GLOBAL RENEWABLE ENERGY TRENDS REPORT - 2025

ENVIRONMENT, EFFICIENCY & RENEWABLE DIVISION

Public Utilities Commission of Sri Lanka

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EXECUTIVE SUMMARY

Energy is the fundamental enabler of life on Earth. Since the Industrial Revolution, energy consumption has grown rapidly to meet human needs, predominantly through fossil fuels. However, fossil fuel-based generation has severely impacted the environment, contributing to global warming and climate change. With rising climate concerns, the global focus has shifted toward reducing emissions and accelerating the adoption of renewable energy. By 2025, renewable energy sources will have become central to the global energy supply chain, outpacing fossil fuels in new power generation capacity.

This report highlights the major trends in renewable energy up to the end of 2024. It draws on global reports to inform policy decisions, examines technological progress across renewable energy technologies, and assesses the investment viability of projects worldwide.

1. GLOBAL DEMAND TRENDS

The IEA report on **Global Energy Review 2025** has highlighted key factors in the global energy trends. The summarized key findings are mentioned below.

1.1. Energy Demand Growth

Global Energy Demand Growth

- Energy demand rose **2.2% in 2024**, faster than the decade average.
- Electricity demand surged **4.3%**, outpacing global GDP growth (3.2%), driven by heatwaves, electrification, and digitalization.

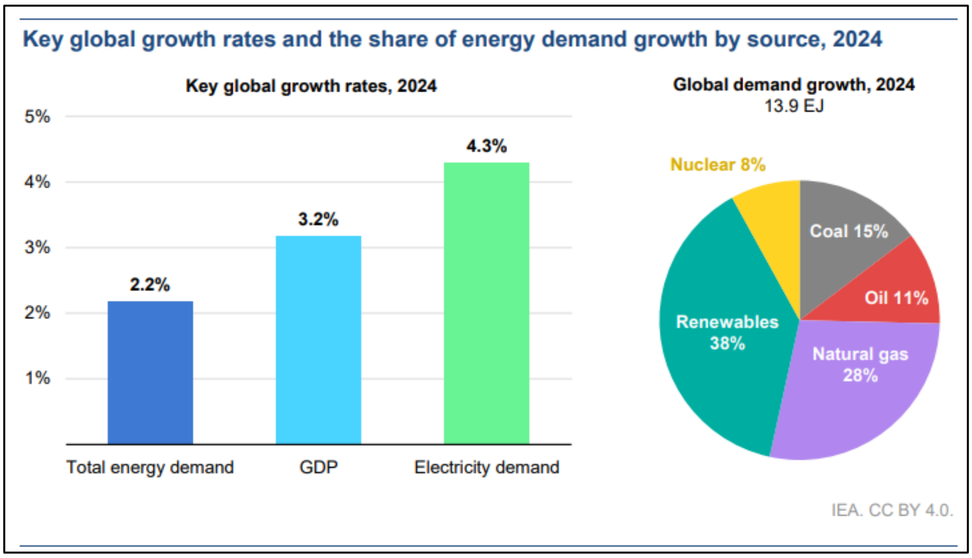


Figure 1: Global Growth Rates

Fuel Mix Contribution

- **Renewables** led supply growth (**38%**), followed by natural gas (28%), coal (15%), oil (11%), and nuclear (8%).

Regional Drivers

- **Emerging & developing economies** accounted for >80% of demand growth.
- **China**: Slower growth (<3%) but largest absolute demand increase.
- **India**: Second-largest growth, exceeding all advanced economies combined.
- **Advanced economies**: Returned to growth (~1%), with the US and EU leading.

Fossil Fuel Trends

- **Oil** demand growth slowed to 0.8%; share fell below 30% for the first time. Road transport demand declined, while aviation and petrochemicals grew.
- **Natural gas** saw the highest growth among fossil fuels (+2.7%), led by China and emerging Asian economies.
- **Coal** demand rose 1%, mainly for power generation in China and India.

Electricity Consumption & Drivers

- Global electricity use rose nearly **1,100 TWh**, over twice the decade average.
- Growth driven by cooling, industrial use, EVs, data centers, and building consumption (60% of growth).

Renewable & Nuclear Generation

- 80% of new generation came from **renewables and nuclear**, contributing 40% of total generation for the first time.
- **Renewables** alone supplied 32%; new capacity additions reached **~700 GW** (80% solar PV).
- Solar PV and wind generation increased **670 TWh**; nuclear generation grew 100 TWh with **7 GW of new capacity**.

Emissions Trends

- CO_2 emissions rose only **0.8%**, decoupling from >3% GDP growth.
- Deployment of solar, wind, nuclear, EVs, and heat pumps prevents **2.6 Gt CO_2 annually** (~7% of global emissions).
- Most emissions growth occurred in emerging economies outside China; advanced economies reduced emissions by 1.1%.

Energy Intensity & Efficiency

- Global energy intensity improvement slowed to **1% in 2024**, down from 2% average pre-2019.
- Drivers: post-COVID industrial growth in emerging economies, extreme temperatures, and underperforming hydropower.

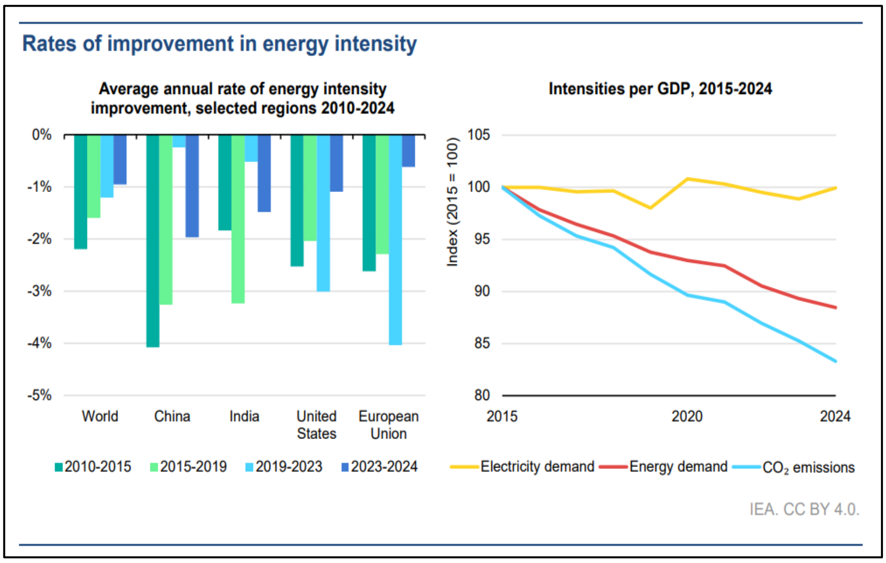


Figure 2: Energy Intensity Growth

As of the report, the global economy has moderate growth, and the energy demand has variations between regions. The largest demand growth has been recorded by China. Global energy demand rose 2.2% in 2024, reaching nearly 650 EJ. Advanced economies rebounded, with the EU and US seeing growth of 1% and 1.7% respectively, while Japan declined 1.2%. Growth in emerging economies slowed below 3%, led by China and India, reflecting post-COVID adjustments and slower industrial expansion. The main factor influencing the demand increase was the extreme weather conditions, especially the high temperature heat waves. By observing the following graphs, it was clear that the year 2024 had high temperatures compared to the previous years.

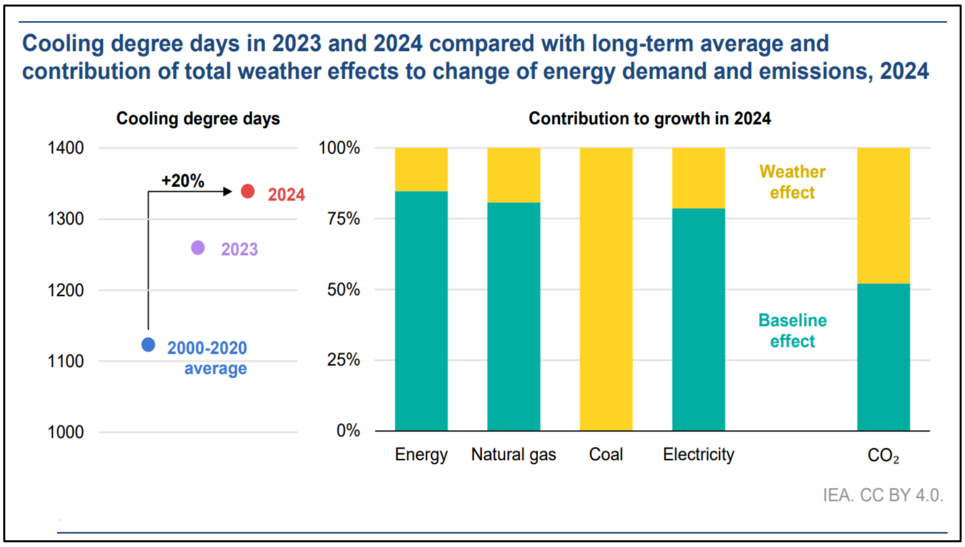


Figure 3: Cooling Degree Days in 2023 and 2024

Global oil demand growth slowed in 2024, rising just 0.8% (1.5 EJ or 830 kb/d) to 193 EJ, down from 1.9% in 2023. This slowdown reflects the end of the post-pandemic mobility rebound, slower industrial growth, and the growing impact of electric vehicles.

Global natural gas demand rebounded in 2024, reaching a new record high with a **2.7% increase (~4 EJ)**. Growth was largely driven by emerging and developing economies, marking a return to structural growth following the supply shocks of 2022–2023, and exceeding the pre-pandemic average of ~2% per year.

Global coal demand grew **1.2% in 2024** (~67 Mtce or 123 million tonnes), driven mainly by the electricity sector, which accounted for two-thirds of consumption. Coal power generation rose nearly 1% to **10,700 TWh**, supported by record temperatures and increased cooling demand, particularly in China and India. While coal remains the largest power source, its share in the electricity mix fell to **35%**, the lowest since 1974. Metallurgical coal use declined 0.5% due to slower steel production, though overall non-power coal demand grew slightly, supported by sectors like nickel mining and chemical production.

1.2. Electricity Demand Growth

Global electricity demand rose 4.3% in 2024, a sharp increase from 2.5% in 2023 and well above the 2010–2023 average of 2.7%. Electrification across sectors drove growth in most major economies, with China contributing the largest share, though nearly all regions saw accelerated electricity consumption. Overall, demand increased by 1,080 TWh, nearly double the decade's annual average.

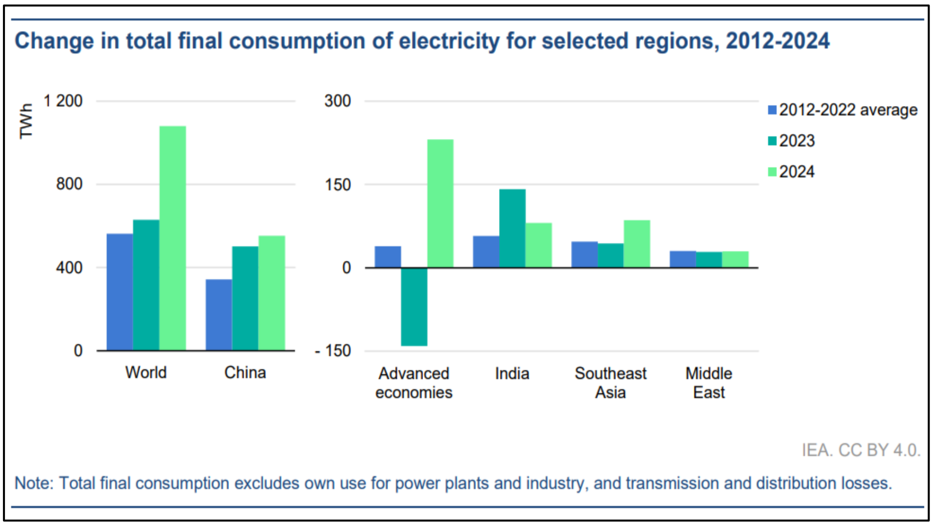


Figure 4: Electricity Consumption Comparison

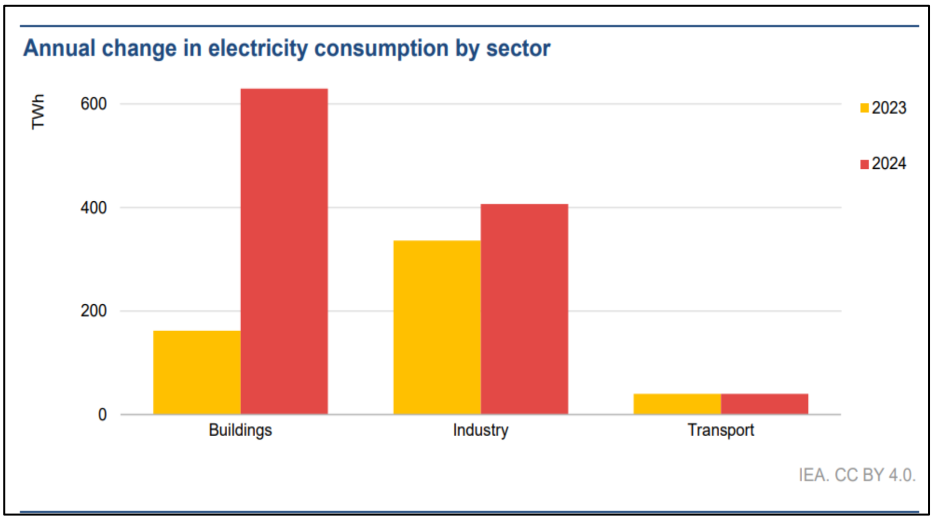


Figure 5: Electricity Consumption by Sector

1.3. Electric Vehicle Demand

As per the IEA report, Global electric car sales surged **over 25% in 2024** to more than 17 million units, representing **over 20% of all car sales. China led the growth**, accounting for nearly two-thirds of global sales with a **40% increase**, driven largely by **PHEVs (+80%)**, while BEVs grew by about 20%. Rising demand for **extended range EVs** further supported this trend.

