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Shaping Tomorrow's Energy Landscape:

Balancing Sovereignty, Affordability and Climate Responsibility

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01

GLOBAL OUTLOOK

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The major event of the year 2022 was Russia's unjustified invasion of Ukraine, which led to a historic increase in gas and electricity prices in Europe. Following these events, measures to strengthen security of supply and energy sovereignty were taken in addition to those to accelerate the energy transition. Carbon-free electricity production technologies have progressed, but despite this, greenhouse gas (GHG) emissions have continued to increase. The summer of 2023 was one of the hottest in history.

In this Outlook, we examine the questions of energy sovereignty and the West's dependence on China, whose weight in the energy transition is continuously increasing. While regulations must be strengthened to reduce dependence on fossil fuels, the speed of implementation of these regulations depends on their costs and their acceptability.

Despite this, it is likely that the objectives of limiting temperature to 1.5°C in 2030 will not be achieved. Adaptation measures must therefore be taken quickly, which requires the mobilization of numerous stakeholders (governments, infrastructure managers, businesses, citizens).

Consumer behavior and financing of the energy transition are key points for success.

These and other topics are analyzed in this Outlook.

I hope you enjoy reading it.

The 2021-2022 crisis and 2023 perspective:

How Europe freed itself from its dependence on Russian gas:

Before the unjustified invasion of Ukraine by Russia (February 2022), Russian gas, mainly imported by pipeline, represented 40% of European gas supplies, around 140 billion cubic meters (bcm) per year.

As I had written in previous WEMO[1] Outlooks, this heavy dependence on Russian gas posed a threat to European security of supply. This threat materialized in 2022.

Russian gas:

In response to the invasion of Ukraine, the European Union (EU) took sanctions against Russia, particularly on Russian oil and coal. It avoided taking sanctions on gas because of Europe's heavy dependence on Russian gas. It is President Putin who decided to progressively reduce the gas flowing by pipeline to Europe. The sabotage of the two North Stream giant pipelines on September 22, 2022, further reduced these flows. Thus, Russian flows transiting by gas pipelines represented in June 2023 only around 7% of the Union's supplies.

Since the last quarter of 2022, in addition to "TurkStream", only two gas pipelines crossing Ukraine are still supplying Europe with Russian gas. However, gas transit contracts between Russia and Ukraine end in 2024 and may not be renewed.

Unveiled in May 2022, the REPowerEU[2] plan aimed to "reduce the EU's dependence on Russian gas by two-thirds by the end of 2022"; additionally, it aims to "make Europe independent of Russian fossil fuels well before 2030". The first part of the plan addresses gas supply sources diversification. The second part deals with acceleration of the energy transition, deployment of energy efficiency measures, and the accelerated commissioning of renewable electricity production means.

Diversified supplies:

1. ***Oil:*** Due to the EU sanctions, Russian oil imports dropped sharply. While they accounted for 31% of EU oil imports in January 2022, by March 2023 it was only 3%. Nevertheless, some of the EU's new imports may trace back to Russia.[3]
2. ***Gas:*** Europe has successfully diversified its gas supply sources:
   a. First, by increasing imports by pipeline from its traditional suppliers (Norway, Algeria, and the United Kingdom). However, these countries have limited potential to increase their exports.
   b. Secondly, by increasing imports of liquefied natural gas (LNG) on international markets (United States and Qatar, in particular), including 45 to 50% on the spot market.

In 2022, the EU imported just over 130 bcm of LNG, a 60% increase from the 80 bcm imported in 2021. In the future, Europe will be able to receive additional LNG as it expands its regasification capacity and as global LNG supplies increase. The global LNG flows are expected to increase by 23 bcm in 2023, largely due to the ramp-up of liquefaction projects in Africa and the United States.

