it the global leader in

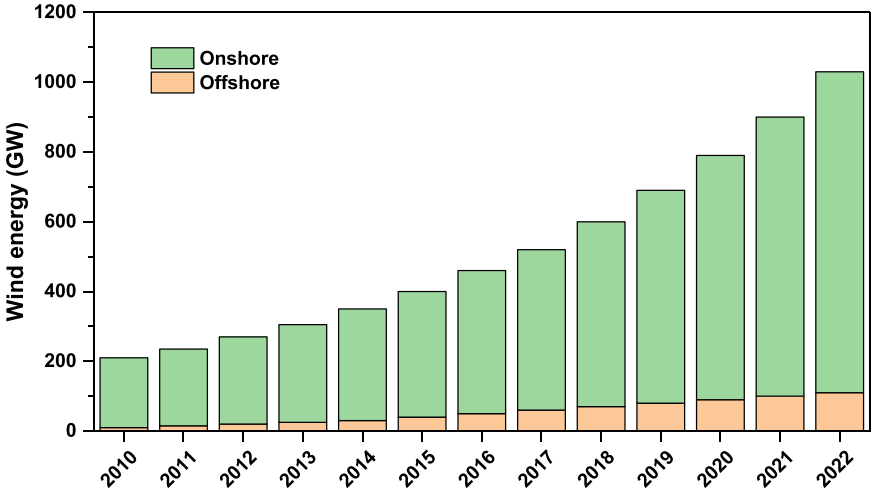

Fig. 38. The global wind energy production [98].

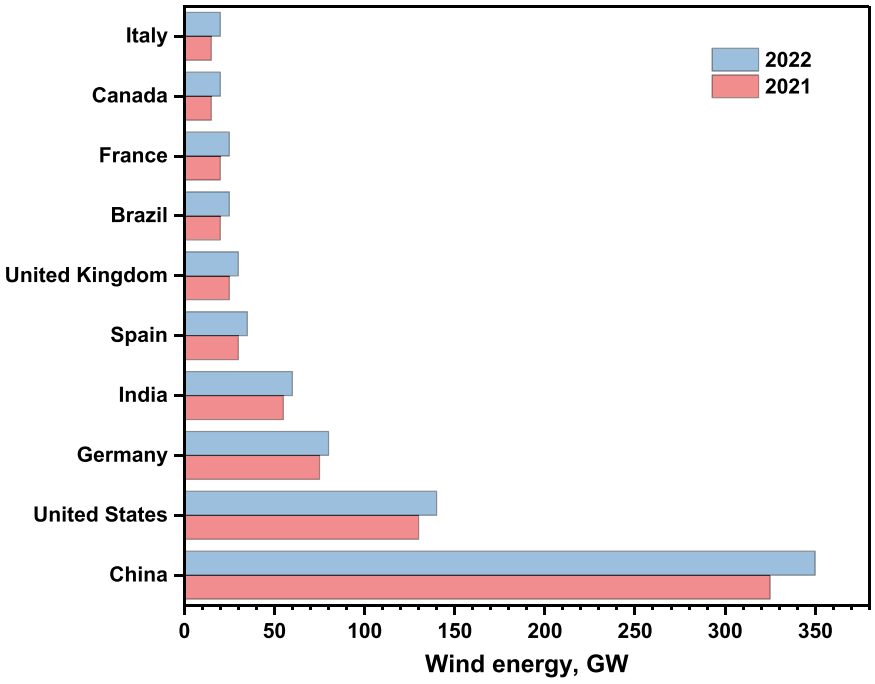

Fig. 39. Wind energy installation capacity [99].

onshore wind capacity. With favorable wind resources across various states, the US has seen a significant increase in its capacity. By 2022, the US had surpassed 120 GW of onshore wind capacity, establishing itself as a major player in the industry. Germany, India, and Spain have also made substantial contributions to the development of onshore wind power. Germany, known for its Energiewende transition, had over 60 GW of onshore wind capacity by 2022. India, with its ambitious renewable energy targets, had exceeded 40 GW of onshore wind capacity, while Spain had reached around 27 GW. Other countries, including the United Kingdom, France, Brazil, Canada, and Sweden, have also experienced substantial growth in onshore wind power capacity during this period [103,104].