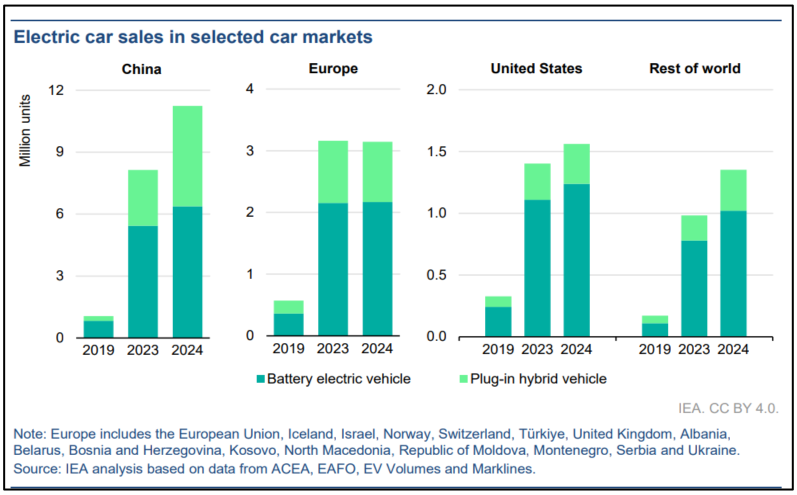


Figure 6: Global EV growth

2. GLOBAL ELECTRICITY GENERATION

As per the IEA report, the following have been observed as the major factors in global electricity generation.

- Global electricity generation grew by **1,200 TWh (4%)** in 2024.
- **Clean energy sources provided over 80%** of this growth.
- **Renewables contributed nearly three-quarters**, led by:
  - **Solar PV: +480 TWh** (fastest-growing source).
  - **Wind: +180 TWh**, but with its slowest growth rate in two decades.
  - **Hydropower: +190 TWh**, supported by wet weather in major markets.
- **Nuclear output rose 4%**, with new projects and reactor restarts in France and Japan.
- Fossil fuels still supplied ~60% of global electricity in 2024.
- **Coal (35%)** remained the largest source, followed by natural gas (>20%); oil contributed only a few percent.
- Renewables + nuclear reached **40%** of global generation for the first time.
- Within renewables: hydro **(14%),** wind **(8%),** solar PV **(7%),** bioenergy & waste **(3%).**
- Nuclear contributed **9%** of global electricity.

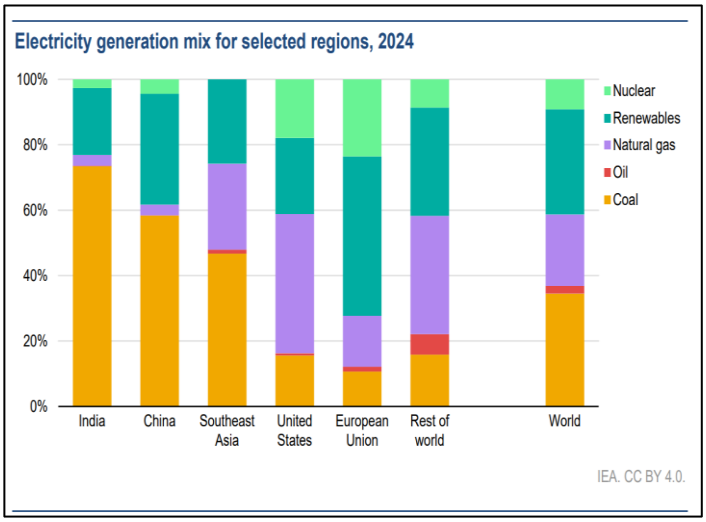
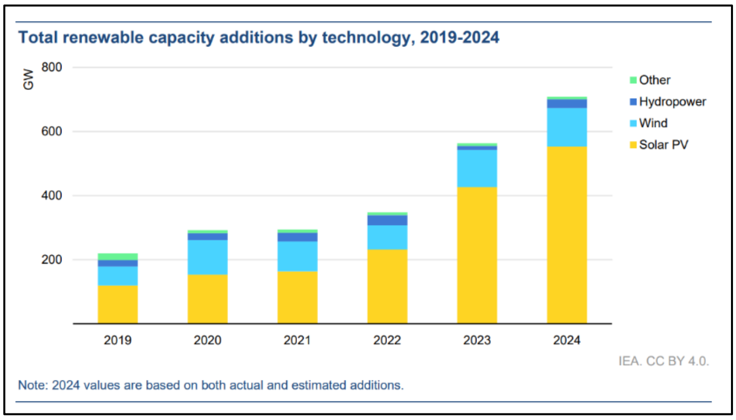


Figure 7: Global Generation Mix-2024

2.1. Solar PV and Wind Growth



In 2024, global renewable capacity grew 25% to nearly 700 GW, the 22nd straight record year. Solar PV led with about 550 GW, raising global capacity to 2.2 TW, while wind added 120 GW. Together, solar and wind made up 95% of the growth. Hydropower more than doubled to 25 GW, driven by major projects in China, Africa, and Southeast Asia, with other sources contributing marginally.

Figure 8: Solar PV and Wind Power Growth

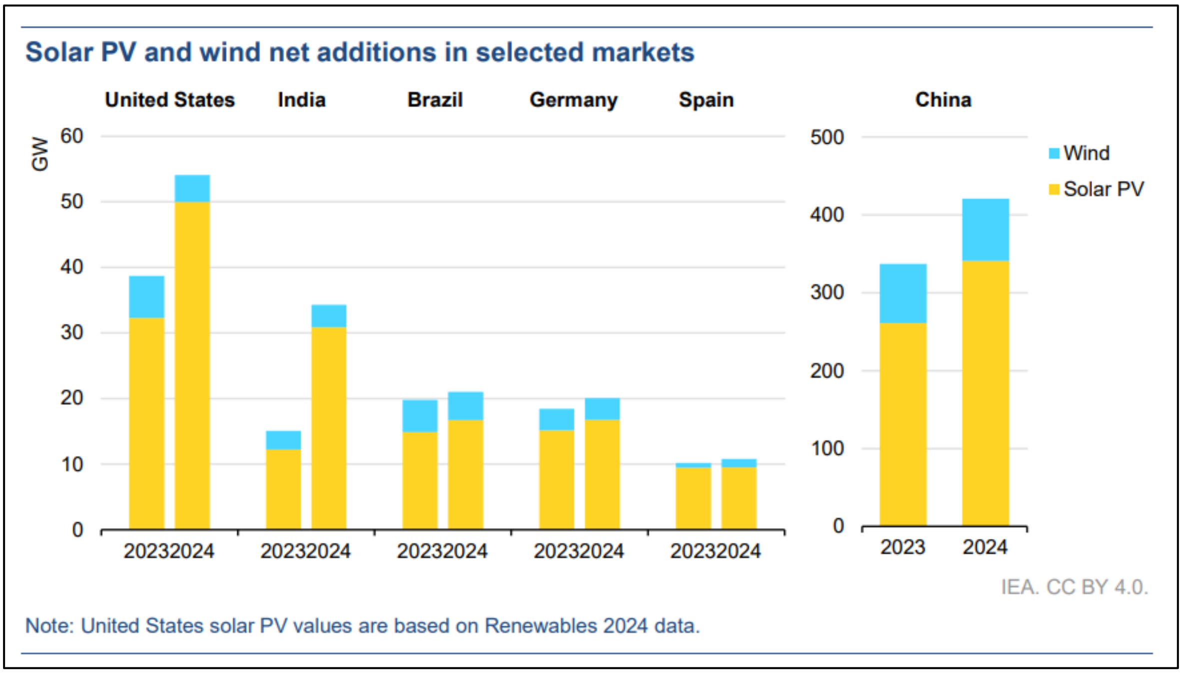


Figure 9: Solar PV and Wind Net addition in different markets

IEA report further highlights the actual electricity generation and technology growth as follows.

Table 1: Electricity Generation and Technology Deployment

	Electricity generation (TWh)			Growth rate	
	2022	2023	2024	2022-23	2023-24
Total	**29 153**	**29 897**	**31 153**	**2.6%**	**4.2%**
Renewables	8 643	9 074	9 992	5.0%	10%
Nuclear	2 684	2 743	2 844	2.2%	3.7%
Natural gas	6 526	6 622	6 793	1.5%	2.6%
Oil	801	762	738	-4.8%	-3.2%
Coal	10 452	10 645	10 736	1.8%	0.9%

	Technology deployment			Growth rate	
	2022	2023	2024	2022-23	2023-24
Electrical capacity (GW)					
Nuclear	8	6	7	-30%	33%
Solar PV	232	426	553	84%	30%
Wind	75	116	119	54%	2.9%
Electric vehicles (Millions)	**10**	**14**	**17**	**34%**	**26%**
Heat pumps (GW)	**112**	**109**	**108**	**-2.7%**	**-1.5%**

3. EMISSION TREND

In 2024, energy-related CO2 emissions rose 0.8% to a record 37.8 Gt, pushing atmospheric concentrations to 422.5 ppm—50% above pre-industrial levels. Emissions from fuel combustion grew by 1% (357 Mt), while industrial process emissions fell by 2.3% (62 Mt). Although emissions hit new highs, growth was slower than global GDP (+3.2%), restoring the long-term trend of decoupling emissions from economic growth. Emission growth was influenced by the increased use of natural gas, driven by higher demand in China, the United States, the Middle East, and India. ‘

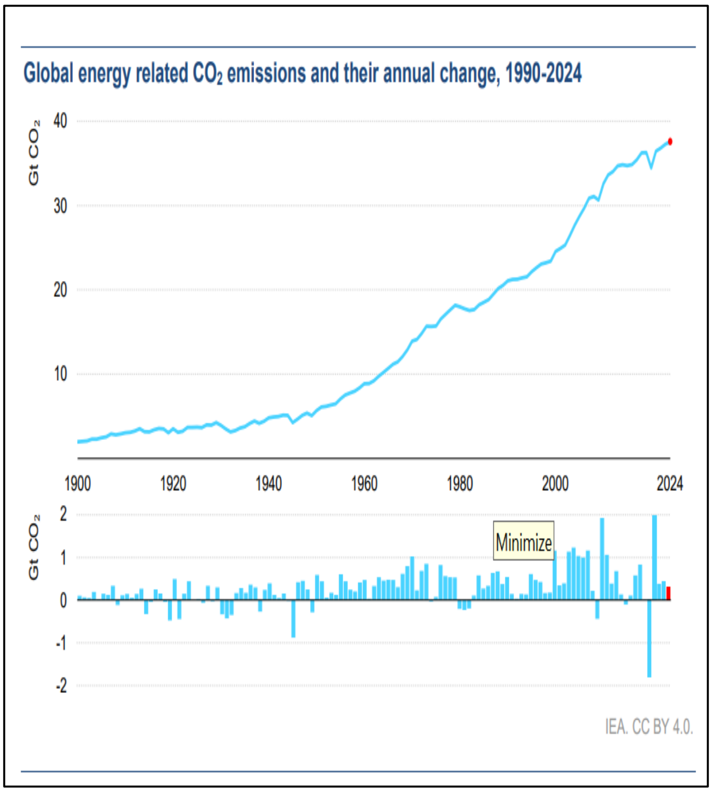


Figure 10: Energy Related Emission

Despite the overall global increase, energy-related CO2 emissions in advanced economies fell by 1.1% (120 Mt) in 2024. This was driven by a 5.7% drop in coal emissions and a 0.5% decline in oil emissions, partly offset by a 0.9% rise in natural gas emissions. The reduction reflects the growing share of low-emission sources, with renewables and nuclear providing over 50% of electricity generation, led by strong growth in wind and solar.