In 2022, the U.S. represented roughly 40% of LNG European imports. Despite cuts in Russian piped gas, the EU increased its Russian imports from sea through LNG imports. Russia overtook Qatar as Europe's second-largest LNG supplier.***In the first seven months of 2023, EU countries imported 40% more Russian LNG than the same period in 20214 ,*** making up around 16% of the EU's total LNG imports from January-July.[5] ***This is against the EU's aim to end its reliance on Russian fossil fuels (coal, oil, piped gas or LNG) by 2027!***

1 https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/
2 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

3 https://www.energymonitor.ai/industry/a-missed-opportunity-eus-new-oil-imports-are-a-backdoor-to-russia/#:~:text=In%20January%202022%2C%20Russia%20accounted,back%20to%20Russia%20after%20all.

4 https://www.globalwitness.org/en/press-releases/eu-imports-russian-lng-have-jumped-40-invasion-ukraine/
5https://www.reuters.com/business/energy/lng-imports-russia-rise-despite-cuts-pipeline-gas-2023-08-30/

2023 gas supply still presents threats:

The diversification of Europe's gas supply sources strengthens its security of supply. However, the EU is exposed to a double risk of rising prices and price volatility on one hand and availability of volumes on the other.

1. ***Higher prices and volatility:*** LNG prices are usually higher than those of gas imported by pipeline (due to factors such as the cost of liquefaction, transportation by vessel, and regasification). Also, their GHG emissions are worse than for piped gas. Being exposed to the spot market, the prices of LNG imports are, by nature, more volatile than the long-term contracts prices of piped gas.

   a. Volume availability: In 2022, confined China saw a drop of more than 20% in its LNG imports.

   However, a rebound in Chinese demand for LNG could limit LNG availability. In June 2023, China imported 32% more LNG than the previous year, and approached its June 2021 record.[6] However, this increase was mainly due to exceptional weather events and low LNG spot prices. For the whole year, China's demand for gas and LNG is expected to grow but not at the same pace as during the first half. Indeed, the current national policy prioritizes energy security of supply with coal and renewables. In addition, continued growth in domestic gas production and ramped-up delivery from Russian pipeline imports will limit the growth of LNG imports.

   At the end of August 2023, the LNG market was not under pressure, as reflected by the U.S. LNG export price, which dropped to around half its August 2022 level.

   b. Some leaders in the energy world are expressing concerns for the year 2024, given the link to the elections in the United States. If the Republican Party returns to power, the United States could ban or limit LNG exports because they are pushing American domestic prices up. It would be a shock for Europe, since the region relies significantly on the U.S. However, shale gas is produced in the U.S. by private companies; these organizations could launch litigation procedures against those penalizing decisions.

Deployment of new regasification infrastructures:

Europe Member States and, in particular, Germany have reacted to the 2022 crisis by increasing the number of Floating Storage and Regasification Unit (FSRU) projects. By mid-2023, eight new terminals were commissioned, and the EU's LNG import capacity is expected to increase by a further 20% by 2024.

However, at the European level, LNG import capacities were already oversized before the crisis. The deployment of new gas infrastructure responds to the poor distribution of LNG terminals on the continent and the difficulty of transporting gas in Europe. For many years I stressed in the WEMO outlooks, the need to invest in pipelines to increase reverse gas flows. During the crisis, it was clear that those investments were not done as it was impossible to transport gas from Spain (which has many re-gas facilities) to Germany, which had none. Also, it is very difficult to transport gas from Western Europe to the very landlocked Eastern European countries.

Several new LNG import terminals are planned for 2026. However, they go against the objective of climate neutrality and could become stranded assets.

6 https://www.spglobal.com/commodityinsights/en/ci/research-analysis/chinas-lng-imports-surged-early-summer-2023-under-the-impact.html#:~:text=According%20to%20S%26P%20Global%20Commodity,record%20for%20June%20in%202021.

Prices:

During the 2022 crisis, electricity and gas prices reached historical heights. They have sharply fallen because of moderate demand linked to the flattish economies and the fear of a new financial crisis.

The European gas price has fallen sharply (€34/MWh in August 2023) since its historic peak of €346/MWh (in August 2022).