The record-high development of onshore wind power can be attributed to several factors. Advancements in wind turbine technology, improved efficiency, and economies of scale have made onshore wind power increasingly cost-effective.

Predicted competitiveness of wind power for the years 2030, 2040, and 2050: the competitiveness of wind power in the future is subject to various factors, including policy frameworks, advancements in technology, and market dynamics. Table 3 provides a general prediction based on the current trends and assumptions surrounding wind power development in 2030, 2040, and 2050.

Table 3
Prediction of wind power development.

Year	Competitiveness of wind power	Key details
2030	Increasingly Competitive	Advancements in turbine technology, improved energy storage, and declining costs make wind power an attractive option compared to traditional energy sources.
2040	Highly Competitive	Continued technological advancements, economies of scale, and favorable market conditions position wind power as one of the most cost-effective energy options.
2050	Dominantly Competitive	Wind power becomes the preferred choice for new energy installations, with significant cost reductions and widespread adoption driven by environmental goals and policy support.

In 2030, wind power is expected to become increasingly competitive. Technological advancements in wind turbine design and manufactur-

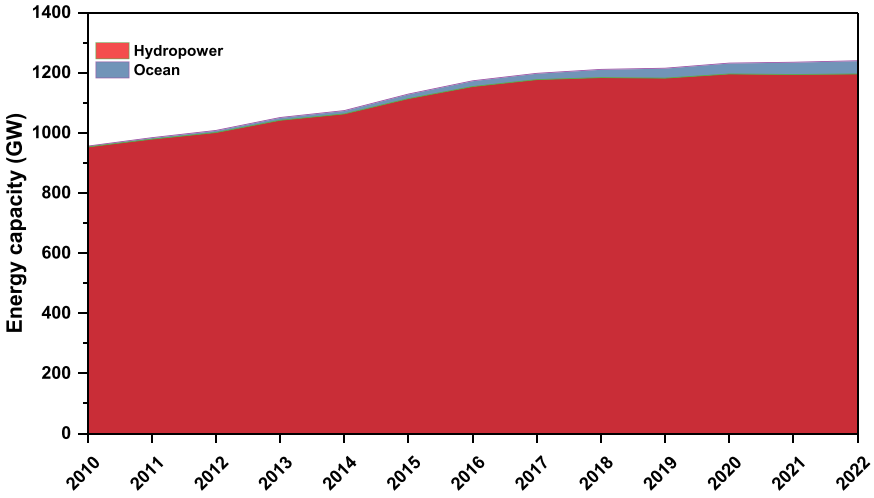

Fig. 40. Global hydropower and ocean energy [106].

ing, such as larger and more efficient turbines, along with improved energy storage systems, will enhance the overall competitiveness of wind power. These developments will contribute to a reduction in costs and increase the reliability and flexibility of wind energy generation, making it a more attractive option compared to traditional fossil fuel-based sources.

By 2040, wind power is predicted to be highly competitive. Ongoing advancements in turbine technology, such as increased efficiency and capacity, combined with economies of scale in manufacturing and deployment, will significantly reduce the costs of wind power installations. As a result, wind power will become one of the most cost-effective ways to generate electricity, surpassing the competitiveness of conventional energy sources.

Looking further ahead to 2050, wind power is expected to be dominantly competitive. Continued innovation and technological advancements, coupled with growing environmental awareness and policy support, will drive the widespread adoption of wind power. By this time, wind power is projected to be the preferred choice for new energy installations due to its affordability, sustainability, and contribution to carbon neutrality goals.

4.4. Hydropower and ocean energy

The yearly progress for hydropower and ocean energy: the growth of hydropower has been relatively steady, with incremental increases in capacity year by year (see Fig. 40). Ocean energy, being a nascent industry, has witnessed slower progress, with limited installations and smaller capacity additions [105]. However, ongoing research and development efforts and increasing investments in ocean energy technology are expected to drive future growth and accelerate the deployment of ocean energy projects.