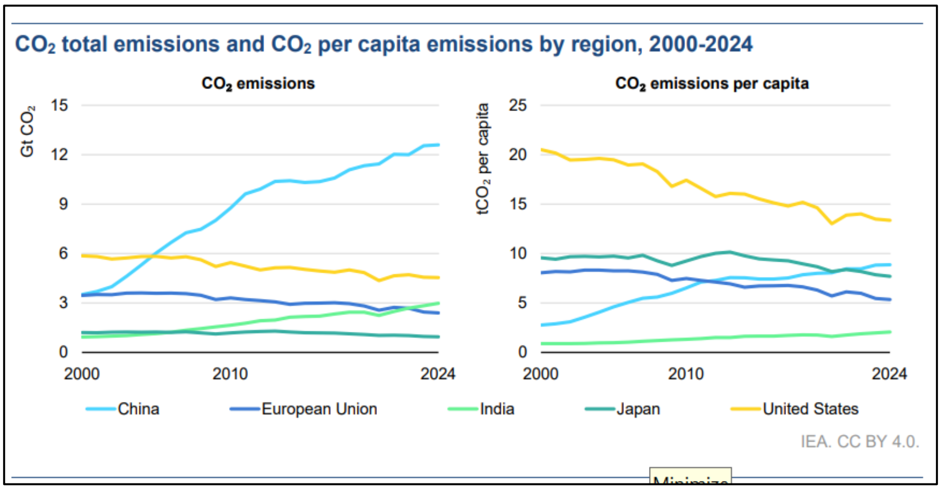


Figure 11: CO_2 emissions by region

Despite rising global emissions, clean energy technologies have begun to make a significant impact. Between 2019 and 2024, the rapid expansion of solar PV, wind power, nuclear power, electric cars, and heat pumps avoided over 30 EJ of fossil fuel demand, about 6% of global fossil fuel use in 2024, equivalent to the combined energy demand of Japan and Korea. While global emissions still rose by 1.3 Gt CO2 over this period, these technologies slowed the pace of growth by preventing about 2.6 Gt of emissions annually, or 7% of global energy-related emissions. Without them, the increase would have been three times greater. Their effect has been especially strong in Australia, China, the EU, and New Zealand, where they avoided more than 10% of energy-related emissions in 2024.

4. RENEWABLE ENERGY GROWTH FORECAST

According to Renewables 2024: Analysis and Forecast to 2030 by IEA, renewable energy consumption across the power, heat, and transport sectors is projected to rise by nearly 60% between 2024 and 2030, increasing its share in final energy consumption from 13% in 2023 to almost 20% by 2030. More than three-quarters of this growth is expected to come from renewable electricity generation, supported by policies in over 130 countries, declining technology costs, and the electrification of road transport and heating. Renewable fuels, including bioenergy, hydrogen, and e-fuels, account for around 15% of forecast growth, expanding rapidly in sectors that are difficult to electrify, such as aviation, marine transport, and biomass-based industries. The remaining 10% of growth is anticipated from other renewables such as solar thermal and geothermal.

- In the electricity sector, the renewable energy share is forecast to rise from **30% in 2023 to 46% in 2030**.
- **Solar and wind** account for almost all of this growth.
- This expansion **helps decarbonize other sectors** where electricity is used, including industrial processes, building heating, and EV charging.
- **Renewable electricity** is used to produce renewable hydrogen, which accounts for **about 75% of renewable hydrogen demand in 2030** for materials, chemicals, and power production.
- In the **heat sector**, the renewable share is expected to reach **~20%**, supplied by solid and gaseous bioenergy, solar thermal, geothermal energy, and ambient heat.
- In the **transport sector**, renewable energy is projected to cover **6% of total demand**, mainly from **liquid biofuels**, with smaller contributions from **hydrogen and e-fuels**.

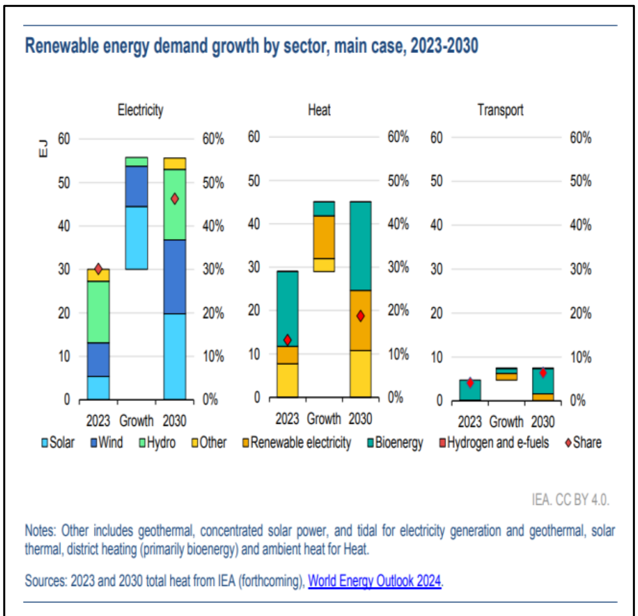


Figure 12: RE Growth by Sector

- Electricity continues to make up only a small share of total, with global consumption accounting **for 23% in 2030**.

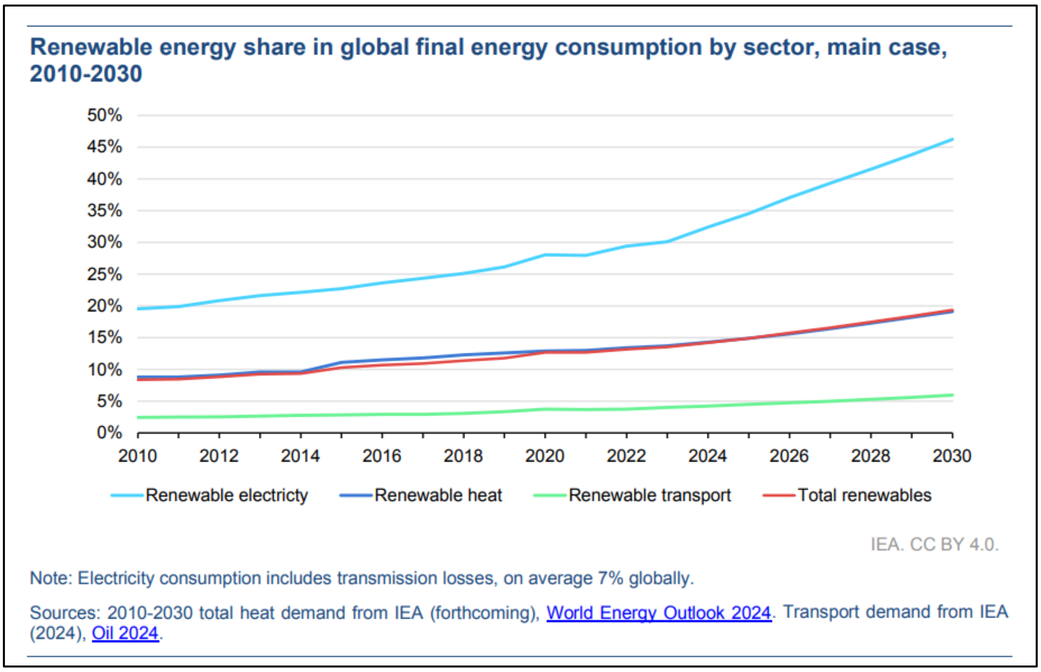


Figure 13: RE share by Sector 2010-2030

4.1. Renewable Electricity

The report further states the following facts,

- Global renewable electricity generation is projected to exceed **17,000 TWh (60 EJ) by 2030**, nearly **90% higher than in 2023**, enough to meet the combined 2030 demand of China and the U.S.
- **2024**: Solar PV and wind generation together surpass **hydropower**.
- **2025**: Renewable electricity generation overtakes **coal-fired generation**.
- **2026**: Wind and solar generation each surpass **nuclear**.
- **2027**: **Solar PV** generation surpasses wind.
- **2029**: Solar PV surpasses **hydropower**, becoming the largest renewable source.
- **2030**: **Wind generation surpasses hydropower**; renewables provide **46% of global electricity**, with wind and solar PV together making up **30%**, and solar PV leading among renewables
- By 2030, variable renewables (solar PV and wind) will account for two-thirds of global renewable electricity generation, up from less than 45% today.
- Solar PV's share in meeting global power demand is expected to triple, while wind nearly doubles.
- Hydropower generation continues to grow, mainly in emerging and developing countries, but its share in total power generation declines slightly.
- The share of other renewables—bioenergy, concentrated solar power, and geothermal—remains under 3%.
- As variable renewables contribute 90% of renewable generation growth, additional power system flexibility will be needed.

- Bioenergy, geothermal, and concentrated solar power expansions remain limited, despite their key role in integrating wind and solar PV into electricity systems.

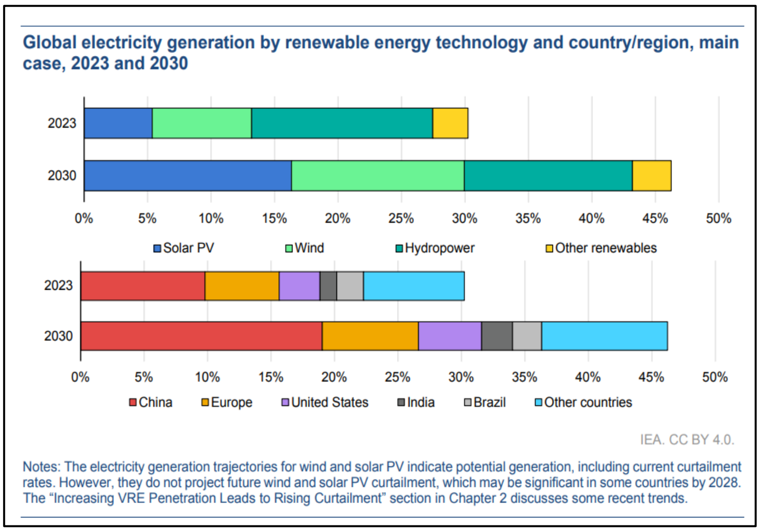


Figure 14: RE Generation Region-wise

According to the IEA forecast, the **main-case renewable electricity trajectory** is **not on track** to meet the IEA Net Zero Emissions by 2050 (NZE2050) goals. The NZE2050 Scenario requires renewables to reach **~60% of global electricity generation by 2030**. The **main-case forecast** falls short by **14 percentage points (~5,000 TWh)** compared with the NZE2050.

4.2. Renewable Transport

As per the IEA forecast, over the next six years, renewable energy demand in the transport sector is expected to rise by 3.0 EJ, double the 1.5 EJ growth recorded between 2017 and 2023. This expansion will be more diverse, with contributions from renewable electricity, aviation and marine biofuels, hydrogen, and e-fuels complementing road transport biofuels. While road biofuels accounted for nearly 90% of renewable transport demand growth during 2016–2023, their share is projected to decline to 33% over the next six years, with renewable electricity making up 50%, aviation and marine biofuels 10%, and hydrogen and e-fuels 7%.

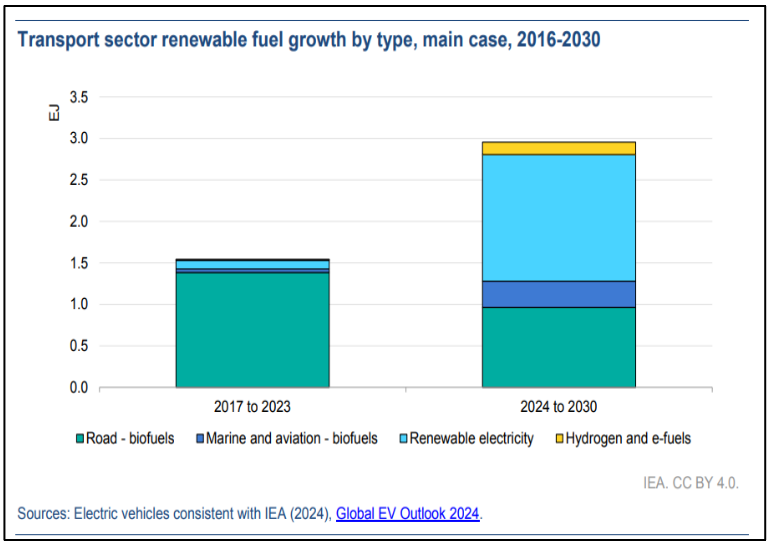


Figure 15: RE Fuel Growth

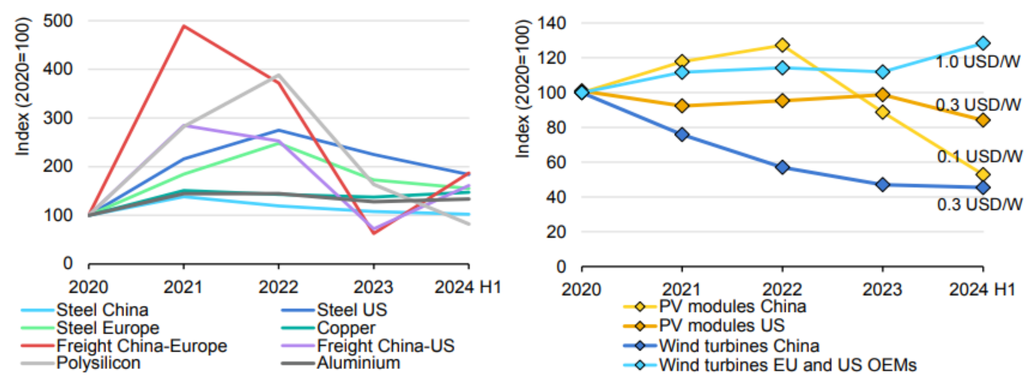
4.3. Renewable Heat

Heat remains the largest end-use energy sector, accounting for nearly half of global final energy consumption and almost 40% of energy-related CO_2 emissions in 2023. Between 2017 and 2023, annual heat demand grew by 7% (+14 EJ), but only half of the additional demand was met by modern renewable heat, leading to a 5% rise in heat-related CO2 emissions, mainly in industry. In 2023, factors such as high interest rates, inflation, reduced construction activity, lower natural gas prices, and shifting policies impacted renewable heat markets. Although heat pumps and solar thermal and geothermal systems have low operating costs, their high upfront investment makes sales sensitive to borrowing costs and consumer sentiment. The global heat pump market stalled in 2023, with newly installed capacity 3% lower than 2022. In Japan, air-to-water heat pump sales fell 10% year-on-year, while in the United States, air-to-air heat pump sales dropped 15%, partly due to high borrowing costs and consumer hesitation.