Even if the American gas prices (which are around five times lower than European ones thanks to shale gas) did not reach historical heights as in Europe, U.S. Henry Hub[7] spot gas price fell from $8.8/million British thermal unit (MBTU) in August 2022 to $2.6/MBTU one year later.

The European electricity spot prices, which are linked to the gas prices, also fell from €576/MWh (for France) in August 2022 to €96/MWh one year later.

This dependance of electricity prices on the gas prices was questioned in Brussels by certain countries (such as France) that use very little gas for their electricity generation. These considerations, together with the sharp increase of spot prices and its consequences on citizen budgets, pushed European leaders to launch a reform of the European electricity prices mechanism (see below).

The drop in European electricity prices was, however, less spectacular than for gas prices. They remained relatively high during the 2023 summer due to very hot weather pushing demand up (through the increased use of air conditioning), the limitation of nuclear plants electricity output (in order not to heat rivers beyond a certain level) and fears around nuclear power availability during the winter.

Reduction in gas consumption:

If the Union has reduced its gas consumption by 13% for the year 2022 compared to 2021, this drop remains largely linked to a mild winter. For example, changes in behavior would have contributed only to one-quarter of the energy savings made in buildings. Energy efficiency levers (beyond building insulation) should be further increased to reduce heating and cooling energy consumption. Since the Russian invasion of Ukraine, heat pump installation, which displaces natural gas to the benefit of electricity, grew at an unprecedented rate (+100% in H1 23 in Germany and +140% in Belgium).

On the industrial side, almost half of the drop in gas demand came from stopping production activities due to the increase in energy prices (gas and electricity). Finally, because of the poor functioning of French nuclear power plants in 2022, there has been no reduction in gas used at power plants as the latter had to make up for missing nuclear electricity.

It is difficult to predict the sustainability of these reductions in consumption, a large part of which was linked to the fear of shortages (notably power cuts) and high prices.

7 https://www.cmegroup.com/education/courses/introduction-to-energy/introduction-to-natural-gas/understanding-henry-hub.html

The year 2023 is full of uncertainties:

The evolution of the conflict in Ukraine is uncertain as all options are open, ranging from a territorial compromise, to the attack by Russia of other neighboring countries and even to a nuclear war. It is important to note that Russia has targeted major energy facilities such as the Zaporizhia nuclear power plant and the Kakhovka dam.

The destruction of the latter by bombardment on June 6, 2023, caused the flooding of more than 600 square kilometers, causing a human and ecological disaster.

This raises questions about the safety of major energy equipment in war zones.

In addition,the October 2023 savage attack by Hamas terrorists in Israel, could destabilize the Middle East.

Inflation:

A series of compounding issues such as rising energy and food prices and high governmental subsidies in the wake of the pandemic, have created high inflation rates. Global inflation in 2022 is estimated to have reached 8.75%.

In 2023, lower energy prices, slower economic growth, stricter monetary policies of the central banks, and supply chain improvements are contributing to decreasing global inflation with divergent inflation trends in western economies.

To curb this inflation, central banks have increased interest rates, triggering increases in everyday products, and creating difficulties for part of the population. This growth in precariousness could be a source of *social conflicts.*

The increase in interest rates leads to an increase in the cost of electricity produced by renewable energies and nuclear[8] (see below).

While the economic slowdown has potential negative consequences on employment, it has the positive consequence of slowing energy consumption and therefore keeping energy prices at reasonable levels.

The winter of 2023-2024 is showing more promising conditions compared to the previous one:

1. At the end of August, European gas storage facilities were 96% full on average, which is a high historical level for this time of year and beyond the rate imposed by European regulations.
2. In 2022, the discovery of stress corrosion in the emergency cooling circuits of a number of nuclear reactors led to a significant drop in French nuclear production. Since then, EDF, with the agreement of the French Nuclear Safety Authority, has undertaken to repair these defects. Thanks to the optimization and control of repairs, the annual cumulative nuclear production was 8% higher in August 2023 than that of the same period in 2022.