Hydropower: China has been at the forefront of hydropower development. With its vast river systems and ambitious renewable energy goals, China has significantly expanded its hydropower capacity. By the end of 2022, China had an installed hydropower capacity of over 370 GW, making it the world largest hydropower producer. Brazil is another major player in hydropower (see Fig. 41). The country has abundant water resources, including the Amazon River, which has enabled the development of large-scale hydropower projects. Brazil installed hydropower capacity reached approximately 105 GW by the end of 2022. For the year of 2022, the installed hydropower capacity in the US was around 103 GW and Canada had an installed hydropower capacity of approximately 84 GW, and Russia had an installed hydropower capacity of around 52 GW [107].

Ocean Energy: Ocean energy from waves, tides, and currents, relatively newer form of renewable energy and has witnessed slower development compared to hydropower. The capacities and progress for the United Kingdom has several demonstration projects and test sites to explore the potential of ocean energy (see Fig. 42). By the end of 2022, the UK had an installed ocean energy capacity of approximately 2 MW, France installed ocean energy capacity was in the range of a few megawatts, Portugal had an installed ocean energy capacity of a few megawatts, and Ireland installed ocean energy capacity was in the range of a few megawatts [109,110].

Future large-scale projects:
Hydropower:

- **Grand Inga Dam (Democratic Republic of Congo):** the project aims to harness the power of the Congo River to become the largest hydropower project in the world, with a potential capacity of up to 40,000 MW. It has the potential to provide electricity to millions of people in Africa [111].
- **Three Gorges Dam (China):** is currently the world largest hydropower project, with a capacity of 22,500 MW. It is located on the Yangtze River and has significantly contributed to China renewable energy goals [112].
- **Belo Monte Dam (Brazil):** located on the Xingu River in Brazil, has a capacity of 11,233 MW. It is one of the largest hydropower projects in Brazil and has faced both support and opposition due to its environmental and social impacts [113].

Ocean Energy:

- **MeyGen Tidal Project (Scotland):** the project is one of the world largest tidal energy projects, located in the Pentland Firth, Scotland. It aims to harness the power of tides to generate clean and renewable electricity, with an installed capacity of 398 MW [114].
- **Swansea Bay Tidal Lagoon (Wales):** the project in Wales aims to utilize the tidal range to generate electricity. With a capacity of up to 320 MW, it has the potential to become a significant contributor to Wales' renewable energy targets [115].
- **Normandie Hydro Project (France):** the project aims to harness the power of tidal streams and currents in the Raz Blanchard region. With a planned capacity of 1 GW, it has the potential to become one of the largest tidal energy projects in the world [116].

These projects highlight the increasing interest and investment in large-scale hydropower and ocean energy projects. They are expected to contribute significantly to the global renewable energy mix, provide clean electricity, and reduce greenhouse gas emissions. However, it is important to consider the environmental, social, and economic implications associated with such projects to ensure sustainable and responsible development.

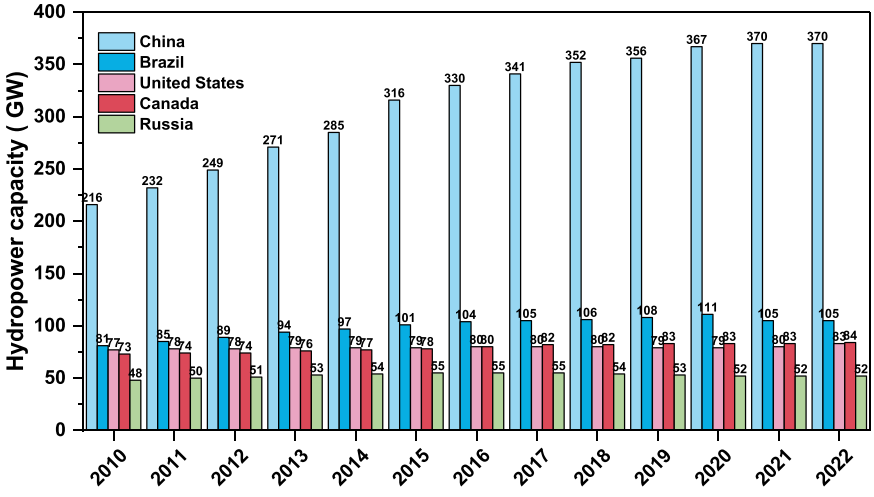

Fig. 41. Hydropower capacities and yearly progress [108].