5. POLICY, TECHNOLOGY AND MARKET TRENDS

Solar PV generation costs are declining due to record-low module prices, while wind power costs remain pressured by supply chain constraints. Raw materials and logistics significantly influence costs, with steel contributing 6–8% for PV and wind, copper 1–2%, aluminum 5–6% for PV, and freight and transport 1–2% for PV and 6–8% for wind. After the COVID-19 economic recovery, these input costs surged, peaking in mid-2022, which raised benchmark PV and wind project costs by approximately 20% between 2020 and 2022. Input prices have since fallen as supply chains eased, except freight, which rose in 2024 due to Red Sea shipping disruptions. Financing costs, measured by the weighted average cost of capital, also increased by 1–2 percentage points in 2023 amid higher interest rates.

Price indices for raw materials and freight (left), and PV modules and wind turbines (right), 2020-2024

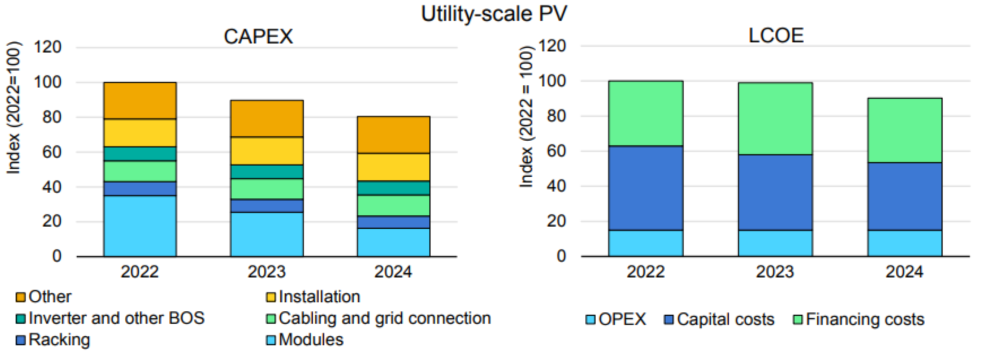


Notes: OEM = original equipment manufacturer.

Source: IEA analysis based on BNEF and PV Infolink data.

Figure 16: Price Indices for Raw Materials, PV modules, and Wind turbines

Index and component breakdown of benchmark utility-scale PV system CAPEX (left), and LCOE (right), 2020-2024

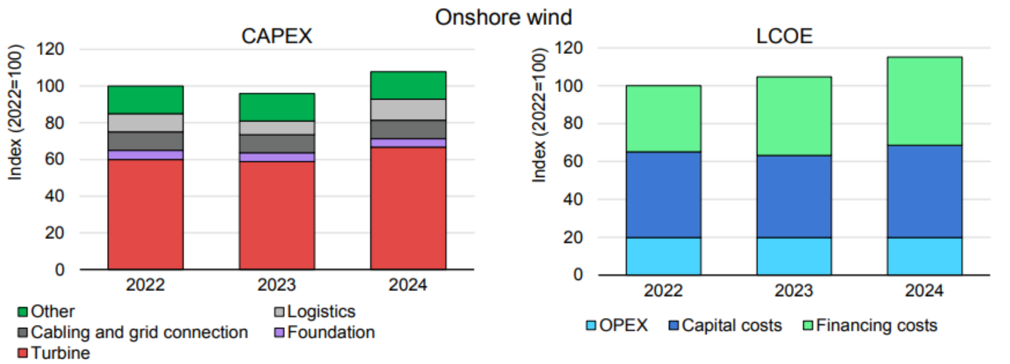


Notes: CAPEX = capital expenses; OPEX = operating expenses; LCOE = levelised cost of energy; BOS = balance of system; Benchmark PV investment assumptions for 2022: CAPEX of USD 0.8/W; 1 200 full-load hours; fixed OPEX of USD 0.01/W/year; WACC of 5%; and 25-year project lifetime.

Source: IEA analysis based on BNEF and PV Infolink data.

Figure 17: Utility Scale PV System Cost Index and Breakdown

Index and component breakdown of onshore wind CAPEX (left), and LCOE (right), 2020-2024



Notes: CAPEX = capital expenses. OPEX = operating expenses. LCOE = levelised cost of energy. Benchmark onshore wind investment assumptions for 2022: CAPEX of USD 1.7/W; 2 600 full-load hours; fixed OPEX of USD 0.03/W/year; WACC of 5%; and 25-year project lifetime.

Source: IEA analysis based on BNEF and PV Infolink data.

Figure 18: Index and component breakdown of onshore wind

5.1. Policy and markets

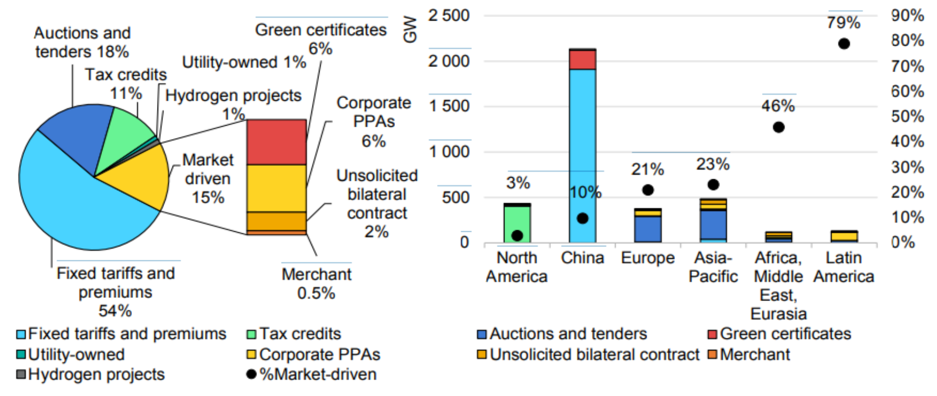
Deloitte's Renewable Energy Industry Outlook highlights five key factors shaping the sector. Federal policy levers are driving growth by aligning industrial policy goals with renewable expansion. Data centers, fueled by the rise of AI, are accelerating demand and broadening renewable energy capabilities. Technological innovation is enabling 24/7 renewable solutions, strengthening system reliability. Workforce development is also a priority, as firms address skills gaps and expand renewable jobs. Finally, carbon management is emerging as a critical area, with renewables underpinning high integrity offset strategies.

The IEA report identified that Policies continue to be the primary driver for renewable capacity additions, though market-driven growth is emerging. Nearly 84% of global utility-scale renewable capacity growth in 2024–2030 is expected to be policy-driven, similar to last year. Policy-driven deployment includes government incentives such as administratively set tariffs and premiums, which account for almost two-thirds of additions, competitive auctions at over one-fifth, tax credits at 13%, and utility-owned projects at 1%. Market-driven deployment is projected to make up 15% of growth, slightly higher than last year, mainly due to green certificate schemes in China, with corporate power purchase agreements accounting for more than 40% of this segment. IEA Renewable energy procurement and policy categories to faster adaptation of renewable energy are mentioned in the following table.

Table 2: Renewable energy procurement and policy categories

Type	Name	Primary driver
Policy-driven	Utility-owned projects	State-owned utility investments for cost recovery or obligation to meet targets
	Fixed tariffs and premiums	Administratively set tariffs offered to developers
	Auctions and tenders	Government solicitations for power using tenders with competitively set tariffs
	Tax credits	Reduced tax liability
Market-driven	Unsolicited bilateral contracts	Bilaterally negotiated contract between a developer and utility
	Merchant	Revenues from the wholesale market
	Corporate PPAs	Bilaterally negotiated contract between a developer and end user
	Green certificates	Revenues from the wholesale and green certificates market
Hydrogen-driven	Hydrogen projects	Demand of renewable electricity from electrolysers

Utility-scale renewable electricity capacity by primary driver, 2024-2030



Notes: Primary drivers refer to the financial incentive or revenue stream by which the investment decision is made. In some markets, projects can benefit from multiple financial incentives and/or stack different revenue streams, but data in this analysis are classified based on assumptions of which incentive or revenue stream most affects the business case for investment. For example, if a project is awarded through a government-held contract-for-difference (CfD) auction, the entire project is assigned to that category regardless of it having other revenue streams such as a corporate PPAs or merchant tail. Forecast refers to utility-scale projects for primary markets equivalent to 95% of global renewable electricity capacity growth. Shares might not add up to 100% due to rounding.

Figure 19: Primary Drivers for Utility-Scale Projects

Solar PV contract prices continue to decline while inflationary pressure persists for wind In the last decade, average auction prices for utility-scale solar PV projects have fallen continuously in all regions. For onshore wind, however, average auction prices have been increasing since 2020. Utility-scale solar PV costs decreased in all regions and settled at an average of USD 40/MWh in the first half of 2024. This drop was instigated largely by India, which led the world in terms of volume of solar PV capacity awarded in auctions and achieved an auction price of USD 34/MWh. In contrast, Europe achieved an average price of USD 67/MWh for projects awarded in auctions in 2024, which represents a reduction of 11%.

Onshore wind prices in the first half of 2024 show mixed regional trends. Globally, the average price fell slightly by 2%, but Europe saw a 2% increase to USD 81/MWh, continuing a rise since 2021. In India, prices rose 12% from USD 39/MWh to USD 43/MWh. The Asia-Pacific region overall saw a 36% decline due to lower prices in Japan, the Philippines, and Thailand compared with 2023.

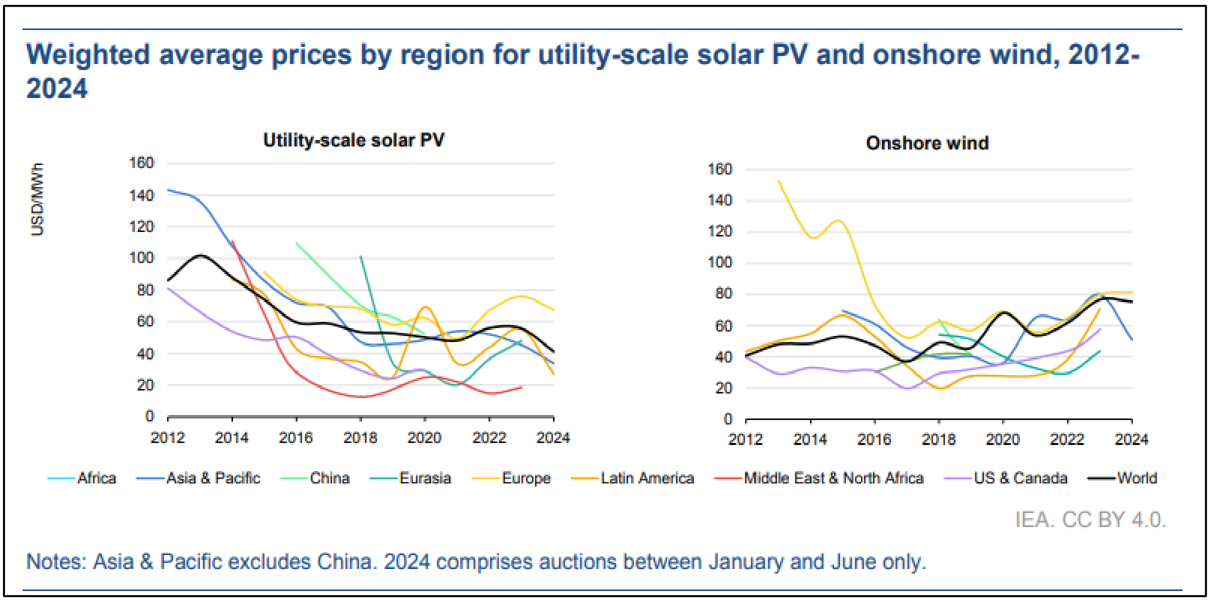


Figure 20: Weighted Average Prices by Region

The role of non-price criteria in renewable energy auctions is becoming increasingly important. In the past, only a few countries, such as China and South Africa, applied such criteria, while most others focused mainly on price to reduce costs and government support. The introduction of zero-price bids in Germany's 2017 offshore wind auctions marked a turning point, encouraging more governments to adopt non-price measures to differentiate bids. Since then, supply chain risks, cybersecurity concerns, sustainability goals, and policies to promote local manufacturing have further accelerated this shift. By including non-price factors, governments can achieve broader objectives such as renewable energy integration, supply chain diversification, local economic growth, and sustainability of equipment sourcing. These measures can also strengthen community benefits, increasing public acceptance and reducing barriers to deployment. However, the inclusion of non-price criteria may lead to higher awarded prices in the short term, reduced focus on cost minimization, and increased administrative burdens on developers. It can also create additional challenges in project planning and compliance, requiring stronger monitoring and legal oversight to ensure fairness.

The IEA report further identified the following market dynamics in the solar PV and wind industry.

Solar PV trade dynamics

- Supply chain diversification, industrial policies, and trade measures are reshaping global solar PV exports and imports.
- In June 2024, ten key solar PV markets introduced trade measures such as import tariffs and antidumping duties.
- Chinese solar PV exports face restrictions in the **United States, India, and Türkiye** due to strict trade policies.
- Chinese exports are expected to remain **strong in Europe and Brazil** in the short term.
- In the **European Union**, the pace and effectiveness of non-price criteria will influence Chinese export volumes in the medium term.