The economic slowdown will probably trigger lower energy consumption. ***However, mild temperatures and sustained energy savings remain key to having a non-eventful winter.***

Following the 2021-2022 energy crisis, besides climate change issues and energy transition acceleration, new concerns have emerged, most notably around energy sovereignty.

8 The levelized cost of the electricity produced by these plants is mainly linked to the investments (the cost of fuel being either zero for renewables or relatively low for nuclear).

Energy sovereignty has become an objective.

Fossil fuels security of supply:

As analyzed above, the unjustified invasion of Ukraine invasion by Russia in 2022, has pushed Europe to diversify its gas procurement sources and hence to increase its security of supply. Threats to European security gas supply have also been looked at: the most important one seems to be a limitation of the U.S. LNG exports linked to a potential Republican victory at the 2024 U.S. elections.

Over 2022 and 2023, the Organization of the Petroleum Exporting Countries and its partners (OPEC+) have continued to restrict their supply to push oil prices up. It also agreed to set a new, lower target for 2024. Meantime, Saudi Arabia decided to unilaterally cut oil production by 1 million barrels per day (b/d) until the end of the year. In July, Saudi crude production dropped to below 9 million b/d, its lowest level since June 2021. Oil prices rose following the news, with Brent rising above $90/barrel.

As happened in the past, oil procurement can be subject to embargos. However, OPEC countries need the oil revenue to balance their budget. This is even more true for Russia, which badly needs those dollars to finance its war efforts. As seen also in the past, high oil prices boost the U.S. shale oil production output, which in turn, limits market prices increase.

Electricity sovereignty issues:

According to the Energy Transition Commission (ETC)[9], a successful energy transition will lead to:

- A dramatic increase in global electricity use, rising from ~28,000 TWh in 2022, to as much as ~110,000 TWh by 2050, with over 75% of this supplied by wind and solar. The rest will be provided by a mix of nuclear, hydropower, and other zero-carbon sources, along with battery and other storage equipment.
- A major expansion of electricity grids, expanding from the current 75 million kilometers of transmission and distribution to over 200 million kilometers by 2050. Knowing the local public oppositions on new overhead line projects and the resulting delays, the grid could become the Achilles' heel of the energy transition.
- A major role for low-carbon hydrogen, requiring electrolyzer capacity of up to 7,000 GW in 2050.
- The near-total decarbonization of the global passenger vehicle fleet by 2050, requiring over 1.5 billion electric cars and ~200 million electric trucks and buses. This requires a total battery capacity of up to 150 TWh.
- Carbon Capture, Utilization and Storage (CCUS) capacity increase of around 7–10 $GtCO_2$ per year, is needed to offset remaining fossil fuel.

9 https://www.energy-transitions.org/publications/material-and-resource-energy-transition/file/

Rare metals security of supply:

ETC studied the supply and demand balance equation of six key energy transition materials (cobalt, copper, graphite, lithium, neodymium, and nickel). It appears that over the long term, there are sufficient resources[10] of all the raw materials (and of land area and water) to support the energy transition. If assessed "reserves" fall short of potential demand – for copper and nickel, for example – prices will go up. Geological research will be triggered, and new mines will open. However, there could be a time lag between growing needs and minerals availability, creating tensions on supply. Presently, for some energy transition metals, projected supply does not seem sufficient to meet rapidly growing demand. For example, from now to 2050, lithium requirements should grow by 15 times, graphite by 12 and copper and cobalt by 5.

Lithium procurement is a strategic issue. Most of the world's lithium reserves are in Bolivia (21 million tons), Argentina (19 million tons), Chile (9.8 million tons), Australia (7.3 million tons), and China (5.1 million tons). None in Western Countries.

China has a dominant position in refined lithium supply and aims to increase its position in mines. For example, in June 2023, Chinese and Russian companies announced a common investment of more than $1.4 billion in the extraction of lithium in Bolivia, to unleash the country's large reserves of the mineral.