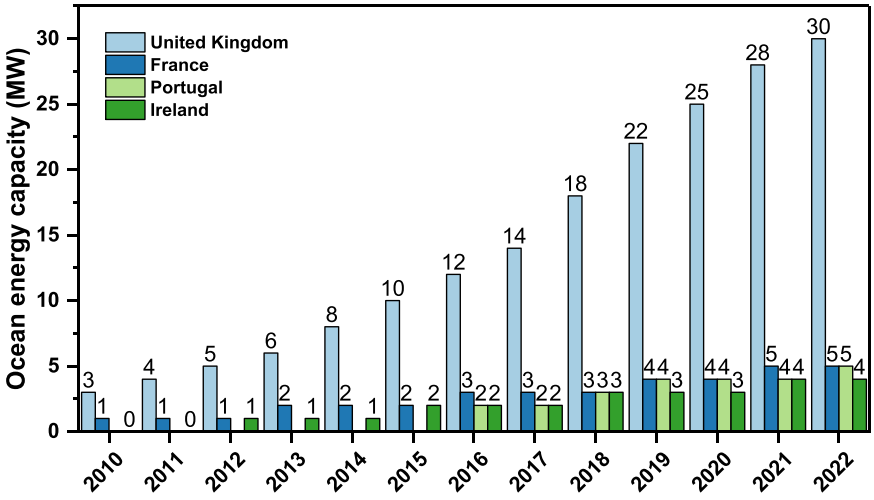

Fig. 42. Ocean energy capacities and yearly progress [109,110].

4.5. Biomass and bioenergy

Ggrowth of biomass and bioenergy production biomass energy production has increased steadily as countries strive to diversify their energy sources, reduce greenhouse gas emissions, and promote sustainable development. However, it is important to note that the actual production figures may vary based on different data sources, updates, and the specific biomass utilization policies and projects implemented in each country. Europe has been a prominent player in global biomass energy production. Germany biomass energy production has increased to around 5 GW in 2022. North America, particularly the United States and Canada, has also witnessed notable biomass energy production. Biomass energy production in the United States has experienced consistent growth, increasing from approximately 4 GW in 2010 to around 10 GW in 2022 as presented in Fig. 43 [117].

Latin America, Africa, and the Middle East have also shown interest in biomass energy production. Countries like Brazil Biomass energy production in Brazil has displayed notable progress, increasing to approximately 6 GW in 2022 as presented in Fig. 44. The Middle East, with countries like Saudi Arabia and the United Arab Emirates, has initiated biomass projects primarily focusing on waste-to-energy and biomass co-firing [118].

The outlook for the biomass energy market is highly promising: according to forecasts by the IEA, biomass energy is projected to emerge as the largest renewable energy source, experiencing significant growth in consumption from 2020 to 2025. This indicates a growing recognition of the potential and value of biomass in the global energy landscape. The IEA predicts that biomass fuels will contribute to approximately 30 % of the overall increase in renewable energy consumption during this period. This highlights the significant role biomass will play in meeting the increasing energy demand while reducing greenhouse gas emissions in sectors traditionally reliant on fossil fuels. The growth of biomass energy is driven by various factors, including supportive policies and incentives implemented by governments around the world to promote renewable energy sources. Additionally, advancements in biomass conversion technologies and improved efficiency in biomass power plants contribute to the increasing viability and competitiveness of biomass energy.

4.6. Geothermal energy

Growth rate of installed power capacity: the growth rate of installed geothermal power capacity has shown a positive trend. For instance, from 2010 to 2022, the global installed geothermal capacity grew from approximately 11 gigawatts (GW) to over 14 GW, representing a growth rate of around 27 % over the period [119,69]. Fig. 45 show the geothermal energy production for the countries has heigh production.

Geothermal capacity by region: different regions have made significant contributions to the growth of geothermal energy capacity. As of 2022, North America held the largest geothermal capacity, with the United States accounting for a substantial portion of the installed capacity. Other regions, such as Asia, Latin America, and Europe, have also witnessed notable growth in geothermal capacity [120].