Wind industry recovery

- The wind sector is beginning to recover after severe financial struggles.
- Western wind equipment manufacturers have recently achieved **positive net margins (~1%)** after **seven quarters of losses**.
- Chinese wind manufacturers continue to show strong performance due to:
  - stable macroeconomic conditions
  - competitive local supply chains
  - robust domestic demand
  - gradual international market share growth

Contrast between Western and Chinese wind manufacturers

- **Western manufacturers**: impacted by supply chain issues, rising inflation, and high interest rates.
- **Chinese manufacturers**: stable and profitable, benefiting from local advantages.

EU policy response

- **October 2023**: European Commission launched the **Wind Power Action Plan** to strengthen environmental and innovation standards and create a level playing field.
- **December 2023**: Energy ministries of **26 EU member states** endorsed the **European Wind Charter**, supporting proposals in the Wind Power Package.
- Goal: protect Europe's wind industry from unfair trade practices and boost domestic manufacturing

The latest Bloomberg NEF (BNEF) report released on February 6, 2025[13], highlights that the costs of clean power technologies such as wind, solar, and batteries are continuing to fall, with further declines of 2–11% expected in 2025. By 2035, the levelized cost of electricity (LCOE) for these technologies is projected to fall by 22–49%. In 2024, battery storage costs dropped by one-third to $104/MWh due to oversupply from weaker electric vehicle sales, and they are expected to fall below $100/MWh in 2025. Solar also saw a sharp cost reduction of 21% in 2024, driven by oversupply and module prices falling to or below production costs, while wind and solar benchmark costs are forecast to drop another 4% and 2% in 2025, respectively.

The report notes that new solar and wind plants are already cheaper than new coal and gas projects in nearly every market worldwide. In the United States, new solar plants are approaching parity with new gas plants despite domestic gas being far cheaper than in Europe or Asia, which suggests solar could become even more competitive if the US gas market is exposed to global prices through LNG exports. However, China's manufacturing overcapacity has fueled protectionist measures such as tariffs in other countries, potentially slowing cost declines in the short term.

6. GRID INTEGRATION

The IEA defines six phases of variable renewable energy (VRE) integration, linked to increasing system impacts from solar PV and wind growth.

Phases 1–3 (early stages):

- VRE has a relatively low impact on the power system.
- Challenges can be managed through operational improvements or adjustments to existing assets.

Phases 4–6 (advanced stages):

- High VRE penetration leads to new system challenges.
- Issues include:
    - Reduced availability of conventional generation.
    - Surplus electricity during low-demand periods.
    - Greater need for flexibility across all time frames.
- Addressing these requires transforming how power systems are **planned, operated, and financed**.

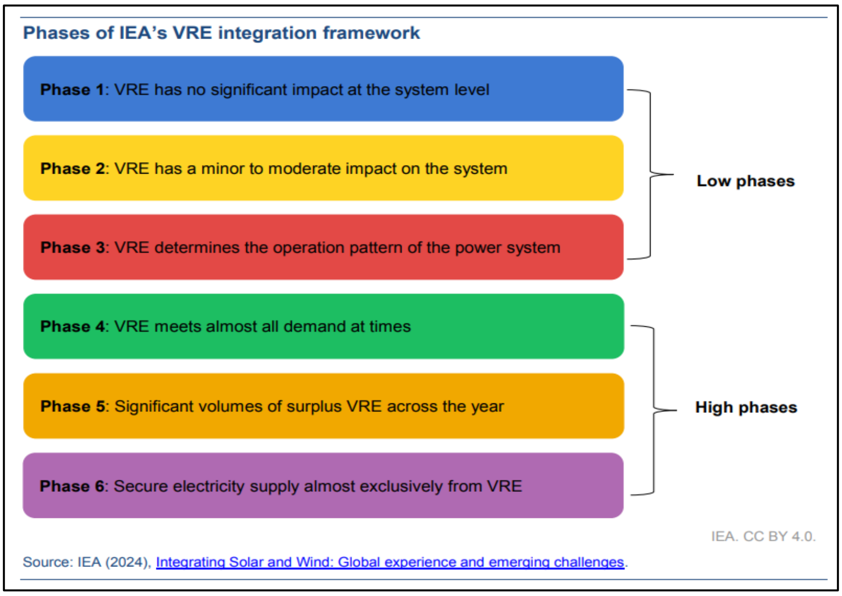


Figure 21: IEA's VRE Integration Framework

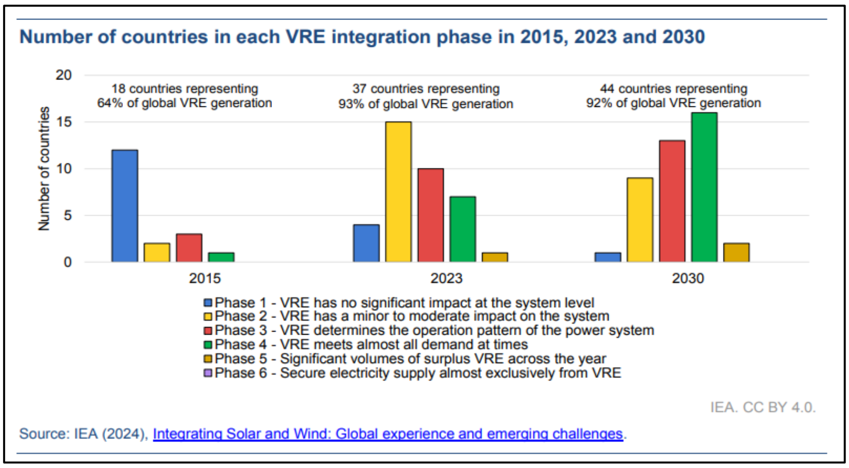


Figure 22: VRE integration phases 2015, 2023, 2030

The above graphs show the number of countries in the different phases identified by IEA. In the IEA's assessment of 37 countries, representing 93 percent of global solar PV and wind generation, most were in Phase 2 or 3 in 2023. Phase 2 countries, such as South Africa, India, and France, show only minor system impacts, while Phase 3 countries, including Italy, Australia, and Chile, face "duck curve" challenges requiring added flexibility. By 2030, most will move to Phase 3 or 4, with 16 countries expected to see VRE generation exceed demand for several hours a year. Denmark is currently the only country in Phase 5, but Ireland is projected to reach it by 2030.

Increasing VRE penetration is driving higher curtailment, underscoring the need for greater system flexibility. Curtailment is most evident in markets with rapid solar PV and wind deployment, where infrastructure and integration measures lag behind. In the early 2010s, China curtailed about 15% of its VRE generation. Since then, strong national and provincial measures, investment in grid infrastructure (around USD 75 billion annually), improved project siting, feed-in-tariff adjustments, and market reforms have reduced curtailment below 3% since 2020. In 2023, curtailment in China stood at 2.0% for solar PV, 2.7% for wind, and 2.4% combined, with wind remaining the most curtailed source.

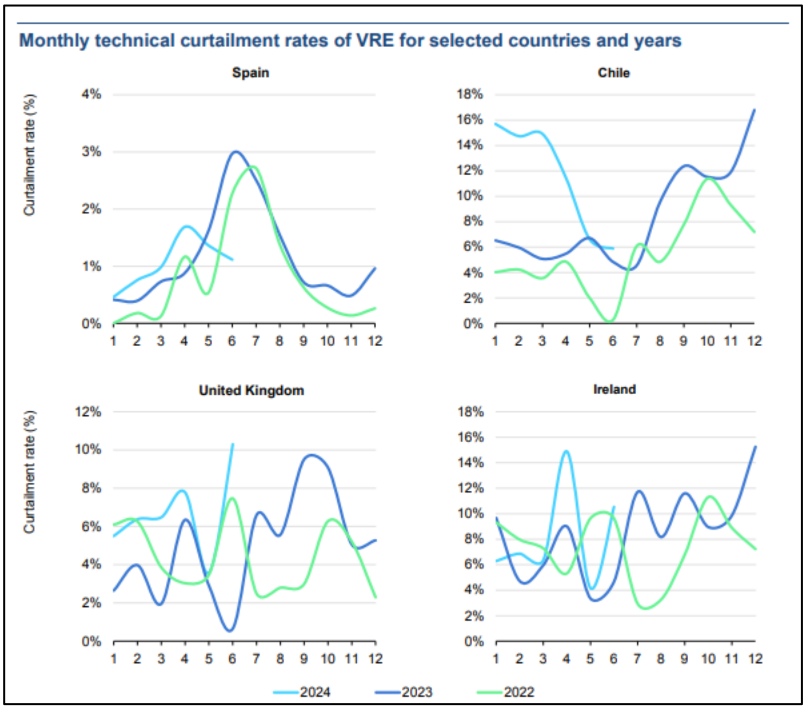


Figure 23: Monthly technical curtailment rates of VRE for selected countries and years

7. RENEWABLE HYDROGEN

In IEA's assessment, global electrolyser capacity is expected to rise by 47 GW between 2024 and 2030, reaching nearly 50 GW, equal to Sweden's total installed capacity. China and Europe account for 59% of this growth, while MENA, India, the United States, and Australia make up around 40%. Smaller contributions are expected from Canada, New Zealand, Asia Pacific, Latin America, and sub-Saharan Africa.

China

In IEA's assessment, China will add over 15 GW of electrolyser capacity by 2030, mainly through state-owned enterprises, to meet national and provincial hydrogen and emissions goals. National targets include peaking emissions by 2030, reaching net zero by 2060, and producing 0.1–0.2 Mt of renewable hydrogen annually by 2025. Provincial governments are providing additional support, particularly for hydrogen and fuel-cell vehicles. However, growth depends on hydrogen's cost competitiveness with fossil alternatives and the expansion of transport infrastructure.

Europe

In IEA's assessment, Europe is forecast to add 12 GW of capacity by 2030, supported by EU and member state policies aimed at energy security and climate neutrality. EU targets 40 GW of electrolysers by 2030, with demand driven by mandates under RED III and aviation rules (ReFuelEU). Financial tools such as grants, auctions, IPCEI, the Innovation Fund, and the EU Hydrogen Bank are also in play, with 2 GW already awarded since 2023. Still, IEA notes that the region may fall short of its 40 GW target due to regulatory uncertainty, slow subsidies, weak demand, and infrastructure bottlenecks, though Germany has committed €4 billion through carbon contracts for difference to stimulate demand.

India

In IEA's assessment, India could reach 5 GW by 2030, supported by national tenders and state-level incentives. The first hydrogen tender of 410 kt per year was oversubscribed by 30%, showing market interest. Still, uncertainty remains regarding sufficient support levels, industry mandates, and land acquisition. Export potential for renewable ammonia is seen as a long-term growth driver.

Middle East & North Africa (MENA)

In IEA's assessment, MENA will add 6.3 GW by 2030, led by Saudi Arabia, Oman, and Egypt, leveraging abundant solar and wind resources, land availability, and trade access. Oman is offering favourable land leases, Egypt provides tax exemptions, and Saudi Arabia supports projects through financing and state ownership, with the 2.2 GW Neom project already reaching financial close. Growth will depend on offtake agreements, with Europe expected as a major demand source, including Germany's H2Global tender that awarded supply from Egypt.

United States

In IEA's assessment, the United States could deploy over 3.4 GW by 2030, supported by Inflation Reduction Act (IRA) tax credits, hydrogen hubs, and state-level incentives. However, uncertainty over IRA 45V tax credit eligibility, particularly time and location matching rules, has delayed some projects until clearer guidance is provided.

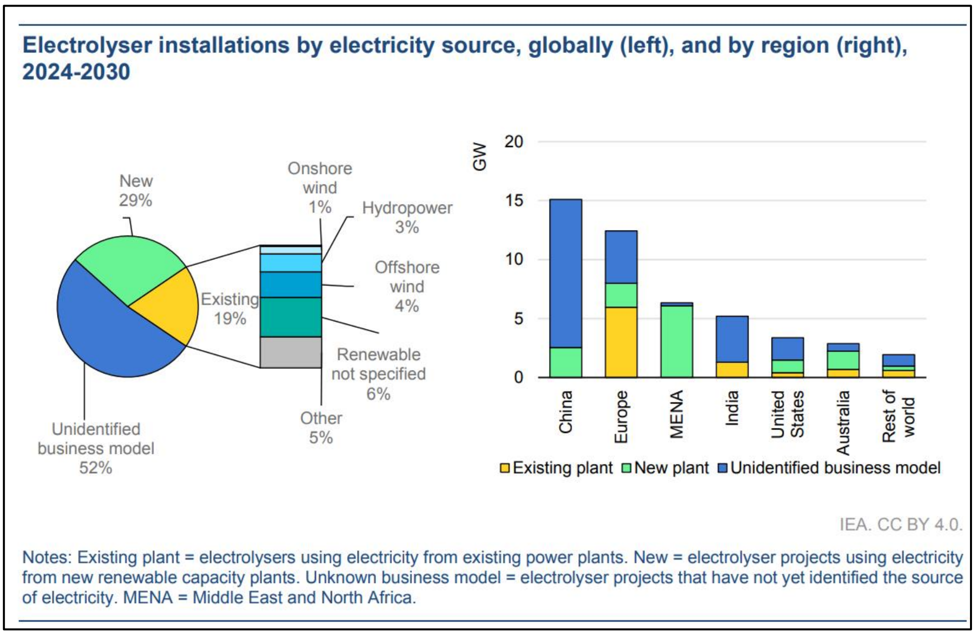


Figure 24: Electrolyser Installation by source and region

8. BATTERY ENERGY STORAGE TREND

Global Outlook

In the IEA's assessment (*Batteries and Secure Energy Transitions, 2023*), battery storage in the power sector more than doubled in 2023, adding around **42 GW** of new capacity. Electric vehicles are the main driver, making the energy sector responsible for nearly **90% of lithium-ion demand**. This rapid growth positions batteries as the fastest-growing clean energy technology worldwide.

