Chapter 14

Solar Energy as an Alternative to Fossil Based Energy in the Emerging Geopolitical and Climate Challenges

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Abstract

United Nations's SDG goal 7 'affordable and clean energy' has been under shock and moment in the current geopolitical environment. The recent technological advancement in renewable segment has thrown new opportunities for energy transformations in favour of renewables. The present chapter has examined economics of solar energy as an alternative to fossil-based energy for achieving climate and crisis resilient challenges of energy supply in world. Descriptive statistics of solar energy show improvement in levelized cost of electricity production, per unit installed cost, reducing carbon foot print of energy, and installed capacity percentage in renewables and total energy production. Although the benign performance on Capacity Utilisation Factor (CUF) front poses challenges in utilisation of full potential in achieving climate and crisis resilient objective of the world.

Key Words: Renewable energy, carbon foot print, installed capacity etc.

Introduction

The recent outbreak of Middle East Crisis across the Persian Gulf has resulted in the almost blockade of world's one of the most important fossil fuel's supply lanes. Consequently, many countries in the world are facing shortages of fossil-based energy resources; resulted in price rise or reduced margins to the companies. This resulting in the increasing living cost across the developing and developed countries. Climate change is already under stressed due to wider use of fossils. That duo has been putting the use of fossil fuels under pressure and stressing states to look into alternatives. Solar energy is emerging an alternative to fossil-based energy; due to its improving cost competitiveness, sun light as public good, decentralised production and consumption etc.

Literature survey

Turanjanin el. al., (2009), used hourly weather data, ad deployed the dynamic simulations to finding the substitution of natural gas with solar energy. They modeled a 10,000 m^2 collector area in the plant's unused area for providing hot water to the families in the

summer months. They proposed a system that could produce heat for energy production annually, by substituting the natural gas. Study found reduction of 1,400 tons per year of CO2 emissions. But the study focussed primarily on hot water production in summers, although, the data volume of water supply was absent.

Zekai Şen (2004), has used the literature review from 1924 to 2004, of almost 80 years. Author used the Global meteorological datasets. This includes the sunshine records, irradiance records etc, the data collection was done from the stations in Greece, Nigeria, Canada, and Turkey. Scholar deployed the linear vs. non-linear estimation models for the assessment. He analysed the standard Angstrom's equation and explored some advanced methods like fuzzy logic, algorithms of genetic for spatial and temporal solar radiance production, and artificial neural networks etc. Results shows that simple linear models are physically restrictive and rely on limited assumptions of normality. Therefore, the authors proposed the 'Unrestricted Model' and use of 'Solar Irradiance Polygons' for alleviating estimation biases in the models. The proposed models will better capture the non-linear features in the data. The limitation of the study was that the basic regression techniques were failing frequently to check the validity of assumptions. This may result in the overestimation during the sunshine.

IPCC's Special Report on renewable energy (2009), a systematic literature review was published. It was based on Web of Science**,** WorldCat, and ENSAD database. Study found that renewable energy technologies, especially the solar and wind have demonstrated lower Co2 emissions in comparison to traditional fossil fuels. The study was limited on inconsistency of methods.

Hyder and Mohsan (2004) have systematically reviews the green technologies viz., wind, solar, hydropower etc. They also look into their operational dynamics including their functional advantage and technological limitations. Pakistan was the study area; and they examined the practical implications of implementing renewables and political and economic challenges before them. They argue in favour of global transition from fossil fuels towards the renewable energy sources. This will mitigate the environmental damage and control the climate change. Increased investment and policy support was suggested to ensure the smooth transition and ensuring a cleaner and stable energy future in the planet. Shahsavari et.al., (2018) found that developing countries have surpassed developed nations in greenhouse gas emissions. This was due to heavy dependency on fossil fuels. They noted solar energy's potential in reducing emissions and controlling climate change. Although, the success of this depends on the policy support.