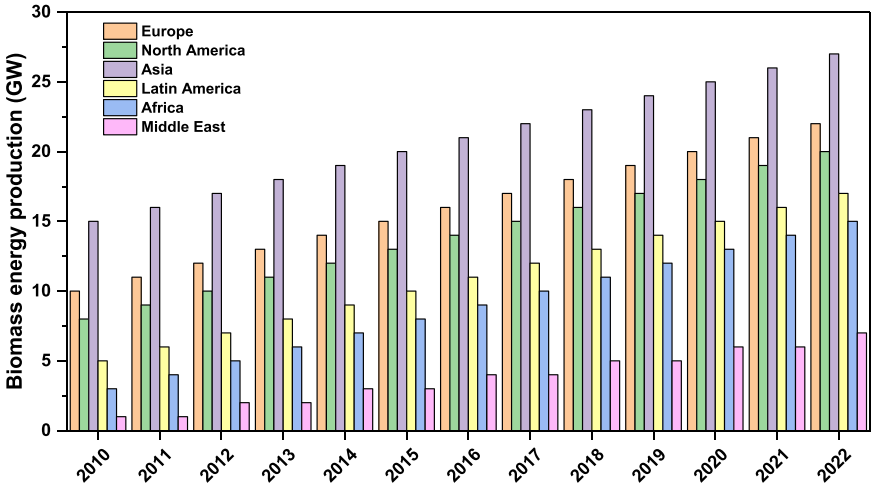

Fig. 43. Biomass energy production by region [117,118].

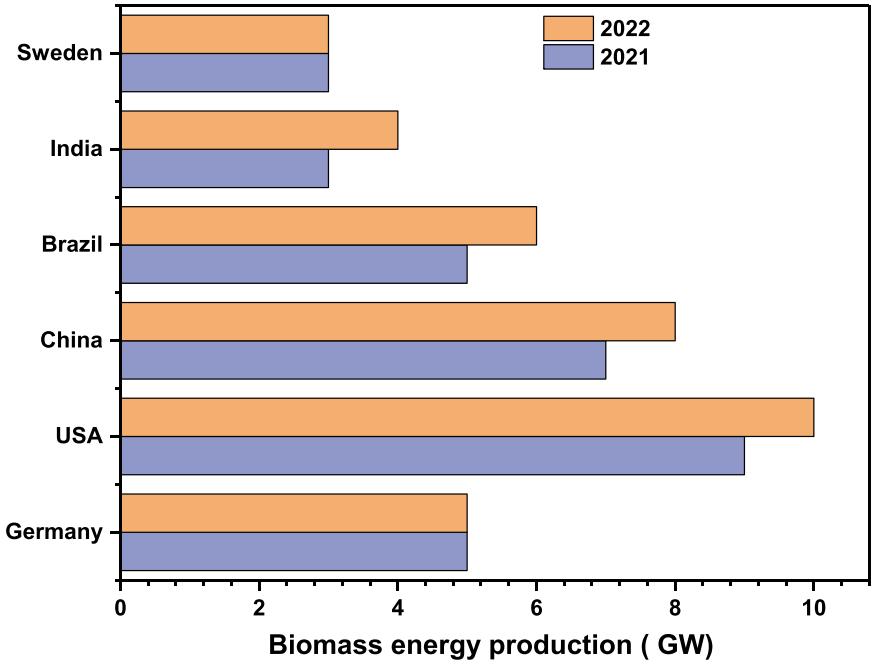

Fig. 44. Biomass energy production by country [118].

Technological advancements: advancements in geothermal technology have played a crucial role in the industry development. Innovations in drilling techniques, enhanced geothermal system (EGS) technology, and binary cycle power plants have improved the efficiency and cost-effectiveness of geothermal power generation. These advancements have enabled the exploitation of geothermal resources in areas previously considered less suitable for geothermal energy production.

Policy support and investment: supportive policies and incentives provided by governments have stimulated the growth of geothermal energy. Financial incentives, feed-in tariffs, and regulatory frameworks promoting renewable energy development have encouraged investments in geothermal projects [122]. The establishment of dedicated funds and initiatives for geothermal research and development has further propelled the industry progress.