According to the IEA, lithium-ion batteries remain dominant, with prices falling by **90% since 2010** (from USD 1,400/kWh to below USD 140/kWh). Two chemistries are leading the market: **high-nickel batteries**, which offer higher energy density and are preferred in EVs, and **lithium iron phosphate (LFP)**, which is cheaper, safer, and accounts for about **80% of new stationary storage**. The IEA also highlights sodium-ion as an emerging alternative for cost-effective storage applications.

The IEA notes that battery manufacturing is highly concentrated, with **China holding over half of global battery production and 85% of cell capacity**, while the EU, US, and Korea each contribute less than 10%. Policies in the US and EU are now expanding domestic capacity, but supply risks remain due to the heavy reliance on a small number of countries for critical minerals. The IEA stresses that policy support must also extend to recycling and diversified sourcing.

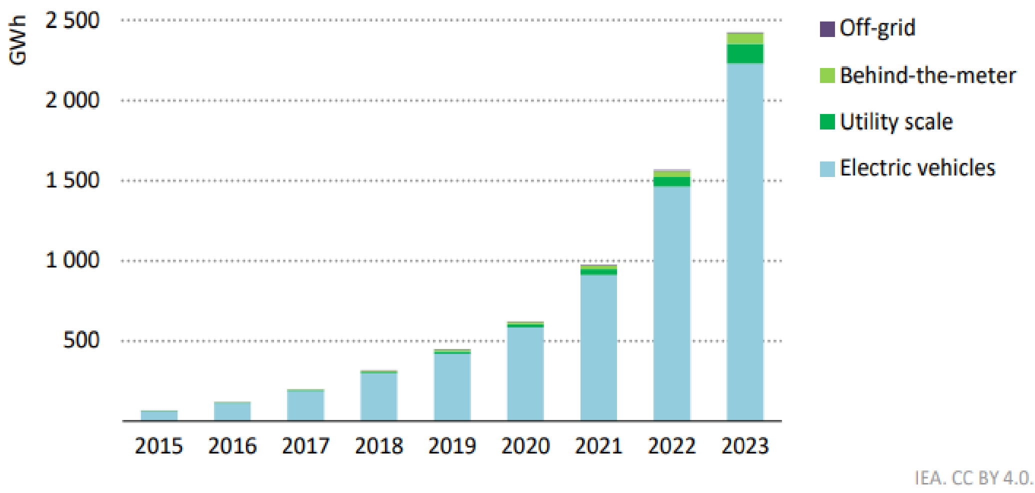
In the IEA's Net Zero Emissions (NZE) Scenario, global battery storage must grow **14-fold to 1 200 GW by 2030**. By the same year, EVs are expected to displace **8 million barrels per day of oil demand**. The IEA estimates that nearly **60% of CO_2 reductions to 2030** are linked directly or indirectly to batteries. Beyond decarbonization, batteries enhance energy security by providing fast-response balancing, reducing fossil fuel imports, and supporting resilience during grid outages.

The IEA projects that lithium-ion costs could fall by a further **40% by 2030**, while sodium-ion may emerge as a low-cost option. By 2030, solar plus storage is expected to be cheaper than new coal in India and competitive with gas in the United States. EVs are also projected to reach price parity with internal combustion vehicles in most markets. The IEA forecasts the global battery market to expand from **USD 120 billion in 2023 to nearly USD 500 billion in 2030** in the NZE Scenario.

The IEA warns that demand for key minerals such as lithium, nickel, cobalt, and graphite could increase **sixfold by 2030**, posing risks of bottlenecks. Without rapid scaling of batteries, the IEA estimates that more than **500 GW of solar PV deployment could be lost by 2030**, undermining global clean energy progress, slowing emissions reductions, and increasing dependence on imported fossil fuels.

The IEA recommends that governments enable batteries to fully participate in power markets, expand EV model availability alongside charging infrastructure, and integrate smart charging. To ensure supply security, the IEA advises building diversified value chains and developing recycling industries. It highlights policies such as **recycled content targets and tradeable recycling credits** as effective measures to reduce reliance on primary minerals while supporting sustainable scale-up.

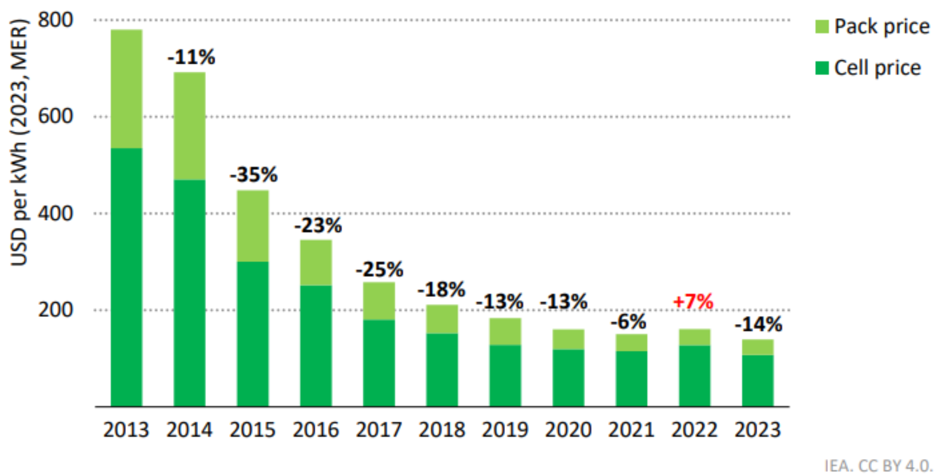
The following graphs highlights the BESS volume increase, cost reduction and EV battery volume usage.



Lithium-ion battery volumes in use have surged over the last three years to 2 400 GWh

Note: GWh = gigawatt-hours.

Figure 25: Lithium-Ion Battery volume surge



Prices for lithium-ion batteries steadily declined over the last decade with a spike in 2022, but dropping again in 2023

Notes: USD = US dollars, kWh = kilowatt-hours. Prices are weighted average across regions and chemistries.

Source: IEA analysis based on BNEF (2023a).

Figure 26: Lithium-Ion Battery Cost Reduction

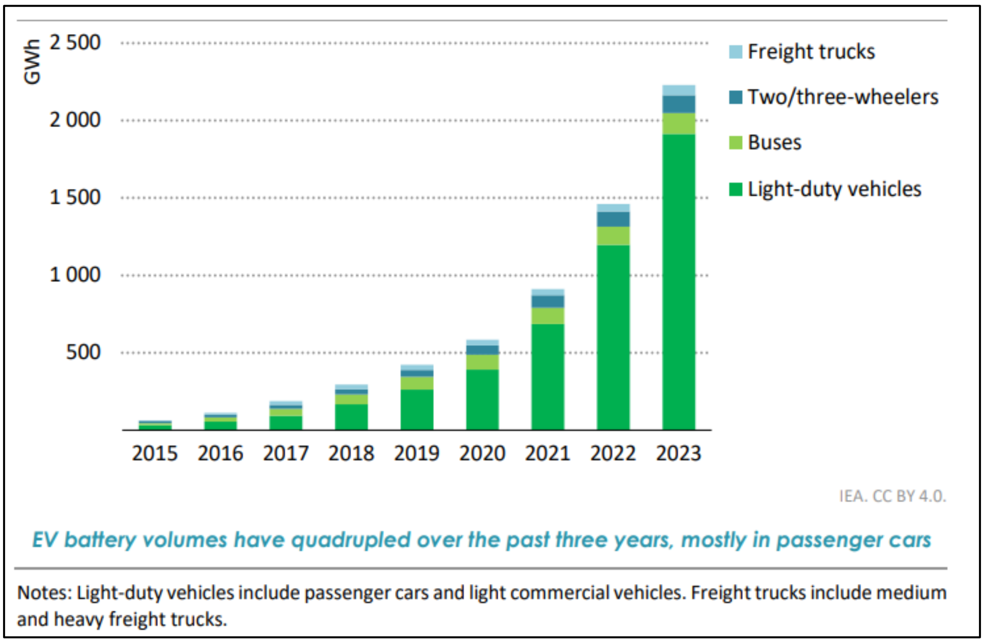


Figure 27: EV Battery Volume

According to the IEA's *Batteries and Secure Energy Transitions* report, global installed battery storage capacity has expanded rapidly over the last decade, rising from about 1 GW in 2013 to more than 85 GW in 2023, with over 40 GW added in 2023 alone, more than double the additions in 2022. This growth has been led by China, the European Union, and the United States, which together accounted for nearly 90% of new capacity in 2023. Around 65% of capacity additions were utility-scale systems connected directly to transmission or distribution networks, while the remaining 35% came from behind-the-meter systems at residential, commercial, and industrial sites, which are generally smaller in scale.

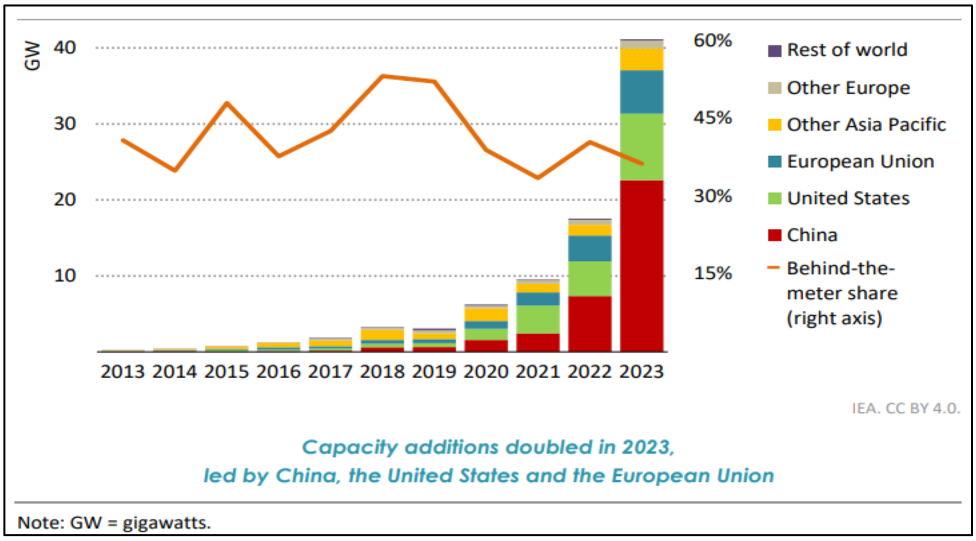


Figure 28: BESS Capacity addition worldwide

In IEA's assessment, battery storage deployment expanded significantly across several regions in 2023. Capacity additions in Australia rose to 1.3 GW, more than 2.5 times higher than the previous year, with nearly 60% coming from utility-scale projects. This growth was supported by wide wholesale electricity price spreads, high ancillary service prices, and incentives for pairing residential PV with batteries. In Japan and Korea, utility-scale additions increased to over 400 MW and 300 MW, respectively, while Japan also continued to add more than 300 MW annually in behind-the-meter storage. Korea's behind-the-meter market, however, has not recovered since its peak in 2018 following the withdrawal of subsidies. In Europe, the United Kingdom led with over 1 GW of new battery storage in 2023, making it the region's largest utility-scale market. In Latin America, Chile emerged as the first country to deploy battery storage at scale, adding nearly 250 MW of utility-scale capacity.

According to the IEA, carbon emissions from batteries mainly stem from mineral refining, the production of cathode and anode active materials, and manufacturing processes. Despite these upstream emissions, batteries deliver significant environmental benefits. Electric vehicles powered by batteries emit roughly half the lifecycle CO_2 equivalent of internal combustion engine vehicles on a global average, and these emissions are expected to decline further as power systems undergo decarbonization.