Zhang et.al., (2022) made an exhaustive review of renewable energy and found the necessary replacement for non-renewable sources to renewable sources for mitigating environmental damage and global warming. The study found the dominance by non-renewable sources due to their long-term reliability and cost competitiveness. The recent technical efficiency improvements in the solar and wind power with the emergence of multi junction solar cells and magnetic synchronous generators resulting in improved conversion efficiency. The paper delves deeper into hybrid strategies and economic metrics like levelized

cost of energy. This shows how the renewable systems becoming competitive with the non-renewables. They suggested technical intermittency and economic barriers to be reduced to achieve a sustainable global power grid.

Maka & Jamal (2022) explores how transition from fossil fuels toward clean energy systems can address the issue of rising electricity demands and climate change. In the process large number of jobs will be created. This study serves to provide a future-oriented vision where clean-energy innovation fosters a stable climate while supporting long-term economic prosperity and human well-being. Ahmed (2022) found that traditional energy sources are the causes of most of the emissions and renewables cost reductions are reducing the emissions and making them more viable. He alos relies on the govt's policy support for the success of energy transitions. Holechek et. al., (2022) examines the possibility of the world to be net zero carbon by 2050. The study found the success will depend on massive renewables expansion, energy conservation and deployment of nuclear energy. The study documents a "Decent Living Standard" concept. That a decent living standards can be achieved by doing lifestyle changes. The consumption side of the energy is explored in decarbonisation strategy.

The Global Electricity Review 2026 by Ember explores the transition of the global power sector, and found that clean energy met all growth in global demand in 2025. The discussed shift largely made by the solar energy. This has halted the rise of fossil-based energy generation and caused renewables to overtake coal energy for the first time in over a century. The study examined the data of 215 nations and found that countries like China and India are being able to decouple the economic growth from carbo emissions. This is leading to a plateau in fossils fuel reliance. The plummeting battery costs and fast renewable deployment are putting the world in the new era of secure, emission free energy access across the globe.

Solar Futures Study (SFS) serves like a sound blueprint for transforming the USA (Unites States of America) to a decarbonised electric grid. This focus on pivotal role of solar energy in meeting climate goals. By using advanced modelling, the study found that trajectory against the rigorous decarbonisation shows that around half of the USA's electricity by 2050 will be provided by the solar energy. This requires huge investment in clean energy with the grid capacity and battery storage to manage different sources of energy. The study also looks into the job creation, better air quality and its impact on the marginalised communities. Therefore, this document function as a call of action, that solar energy is becoming cost effective and achievable. But the advantages can be taken only by the technological innovation and continuous policy support.

Islam et, al., (2026) delves into the comparative analysis of the pathways of energy transitions. And they also examined the structural differences between the Canada and Bangladesh; one is developed and other is developing country. Their study was based on univariate time series analysis. The study show that Canada has a diversified energy composition and carbon pricing mechanism to support its decarbonisation strategy. Although it faces internal political resistance and regional issues of infrastructure. While Bangladesh is heavily dependant on imported fossils. This puts the last one at the fulcrum of price fluctuations and compromised energy security. Nevertheless, its has niche solar energy

programme. The study suggests that for achieving a just and secure decarbonisation requires a coordinated policy approach integrating technological innovation, market conditions, resource endowments.

Rodrigues et. al., (2026) examines the Europe's possible efficient pathways to reach the climate neutrality by 2050. Scholars deployed advanced integrated modelling, and found that around 86 percent reduction in greenhouse gas emissions by 2040 can be achieved by becoming cost effective. The paper focuses on many fold expansion of wind and solar power, electrification of transport, and scaling of storage and carbon capture technologies.

Tagomori et. al., (2026) examines how the commitments and achievements are in line with the Paris Agreement. They found that while net-zero pledges improve our outlook compared to current policies, but a substantial ambition gap remains for limiting warming to 1.5 °C. They also emphasised that possibility of achieving the targets hinges on the long-term policy support in favour of decarbonisation strategies.

The existing literature largely examines the issue of climate change, possible pathways, technological improvement in the clean energy sector, and use of clean energy systems, decarbonisation strategies, net zero strategies etc. The issue of geopolitical disturbances got little attention. Therefore, the present chapter try to address the impact of geopolitical disturbance on energy security and solar energy as an alternative to fossil-based energy.