5. Discussions

The journey towards international renewable energy growth has been transformative and pivotal in transitioning to a sustainable, low-carbon future. It has been characterized by multifaceted developments including the transfer of technology, extensive knowledge sharing, financial backing, supportive policy frameworks, and capacity building, all of which are cemented by collaborative partnerships [123]. Developed nations have played a crucial role in this transformation by sharing their renewable energy expertise and best practices with developing countries, allowing them to leapfrog over conventional energy sources directly into more sustainable options. Financial aid from various sources like multilateral development banks and climate funds has been crucial in this aspect, particularly in regions where access to capital is scarce, ensuring that renewable energy projects are not just dreams but realized achievements. Supportive policy and regulatory frameworks have been instrumental in creating a conducive environment for renewable energy to flourish. Instruments such as feed-in tariffs and renewable portfolio standards have played a key role in incentivizing investments and driving growth. Capacity building initiatives have further ensured that local expertise is developed and harnessed, empowering governments, institutions, and industry professionals to efficiently manage and implement renewable energy projects [124]. Collaborations and partnerships have been the linchpin in this journey, ensuring that the renewable energy deployment is scaled up to meet the growing demands.

The international development experience has showcased significant achievements, displaying how technology transfer, financial support, and strategic partnerships can work hand in hand to boost renewable

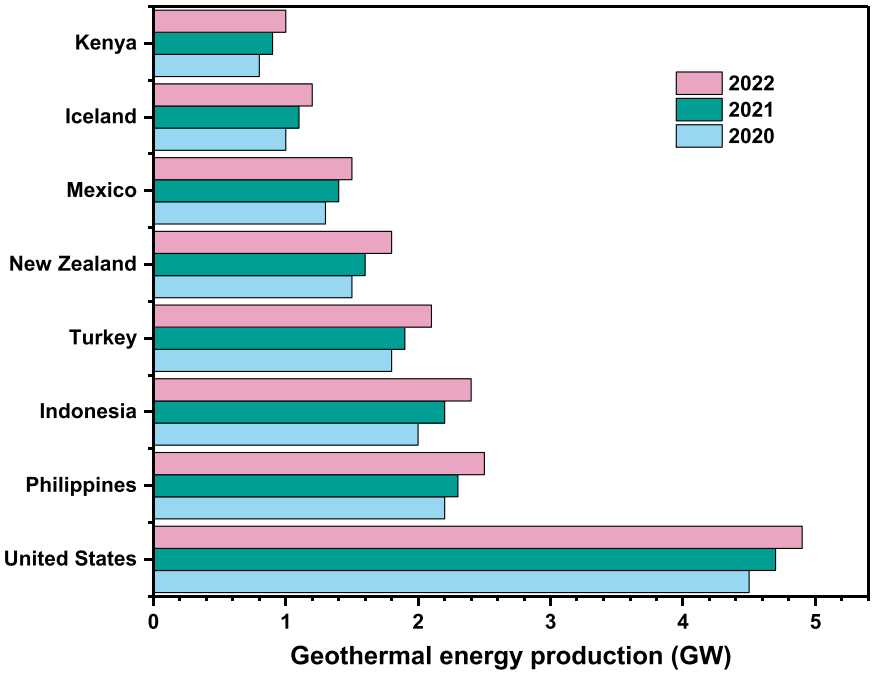

Fig. 45. Geothermal energy production by country [121].

energy growth. These efforts have resulted in expanded renewable energy capacity, considerable cost reductions, improved technology performance, and increased accessibility, even in the most remote of areas. This journey has not only been about achieving quantitative growth but also qualitative improvements, ensuring that renewable energy is not just available but also efficient and reliable. The results speak for themselves, as illustrated by the impressive growth rates of renewable energy capacity in major countries around the world. China renewable energy capacity reached over 895 GW by 2022, accounting for 28 % of the country total energy consumption. The United States, Germany, India, and Japan have also shown commendable progress, with renewables making up significant portions of their energy mix, driven mainly by wind, solar, and biomass. These nations have set exemplary precedents, showing that transitioning to renewable energy is not just feasible but also economically viable and environmentally imperative.