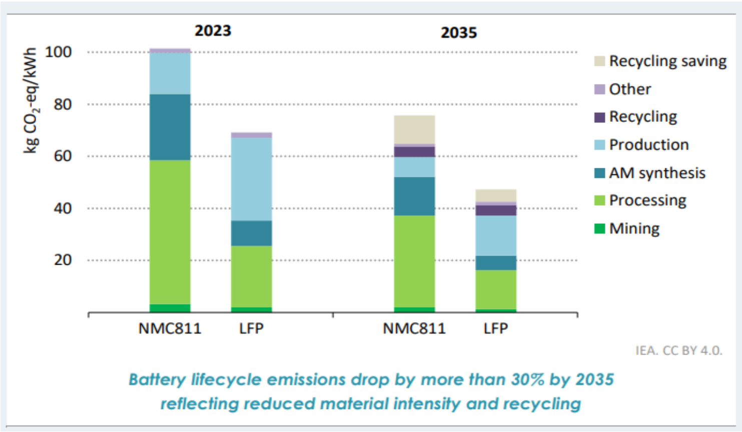


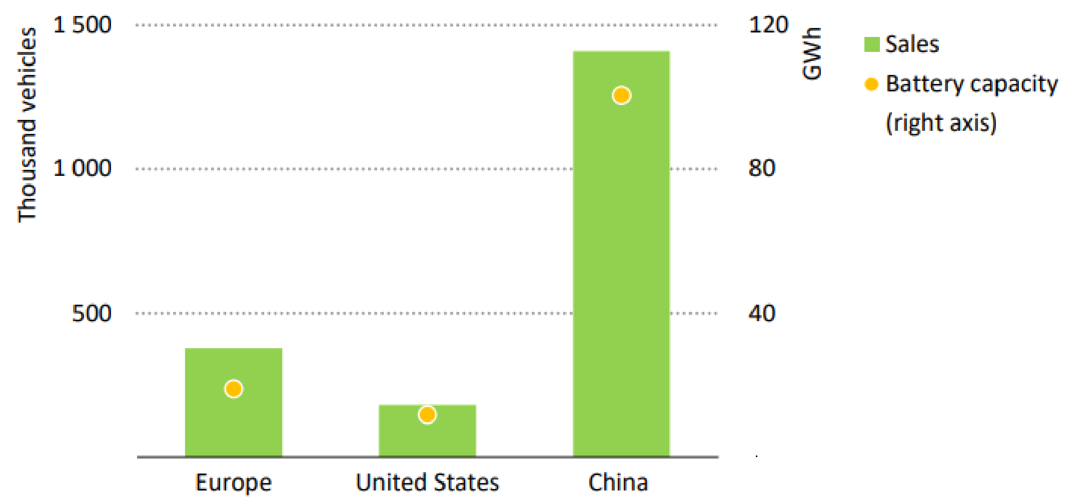
Figure 29: Battery Life Cycle Emissions

LFP batteries, with lower costs, higher cycle lives, and improved safety, have rapidly become the dominant choice for storage, rising from one-third of new capacity in 2020 to 80% in 2023, and are expected to maintain this lead through 2030. Sodium-ion batteries, which avoid costly minerals like lithium, could emerge as a lower-cost alternative for stationary storage, though competitiveness depends heavily on lithium prices and large-scale manufacturing, with their market share projected to reach about 10% of annual additions by 2030, mainly driven by Chinese production. Beyond 2030, alternative chemistries such as redox flow and iron-air may gain traction for long-duration storage, but challenges remain in cost and scalability, while solid-state batteries, though promising for EVs, are unlikely to compete in the power sector where energy density is less critical.

8.1. Vehicle-to-Building and Vehicle-to-Grid Connectivity

Given the rapid expansion of the EV market, large-scale deployment of vehicle-to-building (V2B) and vehicle-to-grid (V2G) technologies could reduce the need for dedicated stationary storage capacity in the power sector. However, several technical, commercial, and regulatory barriers limit the likelihood of broad adoption in the near term. EV batteries are typically designed for a smaller number of charge–discharge cycles compared with stationary storage batteries, and additional cycling associated with V2B/V2G applications could accelerate degradation. Moreover, most EV battery warranties do not cover V2B/V2G operations, reducing their attractiveness to consumers. On the regulatory side, V2G faces many of the same challenges as other forms of behind-the-meter storage and demand response, particularly about market access and revenue streams

For comparison, a typical behind-the-meter battery storage system has a capacity of around 10 kilowatt-hours (kWh), while the average EV battery is 40–60 kWh. Supplying several hours of household electricity during peak times would therefore require only 15–25% of an EV battery's capacity. Such shallow cycling would likely limit the impact on battery lifetime, but it also constrains the potential economic value for the end-use consumer. Coordinating mobility and flexibility needs makes corporate fleets a more promising segment for V2B/V2G than individual households, as fleets can provide greater predictability of availability and larger aggregated services. From a technology perspective, EVs using lithium iron phosphate (LFP) and sodium-ion batteries may be better suited for V2B/V2G applications than nickel manganese cobalt (NMC) or nickel cobalt aluminium oxide (NCA) chemistries, given their lower cost and higher cycle life, although sodium-ion's competitiveness against LFP remains to be proven.



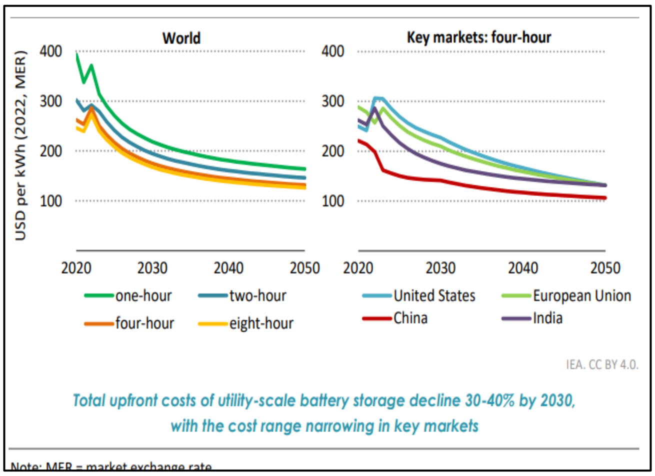
China leads with over 1.4 million V2G-capable LDV sales in 2023, which could make 100 GWh of new battery storage capacity available for V2G integration

Note: V2G = vehicle-to-grid; LDV = light-duty vehicle.

Figure 30: V2G Capable Vehicle Sales by Region

8.2. Utility Scale BESS cost

Utility-scale battery storage costs vary widely depending on site, technology, and regulation, with recent projects ranging between **USD 200–500/kWh**. On average, global capital costs for four-hour storage were **USD 290/kWh in 2022**, and they are expected to fall by around **40% to USD 175/kWh by 2030**. Beyond 2030, costs are projected to decline further, reaching about **55% below 2022 levels by 2050**. It further highlights that the behind-the-meter BESS cost will also decline drastically.



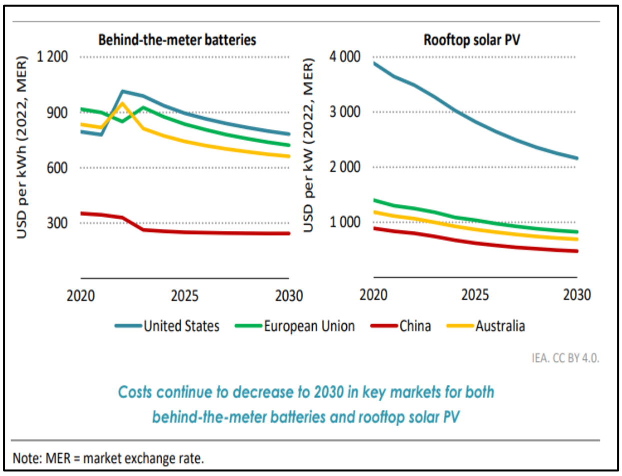


Figure 31: Average Total system capital costs of utility-scale batteries, Behind the meter Batteries and RT solar PV

9. OTHER TRENDS, BARRIERS, AND OPPORTUNITIES.

9.1. Investment and Financing in Renewable Energy

The following are opportunities to invest in Renewable Energy, as mentioned in the global forums.

1. **Solar PV & Battery Storage Leadership**
   - Solar is the cheapest new electricity source in most markets.
   - Pairing with storage opens new revenue streams (peak shaving, ancillary services).
2. **Emerging Markets Growth**
   - Investment is accelerating in India, MENA, Southeast Asia, and Africa.
   - Falling technology costs and policy incentives create strong long-term growth potential.
3. **Corporate Demand & Green Finance**
   - Expansion of corporate PPAs, green bonds, and climate funds is channeling capital.
   - Multinational firms are committing to 24/7 clean power, boosting demand for RE.
4. **Policy-Backed De-Risking**
   - MDB guarantees, auctions, and tax credits reduce financing risk.
   - US IRA, EU Green Deal, and Asia's RE policies are catalyzing large-scale investment.
5. **Grid & Flexibility Solutions**
   - Investments in storage, digital grids, and EV charging are increasingly lucrative.
   - These sectors benefit from both RE expansion and energy security imperatives.

The following has been identified as **Risks** that impact the investment in renewable energy.

- **High Financing Costs**
  Rising interest rates increase capital costs, making some projects less attractive to banks.

- **Grid & Infrastructure Bottlenecks**
  Limited transmission capacity and permitting delays cause curtailment and project slowdowns.

- **Trade & Protectionism**
  Import tariffs and anti-dumping duties on Chinese solar and batteries raise costs and create uncertainty.

- **Revenue Volatility**
  Negative power prices, curtailment, and fluctuating PPA terms reduce investor confidence.

- **Supply Chain Concentration**

  Over 80% of battery cell production and a large share of solar module manufacturing remain concentrated in China, exposing investors to geopolitical and trade risks.

Decarbonizing emerging economies will require trillions of dollars annually, making financing the energy transition the "faultline" of the climate fight. Most funding must come from the private sector, but the public sector plays a key role in catalyzing investment. At Davos 2024, experts highlighted four ways to mobilize capital as per the World Energy forum. [14]

• **De-risking investments** – Creative use of MDB guarantees can reduce financial and political risks, as shown in Chile and sub-Saharan Africa.

• **Standardizing climate assessments** – Shared baselines aligned with the Paris Agreement can help mobilize local finance and involve domestic banks.

• **Jurisdictional carbon credits –** System-wide approaches, such as the US Energy Transition Accelerator, can boost confidence in voluntary carbon markets and ensure credible emission reductions.

• **Prioritizing energy efficiency –** Efficiency delivers quick paybacks and major savings without financial sacrifices, demonstrated by India's UJALA program and Mahindra's industrial projects.

Together, these approaches aim to unlock large-scale private and public investment for clean energy transitions in emerging markets.

In the context of high penetration of Renewable Energy, the curtailment risk is arising more than ever in history. In order to avoid risks associated with this, the **Grid Integration Guarantee (GIG)** has been adopted by most countries. This is a market-transformative instrument designed to mitigate the risk of renewable energy curtailment. By combining big data techniques with actuarial science, it aims to provide deep de-risking of renewable energy assets, making them more attractive to institutional investors. As a short-term intervention, the GIG underwrites curtailment risk by measuring only against scheduled energy, without covering resource, performance, or quality risks. This mechanism has the potential to mobilize part of the half-trillion dollars required for mitigation finance in developing countries, offering capital at more affordable terms. [17]

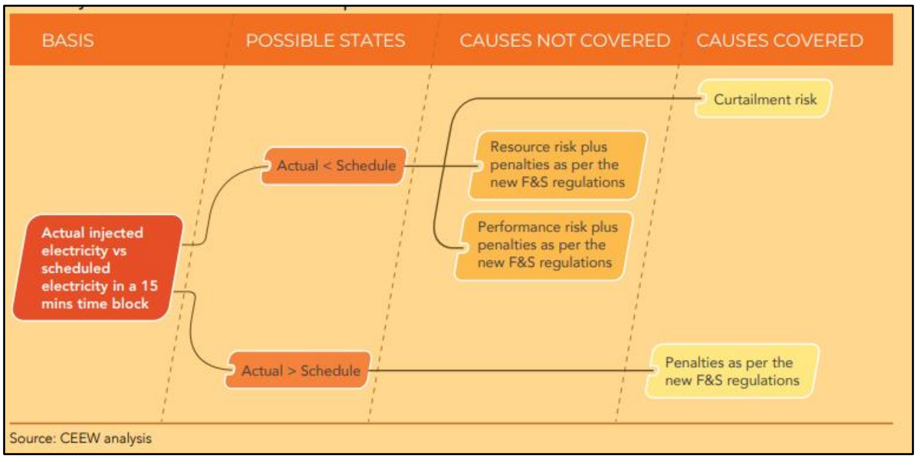


Figure 32: curtailment against the scheduled energy

9.2. Emerging Innovations

Innovation in renewable energy is crucial to achieving global net-zero targets, particularly in sectors such as heavy industry, transportation, and heating that are challenging to decarbonize. While existing clean technologies can help meet near-term goals, breakthroughs are needed to scale solutions, lower costs, and enable deeper decarbonization. Seven key innovations are emerging as game-changers for the future of renewable energy.[15]

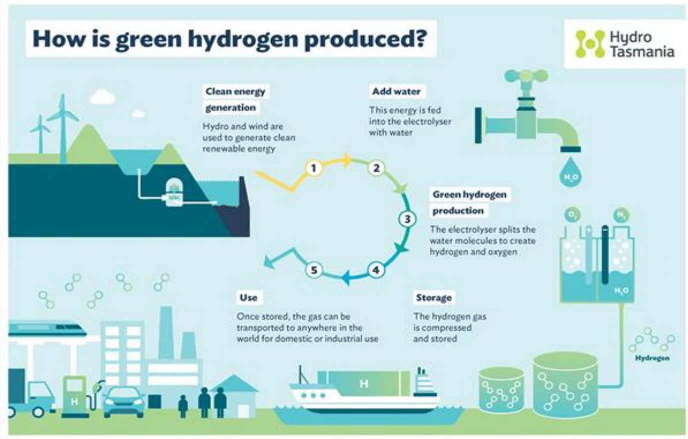


Figure 33: Hydrogen Generation Procedure

- ***Floating Offshore Wind Farms*** are expanding wind generation into deeper waters where winds are stronger and more consistent. Unlike fixed-bottom turbines, floating platforms can access an estimated 51,000 GW of wind potential previously out of reach, making this technology crucial for scaling global wind capacity.