Objective

To examine the possibility of solar energy as an alternative to fossil-based energy in the emerging geopolitical environment and issues of climate change.

Data Base and Research Methodology

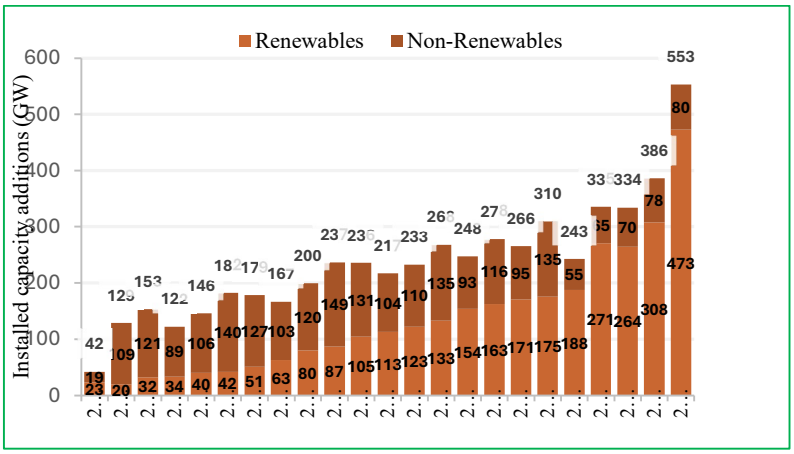
The present study is entirely based on secondary data collected from the IRENA (International Renewable Energy Agency). Variables under study are Capacity Addition by Fuel Groups**,** renewable energy installed capacity's components, renewable energy installed capacity additions by technology, average capacity utilisation factor (cuf) for different technologies, world renewable electricity generation by technology, million tonne equivalent co2 saved by renewable categories, percentage change in usd/unit installed cost of different renewables, percentage of capacity utilisation factor among renewables, levelized cost of electricity, levelized cost of renewable energy, per capita deployment of electricity etc**.** The simple descriptive statistics ahs been deployed for the analysis.

Results and Discussion

In the year 2023, total additional energy installed was around 553 Gw, out of which installed capacity from the renewable sources was around 473 GW (85.5%) and fossil sources contributes only around 14.5 percent additional capacity in 2023.

Capacity Addition by Fuel Groups in Energy Sector

Graph 1



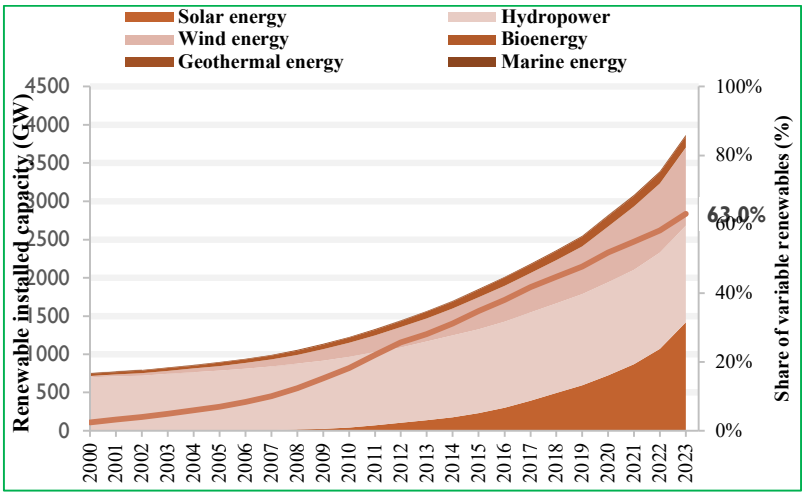
Data Source: IRENA

The graph 1 shows rrenewable capacity additions had a notable increase over the past 23 years, with 2023 seeing a peak of 473 GW of new renewable capacity. Moreover, the share of renewables in annual capacity additions has steadily increased, reaching 85.5% in 2023. Non-renewable capacity additions have remained relatively constant or decreased over the years, staying below 80 GW annually since 2019. The major increase in capacity addition was observed after the Paris Agreement, 2015, after which many countries of the world announced and submitted the Nationally Determined Contributions (NDCs) at the UN. These measures work as incentives for policy making and allocation of funds in the direction of renewable energy addition.