10 A resource is that amount of a geologic commodity that exists in both discovered and undiscovered deposits. Reserves are that subgroup of a resource that have been discovered, have a known size, and can be extracted at a profit

There is major potential to reduce future lithium demand via technology, materials efficiency, and recycling.

1. *Technology:* For example, battery manufacturers are developing batteries without cobalt. Sodium-ion batteries development would reduce the need for lithium.
2. *Efficiency:* An increase in renewables generation equipment efficiency (as wind turbine capacity factors increase, or solar panels yield improvement) would reduce the mineral needs per kWh.
3. *Recycling and reuse* of recycled metals decreases the need for fresh metals. Finally, higher prices triggered by tight supply chains will increase reserve volumes and decrease consumption.

However, this global long-term positive view on supply and demand balance of critical metals does not exclude short-term problems for various reasons, notably public oppositions delaying new mines opening.

Finally, geopolitical considerations can create shortages. As a retaliatory act for the limitations placed on the Chinese semiconductor industry by the U.S., Japan, and the Netherlands, in July 2023, China, the world's top supplier of gallium and germanium, two minor metals used to make semiconductors, announced restrictions on their exports.

Could China be tempted to do the same for lithium and graphite (used notably in batteries) or polysilicon (used in solar panels) products where it has a dominant position?

Strong action to open new mines and accelerate both materials efficiency and recycling should be taken by governments. The U.S. and Europe have launched strategic plans.

Nearly immediately after his election, President Biden issued an Executive Order on America's Supply Chains. Having identified critical minerals and materials as central pieces of the U.S. economy and national security, this strategic plan relies on three key pillars: diversifying supply, developing substitutes, and improving reuse and recycling.

Similarly, in March 2023, the European Commission put forward a European Critical Raw Materials Act, which aims to have at least 15% of the critical, strategic, and rare earth metal needs domestically sourced through similar actions as the U.S. Act.

In May 2023, France presented a plan to launch a €2 billion investment fund for critical metals. More funding is expected in the future. The good news is that high concentrations of lithium have recently been discovered in certain brines from European (Italy, Germany, France, and the United Kingdom) and U.S. geothermal operations. If the projects, now underway, prove that battery-grade lithium can be extracted from these brines at a competitive cost, they would become a very significant lithium resource located in the western world.[11]

11 https://theconversation.com/how-a-few-geothermal-plants-could-solve-americas-lithium-supply-crunch-and-boost-the-ev-battery-industry-179465

Nuclear energy:

In 2022, the European Union finally recognized that nuclear power plants are climate-friendly.[12] Is it a sovereign electricity source?

The operation of nuclear power plants depends on the supply of uranium; questions have arisen about uranium security of supply. However, ***uranium security of supply is not a tangible threat*** since:

1. Uranium resources are well distributed throughout the world. In 2022, Kazakhstan produced the largest share of uranium from mines (43% of world supply), followed by Canada (15%), Namibia (11%), and Australia (10%).[13] However, there are uranium resources in the U.S. and in Europe.
2. It's very high energy concentration makes it possible to store years of production.
3. Typically, nuclear operators have 2- to 5 years of strategic stocks. Nuclear operators have a policy of diversifying their supplies.
4. As in other industry there is recycling. Recycled uranium and plutonium (produced in nuclear plants), currently saves about 5% of fresh ore. It is also theoretically possible to re-enrich and recycle depleted uranium. Because of the relatively low price of uranium, it is not done presently.

The coup in Niger at the end of July 2023 was an interesting test. Niger is the second largest supplier of natural uranium to the EU (with a share of 25%) behind Kazakhstan. But its share in global supply is only around 5%.

The situation presented low supply risk because other sources were available. Moreover, Niger, whose economy is highly dependent on its uranium exports, should resume exportations in the mid-term.

The price of uranium increased by only 10% after the coup. However, by September, uranium prices increased by 20% compared to the previous years caused by an increase in demand for nuclear energy worldwide. This increase has a very little impact on nuclear electricity competitiveness since uranium cost is less than 5% of nuclear electricity total cost.