The global energy situation is at a crucial juncture, characterized by a paradigm shift from fossil fuel reliance to cleaner, more sustainable energy sources [125]. This transition is driven by the pressing need to address climate change and the increasing economic viability of renewable energy sources. Despite the promising growth in renewable energy, the world energy mix still has a considerable portion of fossil fuels, highlighting the persisting challenges and the need for continued efforts. Existing infrastructure, policy landscapes, and the intermittent nature of some renewable sources present hurdles that need strategic and innovative solutions. The COVID-19 pandemic has further complicated the situation but also presented opportunities for green recovery, emphasizing the need for investment in renewable energy and energy efficiency [126]. The coming years are crucial, as the impact of these recovery plans and the world commitment to transitioning to a more sustainable energy future will be truly tested. The international development experience in renewable energy growth offers invaluable lessons and a blueprint for countries worldwide, demonstrating that with the right support, policies, and partnerships, a sustainable and low-carbon future is within reach.

6. Conclusions

The main points discussed highlight the significant development and growth of the renewable energy industry, which is essential for achieving a sustainable and clean energy future. The international development experience has played a crucial role in advancing renewable energy technologies, policies, and collaborations worldwide.

Key factors contributing to the industry development include technology transfer, financial support, policy frameworks, capacity building, and collaborative partnerships [127]. Developed countries have shared their expertise with developing nations, enabling them to adopt renewable energy technologies and bypass conventional energy sources. Financial support from multilateral development banks and climate funds has facilitated the deployment of renewable energy projects, especially in regions with limited access to capital. Policy and regulatory frameworks have created an enabling environment for renewable energy growth, with incentives driving investments. Capacity building initiatives have empowered governments and professionals to implement and manage renewable energy projects effectively. The international development experience has led to significant achievements, such as expanded renewable energy capacity, cost reductions, improved technology performance, and increased accessibility in remote areas. It has also contributed to the advancement of human rights, gender equality, and social justice through inclusive development approaches. Collaboration and partnerships have played a crucial role in scaling up renewable energy deployment and fostering innovation.

The significance of the renewable energy industry development trend lies in its potential to address climate change, reduce greenhouse gas emissions, and mitigate environmental impacts. By transitioning to clean and sustainable energy sources, we can achieve a more resilient and environmentally friendly energy future [128]. The development of renewable energy technologies is critical for diversifying energy sources, reducing dependence on fossil fuels, and promoting energy security. Furthermore, renewable energy offers opportunities for economic growth, job creation, and improved energy access, particularly in underserved regions. To maintain and accelerate the renewable energy industry growth, challenges such as policy uncertainties, financing constraints, and grid integration issues need to be addressed. Continued international cooperation, knowledge sharing, and financial support will be crucial in meeting climate targets and sustainable development goals [129].

The renewable energy industry development trend is of paramount importance in realizing a sustainable and clean energy future. The in-

ternational development experience has demonstrated the effectiveness of technology transfer, financial support, policy frameworks, capacity building, and partnerships in advancing renewable energy growth. By embracing renewable energy and leveraging the lessons learned from international experiences, we can transition towards a more sustainable, low-carbon, and resilient energy system for the benefit of present and future generations.

Study limitations

Despite the thorough analysis presented in this study, there are certain limitations that need to be acknowledged to fully understand the scope and implications of the research.

Temporal and geographical coverage: the study spans from 2010 to 2022, providing a comprehensive view of the renewable energy landscape during this period. However, this range may not capture the full extent of the historical development of renewable energy, especially in regions where its adoption started earlier. Additionally, the study might not include the very latest advancements or policy changes made in 2023, potentially missing out on critical updates or shifts in trends. Geographically, while the study endeavors to cover various global regions, there may be certain areas or countries that are underrepresented, leading to a skewed understanding of international growth.

Data reliability and sources: the study relies on academic articles, policy documents, and industry reports, which are credible sources. However, the availability, accuracy, and comprehensiveness of these sources can vary significantly, especially in regions with less developed research infrastructure or transparency in energy reporting. The reliance on published documents also raises the issue of publication bias, where positive results or success stories are more likely to be published than negative outcomes or challenges.

socio-economic and political complexity: while the study assesses the impact of renewable energy adoption across diverse socio-economic landscapes, the complexity and nuances of local political and economic contexts might not be fully captured [130]. The interplay of various factors such as political will, economic stability, public awareness, and cultural attitudes towards renewable energy can greatly influence the adoption rates and effectiveness of policies, which might not be entirely accounted for in the study.