The graph 2 reflect the composition of renewable sources of energy in world. The contribution of Hydropower is almost constant over the study period. The increase in the renewable energy's installed capacity is largely driven by the increase in the contributions of wind energy, whose contribution stated after 2005 followed by the contribution form the solar energy, especially after the Paris Agreement. The contribution in the installed capacity from the solar energy is increasing at a faster pace in comparison to the wind due to economies of plant scale, govt polies, low investment requirement, distributional economics of it. The solar installation was increasing at the CAGR of 35.9 percent, followed by 19.5 from wind, and 7.5 from bio-energy during 2000 to 2023.

World Renewable Energy Installed Capacity's Components

Graph 2



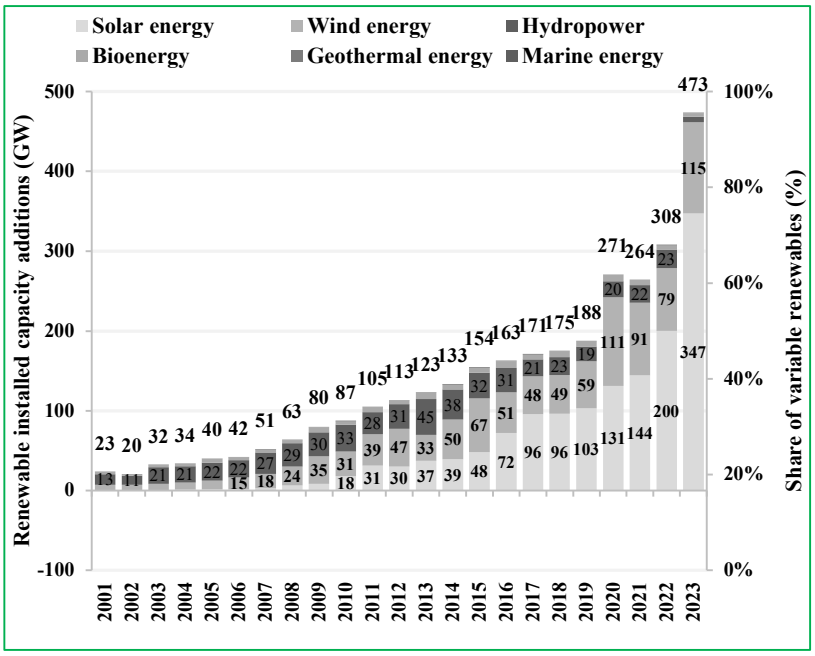
Data Source: IRENA

The graph 3 shows the World renewable energy installed capacity additions by technology during the study period. Total renewable energy additions as 473 GW, out of which solar added 346 GW i.e., 73 percent and 116 GW by wind energy (25 percent) with variable renewables of 98 percent in 2023.

Solar and wind have been the technology of choice since 2010. Solar has outpaced wind in additions consistently. The status of solar energy as the main source of capacity is likely to remain in future years, also reflected by its predominance in 347 GW out of 473 GW of renewable power additions in 2023.