The circular economy is essential to ensure sustainable growth:

It is what the EU is implementing with the *battery passport EU regulation.*[14]

By 2030, the EU will need 5 times more cobalt and 18 times more lithium compared to the demand in 2018, numbers which exponentially increase when estimating demand in 2050.

An update to the 2006 Battery Directive aims to ensure the growth of the battery industry is done sustainably. In July 2023, the EU Battery Regulation Amendment was adopted by the EU Council, laying out the structure to achieve sustainable battery lifecycles. This includes a digital record system to enable the transfer of key information between parties – the battery passport.

According to this regulation, by the beginning of 2030, batteries must contain a minimum of 12% cobalt, 85% lead, 4% lithium, and 4% nickel which is from non-virgin sources. To meet these targets, all waste batteries collected must enter a recycling process. This process should improve its efficiency over time.

Battery producers will be obligated to report the carbon footprint associated with the overall lifecycle (excluding the use phase) of the specific manufacturing batch of batteries. As more data requirements are added to battery passports, it will also lead to greater traceability in battery supply chains.

12 https://www.reuters.com/business/sustainable-business eu-parliament-vote-green-gas-nuclear-rules-2022-07-06/
13 https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx

14 https://www.circularise.com/blogs/eu-battery-passport-regulation-requirements#:~:text=According%20to%20the%20Battery%20Regulation,listed%20in%20the%20European%20market.

Lifecycle assessment:

It is the only sustainable approach to compare the emissions of different electricity generation technologies.[15] These assessments over the lifecycle show a wide range of emissions per kWh. Most of renewable technologies' GHG emissions are embodied in infrastructure (up to 99% for photovoltaics), which suggests high variations in lifecycle impacts due to raw material origin, energy mix used for production, transportation modes, and installation.

Nuclear power is the lowest emitting technology with a range of 5.1-6.4 g CO_2 eq./kWh while coal power shows the highest scores, with a range of 751-1095 g CO_2 eq./kWh. Equipped with Carbon Capture and Storage, and accounting for the CO_2 storage, the coal plants score can fall to 147-469g CO_2 eq./kWh

A natural gas combined cycle plant without CCS emits around half the emissions as compared to coal plants, but 80 times more than nuclear electricity. ***This demonstrates that gas is not a long-term viable option regarding climate change and that it should be considered as a transition generation source.***

Wind power emits between 50-200% more GHG than nuclear.

For solar photovoltaic power, 40% of GHG emissions is due to the electricity consumption for silicon refining. Thus, this technology has a large range of lifecycle GHG emissions per kWh depending on the electricity carbon content. Under European conditions, photovoltaic technologies show lifecycle emissions of about 37 g CO_2 eq./kWh, around 800% more than nuclear. In other regions, emissions can be much higher.

In addition to the sovereignty benefit, one advantage of manufacturing PV cells in Europe is to lower emissions by using low-carbon electricity and avoiding transportation.

Industrial sovereignty:

In 2022, President Biden signed the U.S. Inflation Reduction Act (IRA)[16], a program that proposes almost $370 billion in federal incentives to shift the U.S. grid to 80% clean electricity and cut climate pollution by 40% by 2030. It also contains significant incentives to located clean energy plants in the U.S. One year later, the results are impressive: $278 billion have been announced in new private clean energy investments. Projects announced account for 170,000 new jobs.[17]

Given the rapid uptake, the estimate of public IRA investment over the next decade could reach more than $1 trillion.

In March 2023, Canada's federal government adopted a 30% Investment Tax Credit plan for solar, wind, and energy storage projects. This plan mirrors the U.S. Inflation Reduction Act.[18]

In Europe, the Net-Zero Industry Act[19], presented in March 2023, has the ambition of redeveloping a decarbonized and more autonomous industry in Europe.

This act is a positive step but much less powerful than the IRA. Hence, the latter could attract projects formerly designed to be in Europe.