- ***Hydrogen Fuel Cells for Home Energy Storage*** are emerging as an alternative to lithium-ion batteries for residential and small business energy needs. With higher energy density and longer lifespans, fuel cells are particularly suited for remote or off-grid communities and are projected to grow rapidly as costs fall.

- ***Enhanced Geothermal Systems (EGS)*** can unlock geothermal power in areas lacking natural reservoirs by artificially creating underground heat reservoirs. This technology could provide over 100 GW of reliable electricity in the United States alone, vastly expanding the global geothermal potential.

- ***Bioenergy with Carbon Capture and Storage (BECCS)*** combines renewable energy with negative emissions by capturing CO_2 released during biomass combustion. It is the only renewable solution that actively removes carbon while producing energy and is considered critical by the IEA for achieving mid-century net-zero targets.

- **Tidal Energy** Turbines harness predictable ocean tides to provide a consistent renewable energy source. Recent advancements allow turbines to operate in lower-velocity tidal flows, expanding deployment opportunities and making tidal power a growing contributor to the energy mix.

- **Green Hydrogen,** produced from renewable-powered electrolysis, offers a clean alternative to fossil-based hydrogen. It is seen as a cornerstone for decarbonising industry, transport, and power, with the potential to meet up to 24% of global energy needs by 2050 as costs fall from current levels of USD 3–8/kg to as low as USD 1–2/kg.

- **Artificial Intelligence (AI)** in Renewable Energy is transforming how systems are managed, from predicting wind and solar output to balancing supply and demand on grids. AI can boost efficiency, reduce costs, and maximize renewable integration, with early applications like Google's DeepMind improving wind farm output by 20%.

- **Microgrids** are emerging as a vital solution for electrification in low-resource and remote areas with the development of AI and communication technologies. Their flexible, modular, and cost-effective design allows communities, schools, and hospitals to reliably access energy where traditional grid extension is not feasible. From Myanmar to Ethiopia, microgrids are enabling clean and decentralized energy access while reducing reliance on diesel, which is costly and carbon-intensive. In middle- and low-income countries, they also create new opportunities for energy entrepreneurship by supporting local businesses and community-driven models. Recognizing their transformative role, the World Bank has committed USD 1.2 billion in co-financing to scale up mini-grid deployment at an unprecedented pace, positioning microgrids as a cornerstone of sustainable development and energy transition.

- The advancement of **storage technologies** has provided a strong boost to the growth and integration of renewable energy worldwide. Beyond conventional batteries, new solutions such as thermal storage, supercapacitors, and mechanical storage systems are emerging as vital tools for balancing supply and demand. Thermal storage enables the capture and reuse of heat for power generation or industrial use, improving system flexibility. Supercapacitors offer rapid charging and discharging cycles, making them ideal for stabilizing grids and supporting short-term fluctuations in renewable output. Mechanical storage technologies, including flywheels and compressed air systems, provide durable and long-duration options to complement intermittent renewables like wind and solar. Together, these innovations will play a critical role in enabling higher shares of renewable energy in the global energy mix.

Storage type	Electrical		Mechanical			Electromechanical			Chemical	Thermal
Technologies	Super capacitors	SMES	PHS	CAES	Flywheels	Sodium sulfur	Lithium ion	Redox flow	Hydrogen	Molten salt
Maturity	Developing	Developing	Mature	Mature	Early commericialized	Commericialized	Commericialized	Early commericialized	Demonstration	Mature
Efficiency	90-95%	95-98%	75-85%	70-89%	93-95%	80-90%	85-95%	60-85%	35-55%	80-90%
Response time	ms	<100ms	sec-mins	mins	ms-secs	ms	ms-secs	ms	secs	mins
Lifetime-years	20+	20+	40-60	20-40	15+	10-15	5-15	5-10	5-30	30
Charge time	s - hr	min - hr	hr - months	hr - months	s - min	s - hr	min - days	hr - months	hr - months	hr - months
Discharge time	ms – 60 mins	ms – 8s	1 – 24 hs +	1 – 24 hs +	ms – 15 min	s - hr	min - hr	s - hr	1 – 24 hs +	min - hr
Evirnomental impact	None	Moderate	Large	Large	Almost none	Moderate	Moderate	Moderate	Depends on H2 production method	Moderate

Figure 34: Overview of energy storage technologies [16]

9.3. Environmental issues /disposal of solar panels/End-of-Life Management

The global transition to renewable energy brings with it a critical challenge: balancing human rights and environmental and biodiversity protection with the urgent need to deliver clean, affordable energy and mitigate climate change. As the pace of this transition accelerates, it is essential to recognize and carefully manage the trade-offs involved, minimizing potential risks while ensuring that sustainability goals are achieved without compromising social and ecological well-being.

Table 3: Potential adverse impacts of renewable energy [16]

Renewable energy	Potential adverse impacts
Solar energy	• Large utility-scale solar facilities (solar thermal plants) can raise concerns about land degradation and habitat loss. • The PV cell manufacturing process includes hazardous materials. The amount and type of chemicals used depends on the type of cell.
Wind energy	• Offshore wind farm developments can have a substantial impact on the structuring of coastal marine ecosystems on basin scales.[137] • Potential impacts on local ocean dynamics and the structure of the marine ecosystem.
Hydropower	• Potential loss of biodiversity and agricultural land. • Displaces local communities. • the creation of hydropower reservoirs leads to an initial increase in greenhouse gas emissions from the decomposition of organic matter.
Geothermal energy	• May emit carbon dioxide, silica, methane, ammonia, and sulfur dioxide, and depending upon the depth and location of the reservoir, some may contain lethal substances such as boron, mercury, and arsenic. • Can have impacts on both water quality and consumption.
Bioenergy	• Energy created by burning biomass creates greenhouse gas emissions, but at lower levels than burning fossil fuels. • Negative environmental impacts related to large-scale increases in forest and bioenergy plantations, resulting deforestation and land-use change.
Ocean energy	• Disturb the ocean's ecosystems. • Equipments used to capture this ocean energy can disrupt and destroy marine life.

The transition to a zero-carbon world will require a sixfold increase in the extraction of critical minerals such as copper, lithium, nickel, and cobalt by 2030, raising serious environmental and human rights concerns. Solar PV cells depend on silver, copper, and sometimes toxic metals, while EV batteries rely on lithium, cobalt, and nickel. The Business and Human Rights Resource Centre's Transition Mineral Tracker recorded nearly 500 allegations of human rights abuses between 2010 and 2021, including child labour and attacks against Indigenous peoples and human rights defenders. Mining also causes significant environmental harm, including water pollution, ecosystem destruction, and health risks to local communities. Large-scale renewable projects like hydropower reservoirs, mineral extraction, and wind farms can further displace vulnerable populations, disrupting livelihoods and creating long-term socio-economic risks. Additionally, solar PV waste is emerging as a major challenge, with IRENA estimating 78 million tons of decommissioned panels by 2050, while other studies suggest the problem could be even more severe.

Good practices for end-of-life (EOL) photovoltaic (PV) management are urgently needed. Although research on solar panel reuse and recycling is still at an early stage, some promising developments have emerged. Current studies are exploring the use of microbes to recover valuable metals from electronic waste.

The challenge of closing the material lifecycle loop presents an opportunity to make the energy transition as sustainable and circular as possible. As PV demand grows, it will be essential to identify and develop the technical, economic, and regulatory frameworks required to establish a PV circular economy. Achieving this will necessitate coordinated efforts across the entire PV value chain.

For low-income countries (LICs), a cost-effective approach could involve refurbishing, repurposing, or repowering solar panels for a “second life”.

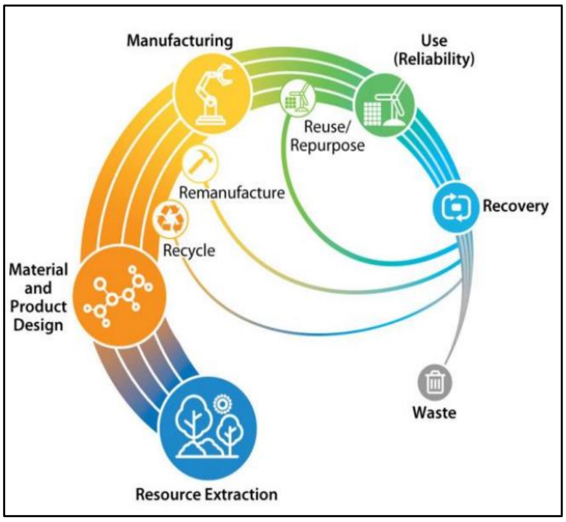


Figure 35: Circular Economy for Energy

9.4. Workforce and skills gap

Jobs in renewable energy are set to rise sharply, with forecasts projecting 42 million positions globally by 2050, four times the current level, driven by expanding investments in clean energy. Energy efficiency measures are expected to add 21 million jobs, while another 15 million could come from system flexibility needs. As of 2022, renewable energy employment stood at 12.7 million, up from 12 million in 2021, with solar PV as the fastest-growing sector, employing 4.3 million people. According to the ILO and IRENA, front-loaded investments in the energy transition could push total energy jobs to 139 million by 2030, including more than 74 million in efficiency, electric vehicles, power systems, and hydrogen. Green jobs are also central to ensuring a just transition, particularly for youth. To support this, UNICEF, ILO, and UNEP have launched the Green Jobs for Youth Pact, aiming to create 1 million new green jobs with existing employers, green 1 million current jobs, and support 10,000 young entrepreneurs in building sustainable businesses. [16]

Global energy employment has expanded significantly since 2019, driven almost entirely by the growth of clean energy. By 2022, the sector employed nearly 67 million people, 3.4 million more than pre-pandemic levels. Clean energy accounted for 35 million jobs, surpassing fossil fuels (32 million) in 2021. The strongest growth came from solar PV, wind, EV and battery manufacturing, heat pumps, and critical mineral mining, which together employ around 9 million workers. Solar PV leads with 4 million jobs, while EVs and batteries have been the fastest-growing segment, adding over 1 million jobs since 2019. Much of this expansion is concentrated in construction and manufacturing, which now represent more than half of all energy employment. Regionally, clean energy jobs expanded globally, with China experiencing the largest workforce shift, adding 2 million clean energy jobs while fossil fuel jobs declined by 600,000. While this trend marks a positive reorientation, labor shortages pose a serious challenge. The clean energy sector requires higher-skilled workers than most industries, and rising job vacancy rates—especially in construction, which is essential for scaling clean technologies and retrofitting buildings—risk slowing the energy transition. [18]

9.5. Corporate Greenwashing - Overstated renewable commitments by companies

As the global energy landscape shifts toward renewables, corporate boards of directors carry increasing responsibility to ensure that their companies' renewable energy commitments are genuine, measurable, and aligned with long-term strategies for a net-zero economy. Beyond approving pledges, boards must monitor progress, assess whether business plans are compatible with decarbonization pathways, and ensure transparent reporting in line with frameworks such as the Task Force on Climate-related Financial Disclosures. A key concern is the risk of corporate greenwashing—the practice of overstating or misrepresenting environmental achievements, such as exaggerating renewable energy commitments or delaying targets to create a false sense of progress. Greenwashing tactics may include misleading marketing, unverified eco-labels, or selective disclosure of information. Boards, guided by investor expectations and stakeholder accountability, must therefore scrutinize renewable energy strategies closely to distinguish genuine progress from superficial claims, safeguard corporate credibility, and drive durable value for shareholders, employees, and communities.

Figure 36: Greenwashing News [19]

For consumers, greenwashing can distort purchasing decisions by presenting false or exaggerated sustainability claims. This not only leads to dissatisfaction but also erodes trust in companies and sustainability messaging. Feeling deceived, consumers may become skeptical of all environmental claims, which in turn reduces the incentive for businesses to genuinely pursue sustainable practices.

For corporates, engaging in greenwashing carries serious risks including reputational damage, loss of consumer confidence, financial penalties, behavioural remedies, and even private litigation. However, the complexity of regulatory frameworks and the lack of consistent standards mean that even well-intentioned companies can face accusations of greenwashing. This fear of being unfairly targeted has given rise to “greenhushing,” where firms avoid communicating their sustainability efforts altogether. Both practices undermine transparency and weaken the push toward genuine corporate responsibility.

For society, greenwashing threatens the effectiveness of regulatory and market-based climate policies. By masking their true environmental footprint, companies may circumvent rules, slowing down economic transformation and increasing climate-related risks. Ultimately, this can force governments to adopt more drastic interventions, making the transition to a sustainable economy more costly and disruptive.

10. CONCLUSION

In conclusion, the global energy demand continues to rise, increasing the need for clean and sustainable solutions. Renewable energy is central to climate mitigation, with rapid deployment of solar PV, wind, and energy storage, alongside emerging solutions like green hydrogen and decentralized energy access, being essential to limit global warming and achieve sustainable development goals. As the costs of renewable technologies decline, it is crucial to adopt sustainable approaches to maintain momentum. Realizing this potential requires coordinated policy support, secure and sustainable supply chains for critical minerals, adequate financing, and robust grid integration. Accelerated action across sectors, coupled with international cooperation, is critical to aligning energy systems with the Paris Agreement and safeguarding the planet against the intensifying impacts of climate change.

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