World Renewable Energy Installed Capacity Additions by Technology

Graph 3

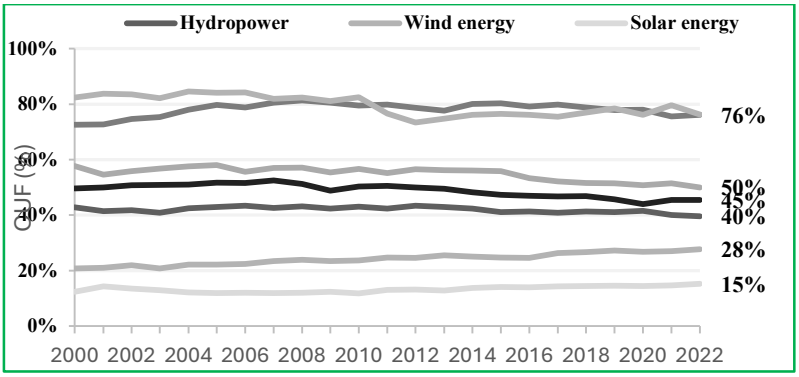


Data Source: IRENA

This increase in the contribution alone did not give us true picture about the electricity produced from renewables but the capacity utilisation factor gives us the true picture. The following graph 4 shows the capacity utilisation factor by the different technologies of power production in the world.

Average Capacity Utilisation Factor (CUF) for different technologies at World level

Graph 4



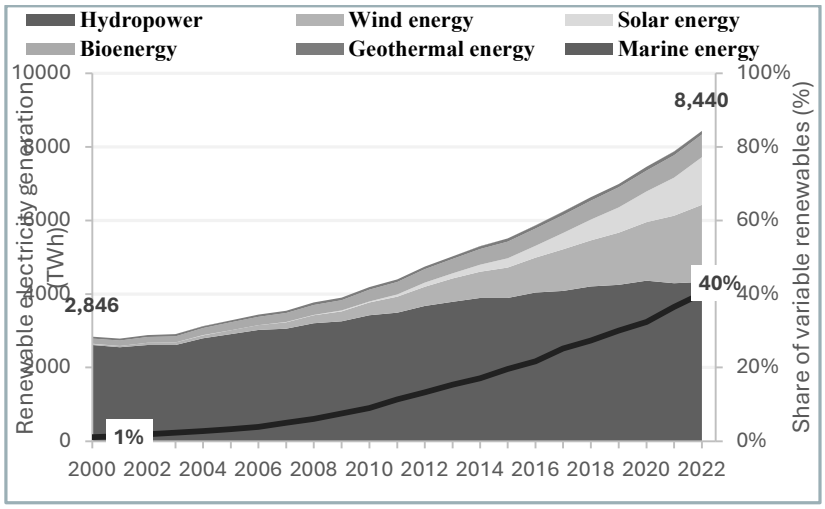
Data Source: IRENA

The largest CUFs was observed for nuclear and geothermal energy, producing at 76 percent of the plant capacity. This was followed by the bioenergy, fossil fuel and hydropower around 46 percent. Wind due to localised in nature has CUF around 28 percent. And the least is of solar energy at 15 percent. There was no significant improvement was observed in CUF of most of the energy sources except wind and solar. They are showing some improvement over the study period. That is why there are becoming efficient in the course of time. But the graphs above in the paper shows the increase in VRE, the CUF for renewables will decrease, because we require more installed capacity to produce the same amount of energy/ electricity. Bioenergy's CUF is also decreasing because biogas takes larger role than bagasse. The above discussed CUF has important implication on the energy production from different sources of energy.

The graph 5 shows the production. The year 2022 observed 8440 TWh renewable energy generation out of which 4330, 2098, 1294 TWh energy was produced by hydro, wind and solar energy respectively. Although the installed capacity in the wind and solar in 2022 was almost same.

World Renewable Electricity Generation by Technology

Graph 5



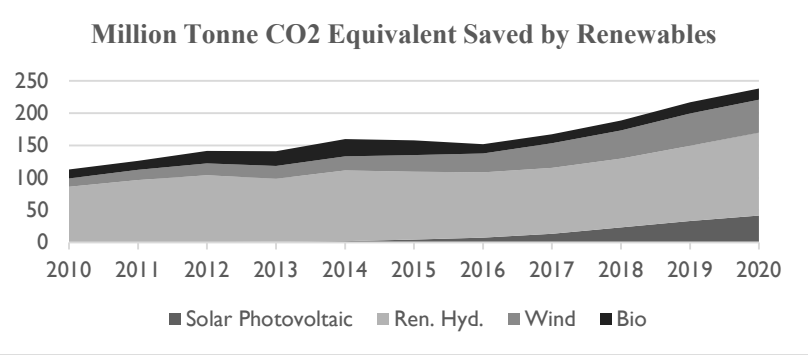
Data Source: IRENA

The 40 percent VER in 2022 was also responsible for this performance. While capacity of VRE is already over 50% of the total, generation lags at 40% due to lower capacity utilisation factors.