Technological evolution and innovation: the rapid pace of technological advancement in the renewable energy sector is a double-edged sword. While it presents tremendous opportunities for growth and efficiency improvements, it also means that any analysis can quickly become outdated. The study might not capture the latest innovations or predict future technological breakthroughs accurately, potentially limiting its applicability for future planning and decision-making.

Environmental and ecological considerations: while the study delves into the environmental impacts of transitioning to renewable energy, the potential negative impacts of renewable energy production and infrastructure (e.g., habitat disruption by wind farms or large solar installations, and the ecological impacts of hydroelectric dams) might not be extensively covered. A more balanced perspective that critically examines the environmental trade-offs associated with different renewable energy sources could provide a more holistic understanding of their sustainability.

Future outlook

Long-term international renewable energy growth faces several challenges that need to be addressed for a successful and sustainable transition. Here are ten key challenges associated with long-term international renewable energy growth:

1. **Policy and regulatory uncertainty:** inconsistent or uncertain policy frameworks can hinder investment and slow down the growth of renewable energy [131]. Establishing stable and predictable policies is crucial to provide a supportive environment for long-term renewable energy development.
2. **Intermittency and grid integration:** renewable energy sources such as solar and wind are intermittent in nature, which poses challenges for grid integration and stability. Developing effective energy storage solutions and enhancing grid flexibility are essential to accommodate higher levels of renewable energy and ensure reliable power supply.
3. **High initial costs and financing:** the upfront costs of renewable energy technologies can be higher compared to conventional energy sources. Access to affordable financing options and financial mechanisms that de-risk renewable energy investments are needed to overcome this challenge.
4. **Limited infrastructure and grid constraints**: expanding renewable energy requires adequate infrastructure, including transmission lines, smart grids, and charging infrastructure for electric vehicles. Overcoming existing grid constraints and ensuring the availability of necessary infrastructure are crucial for seamless integration of renewable energy [132].
5. **Technological advancements and innovation:** continued research and development are essential to drive technological advancements, improve efficiency, and reduce costs in the renewable energy sector. Investing in innovation and promoting collaboration between academia, industry, and governments is necessary to overcome technological challenges.
6. **Resource availability and variability:** the availability and variability of renewable energy resources vary across regions. Not all countries have abundant solar, wind, or geothermal resources. Identifying suitable renewable energy resources and adapting technologies accordingly is crucial for maximizing renewable energy potential [133].
7. **Environmental and social impacts:** renewable energy projects can have environmental and social impacts, such as land use conflicts, wildlife impacts, and displacement of communities. Ensuring sustainable project development through proper environmental assessments, community engagement, and stakeholder participation is important.
8. **Transition from fossil fuels:** many countries still heavily rely on fossil fuels for their energy needs. Transitioning from fossil fuels to renewable energy sources requires careful planning, infrastructure upgrades, and addressing socioe-conomic challenges associated with existing fossil fuel industries.
9. **Capacity building and skill development:** building local capacity and expertise in renewable energy technologies, project development, and maintenance is crucial [134]. Providing training and educational programs to develop a skilled workforce in the renewable energy sector is essential for long-term growth.
10. **International cooperation and collaboration:** achieving long-term international renewable energy growth requires enhanced collaboration and knowledge sharing among countries. Sharing best practices, experiences, and technology transfer can help overcome common challenges and accelerate the global transition to renewable energy.

Addressing these challenges requires a comprehensive approach involving governments, businesses, communities, and international organizations. By proactively addressing these challenges, countries can unlock the full potential of renewable energy and create a sustainable, low-carbon future. Fig. 33

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Qusay Hassan: Conceptualization, Methodology, Validation, Supervision, Project administration, Writing – review & editing. **Sameer Algburi:** Investigation, Formal analysis, Visualization. **Aws Zuhair Sameen:** Data curation, Visualization, Writing – original draft. **Tariq J. Al-Musawi:** Visualization, Writing – original draft. **Ali Khudhair Al-Jiboory:** Writing – original draft. **Hayder M. Salman:** Investigation, Resources, Formal analysis. **Bashar Mahmood Ali:** Methodology, Validation. **Marek Jaszczur:** Funding acquisition, Supervision, Project administration, Writing – review & editing.

Acknowledgments

The study was funded by Al-Mustaqbal University (Proj. 1/2024).

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