French President Macron has successfully launched the "Choose France"[20] program with a dedicated agency "Business France" to bring low-carbon investments to France. Thanks to these actions, four battery plants will be built in the north of France (ACC, Verkor, AESC- Envision, and ProLogium). Gravithy, the green steel company, will build its first plant in the south of France and Holosis (a solar panel plant) will be built in Sarreguemines (Eastern France). More details on these projects are presented later.

15 unece.org/sites/default/files/2021-11/LCA_final.pdf
16 On August 16, 2022, President Biden signed the Inflation Reduction Act into law, marking the most significant action Congress has taken on clean energy and climate change in the nation's history. https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/
17 https://rmi.org/its-the-iras-first-birthday-here-are-five-areas-where-progress-is-piling-up/
18 https://pv-magazine-usa.com/2023/03/30/canada-formalizes-six-year-30-federal-itc-credit-among-other-incentives/
19 https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en
20 https://www.diplomatie.gouv.fr/en/french-foreign-policy/economic-diplomacy-foreign-trade/news/article/the-choose-france-summit-france-s-flagship-forum-for-economic-attractiveness

European electricity market reform:

In previous WEMO Outlooks, I stressed the urgent need for this reform.

Because of the 2021-2022 energy crisis and the need to decouple electricity prices from gas prices, the EU heads of States pushed the Commission to launch this reform.

On March 14, 2023, the European Commission (EC) published a proposal to reform the EU electricity market. The objectives are[21]:

1. Protecting consumers from volatile energy prices.
2. Enhancing stability and predictability of the cost of energy, thereby contributing to the competitiveness of the EU economy; and
3. Boosting investments in renewable energy.

To address the *first* objective, the proposal foresees notably:

- To allow Member States to implement a specific type of regulated retail prices (i.e., block tariffs), which have been used during the 2021-2022 crisis to protect consumers.
- To allow consumers to share renewable energy more easily.
- To encourage suppliers to shield against high prices through the increased use of long-term contracts with generators to stabilize energy supply for their customers.

To address the *second* objective:

- The proposal aims to optimize the functioning of short-term markets, for example, reducing the minimum bid size for intraday and day-ahead markets to 100 kW to improve liquidity.
- The *proposal encourages customers to enter stable long-term contracts*, such as Power Purchase Agreements (PPAs[22]) and Contracts for Difference (CfDs[23]). It also seeks to increase forward markets liquidity.

Access to PPAs is currently available only to major actors in a few Member States. The States are thus asked to implement measures to make PPAs more widely accessible, notably by decreasing risks associated with buyers' payment default (through state guarantees).

21 https://fsr.eui.eu/a-summary-of-the-proposal-for-a-reform-of-the-eu-electricity-market/

22 PPAs are long-term private contracts between a renewable energy or low-carbon generator and a consumer.

23 CfDs are Contract for Difference based on a difference between the market price and an agreed "strike price".

The European Commission EC recommends two-way CfDs[24], which imply setting a minimum that can be earned by the energy producer, but also a maximum price, so that any revenues above it are paid back to the public actor. CfDs have already been used for wind and solar. Their use would be extended to geothermal, hydro without reservoir, and nuclear power (existing plants and new ones).

As for the *third* objective, CfDs and PPAs could give reliable revenues to renewable energy suppliers (lowering the financial risk and reducing the cost of capital). This would contribute to the objective of tripling renewables deployment in line with European Green Deal goals.

The *European electricity market reform is a particularly sensitive topic in France* because the regulated system for the sale of nuclear electricity, Accès Régulé à l'Electricité Nucléaire Historique (ARENH), ends in December 2025. This regulation obliges EDF to sell 100 TWh (between one-third and one-quarter of its nuclear electricity production) to its competitors at the very low price of €42/MWh. This regulation is very penalizing for EDF and partly explains its financial difficulties.