The Graph 7 shows the CO2 equivalent saved by the generation of renewable energy from different sources. Over the study period most of the CO2 equivalent saved by the Renewable Hydropower Sector. This was followed by the Wind energy and Biomass. Solar photovoltaic has made significant and fastest strides in the decarbonisation. The cause of this needs to be examined further.

Million Tonne Equivalent CO2, Saved by Renewable Categories

Graph-6

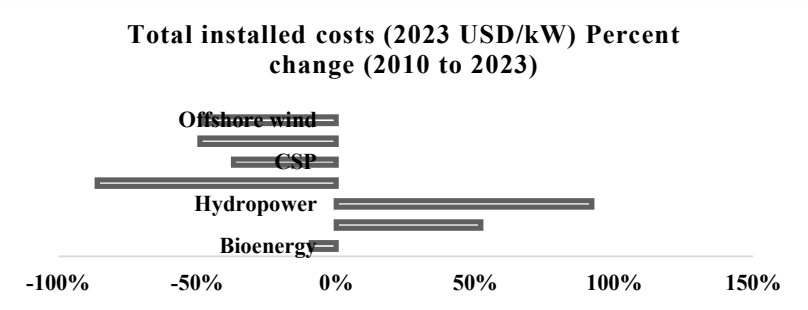


Data Source: IRENA

The above question was answered by the significant decline in the per unit cost of solar power installation across the world, caused by decent technological improvements. same is the case of wind energy. Although, installation costs of hydropower and geothermal is increasing.

Percentage Change in USD/Unit Installed Cost of Different Renewables

Graph-7

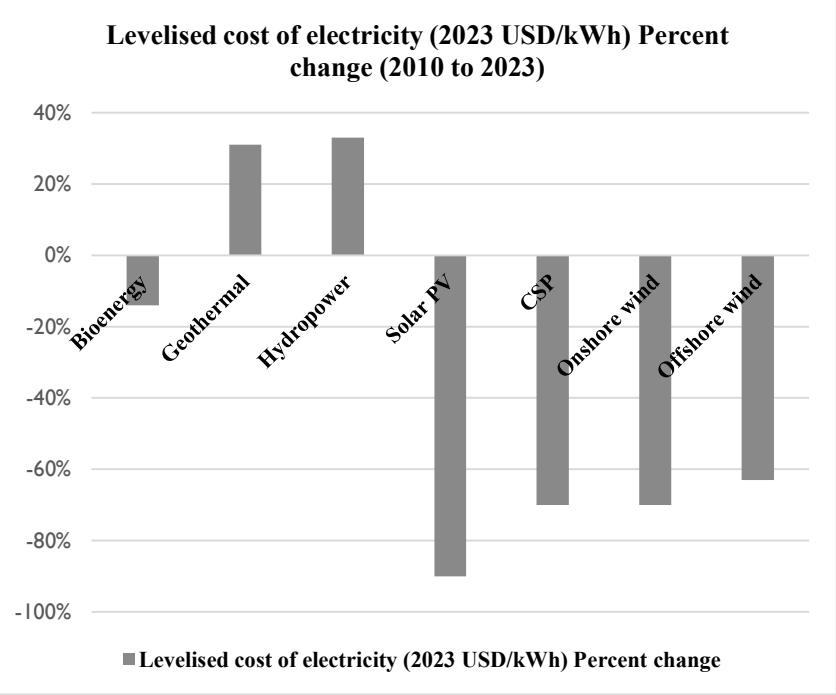


Data Source: IRENA

The Graph-8 shows the change in levelized cost of electricity from 2010 to 2023, over 13-year period. Efficiency and cost competitiveness depends on this change. Graph shows the significant improvement in levelized cost of electricity in solar photo voltaic segment followed by wind energy in the world. Although, the geothermal and hydropower are worsening in comparison to non-renewables. This all improvement is caused by the technological breakthrough, policy support, and incentives.

Percentage Change in Levelized Cost of Electricity of Renewables vs. Non-Renewables

Graph-8

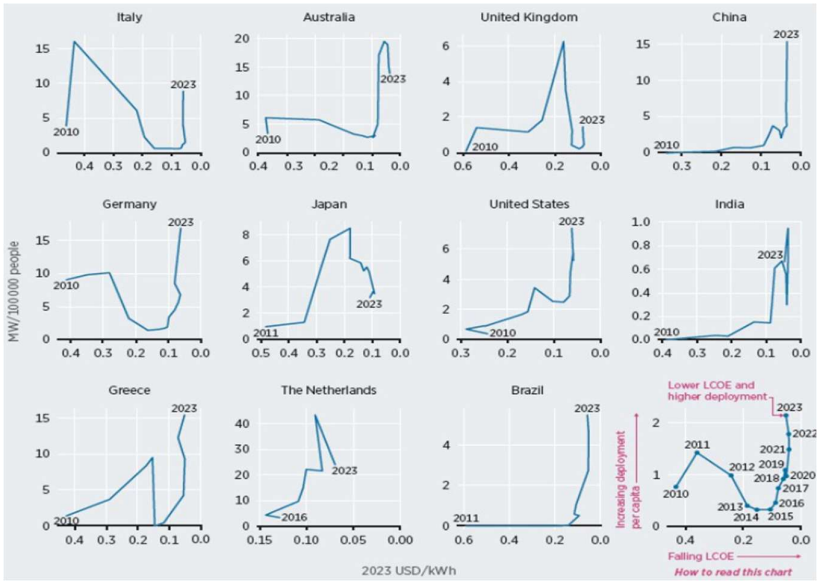


Data Source: IRENA

The Graph-8 shows the changes in annual new solar PV capacity additions per capita compared to LCOE (levelized cost of electricity) trends by country, 2010-2023. Developed economies like Italy, Germany, Australia, Netherland and Greece shows 10 to 15 MW perc capita deployment of renewable energy. In developing countries, the China is out performer and is in parity to the developed economies. India's this metric is dragged down by the huge population, although significant improvement noted in many studies.

Levelized Cost of Renewable Energy and Per Capita Deployment of Electricity

Graph-9



Data Source: IRENA

The above graph shows the decline in levelized cost of energy is an important indicator for improvement in per capita renewables installation in world, which depends on technological improvement.

Conclusion

Out of the total renewable energy production the renewables hydropower is dominating, followed by wind energy and some recent improvement in solar segment. Recent installed capacity data shows that around 85 percent of the addition in the world came from renewable energy sources. This paints a rosy picture, but still miles to go to fight climate change and reducing fossil fuel dependency of world energy production systems. As total contribution from the renewable segment is still low. The capacity utilisation factor is an important impediment in the scaling of solar energy, although some recent improvement is observed recently. Renewables segment of energy production runs the decarbonisation process.

The renewable hydropower sequestered maximum million tonnes of CO2 equivalent in the history of energy production. But recently the solar energy's sequestration speed is increasing at the fastest pace, and showing the solar energy's potential in fighting the issue of climate change. Technological breakthrough resulted in reduced per unit cost of renewables installation from 2010 to 2023, dominated by solar photovoltaic followed by solar energy. A significant decline was observed in levelized cost of renewables dominated by the solar energy, and followed by wind power. The decline in levelized cost of renewable energy directly corelates with its deployment in the world. The above-mentioned technological improvement in the solar photovoltaic show the promising future in fighting climate change, but being the solar energy as an alternative to traditions fuels requires huge investment and more sophisticated technological advancement with policy consistency in the word. After that the geopolitical uncertainties can be countered effectively.

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