There is a certain urgency for EDF and its customers to define the conditions of sale from 2026 onwards. EDF, heavily indebted and which must finance (at least in part) the construction of the new EPRs[25] needs visibility on its finance trajectory. Its major customers also wish to know the conditions for purchasing electricity two years in advance.

EDF defends the conclusion of long-term electricity sales contracts in the form of PPAs to set its prices more freely to finance its investments in existing power plants and new means of production (renewable and nuclear). These investment needs should reach around €25 billion.

In this context, on September 7, 2023, EDF announced the launch of an experimental auction system with the placing on the wholesale electricity market of volumes to be delivered in 2027 and 2028 (over five years). Presently, the French wholesale market only allows electricity to be purchased until 2026 (three-year contracts). EDF wants to increase its visibility and that of consumers in the context of high prices.

The agreement that took place in October 2023 between France and Germany has cleared the way to the finalization of this import reform. However numerous details have still to be agreed upon before the 2024 European elections.

24 In two ways CfDs if the "strike price" is higher than a market price, the CfD Counterparty must pay low carbon generator the difference between the "strike price" and the market price. If the market price is higher than the agreed "strike price», low carbon generator must pay back the CfD Counterparty the difference between the market price and the "strike price."

25 European Power Reactor or Evolutionary Power Reactor

Climate change consequences are happening quicker than expected.[26]

June, July, and August 2023 were the hottest months ever recorded since 1940. According to the Copernicus Climate Change Service[27], "The world will continue to see more climate records and more intense and frequent extreme weather events, until we stop emitting greenhouse gases."

Global energy related GHG emissions grew by 0.9% or 321 Mt in 2022, reaching a new high of over 36.8 Gt. This growth was slower than 2021's 6% increase, which followed a 4.6% drop in 2020 as lockdowns in the first half of the year restricted global mobility and hampered economic activity.[28]

Increased deployment of clean energy technologies such as renewables, electric vehicles, and heat pumps helped prevent an additional 550 Mt in CO_2 emissions. Industrial production curtailment, particularly in China and Europe, also averted additional emissions.

CO_2 growth in 2022 was well below global GDP growth of 3.2%, reverting to a decade-long trend of decoupling emissions and economic growth which was broken by 2021's sharp rebound in emissions.

According to a new climate report issued by the United Nations in early September 2023, "the world is not on track to meet the long-term goals of the Paris Agreement," including capping global warming at 1.5° Celsius since pre-industrial times[29] and achieving net zero carbon by 2050.

What measures should be taken?

Accelerate clean technologies deployment.

A successful energy transition to reach net zero carbon in 2050, implies a huge growth in electricity generation. According to the Energy Transition Commission[30], it should rise from ~28,000 TWh in 2022, to as much as ~110,000 TWh by 2050, with over 75% of this supplied by wind and solar. The rest will be provided by a mix of nuclear, hydropower, and other zero-carbon sources, along with battery and other storage.

China has a dominant role in clean technologies, both by its domestic investments and by its position in the international market. The country spent $546 billion in 2022 on investments that included solar and wind energy, electric vehicles, and batteries. That is nearly four times the amount of U.S. investments, which totaled $141 billion. The European Union was second to China with $180 billion in clean energy investments.[31]

26 https://www.iea.org/reports/co2-emissions-in-2022
27 https://climate.copernicus.eu/summer-2023-hottest-record
28 https://www.iea.org/reports/co2-emissions-in-2022
29 https://www.lemonde.fr/en/international/article/2023/09/08/un-world-not-on-track-to-meet-paris-climate-goals_

30 https://www.energy-transitions.org/publications/material-and-resource-energy-transition/
31 https://www.scientificamerican.com/article/china-invests-546-billion-in-clean-energy-far-surpassing-the-u-s/#:~:text=The%20country%20spent%20%24546%20billion,billion%20in%20clean%20energy%20investments.

We will concentrate our analysis on clean electricity generation by acknowledging that "green heat", as provided by biomass and geothermal, is an important complement notably because it is storable.

We will not analyze in detail the progress in CCUS, as this was done extensively in the 24th edition of WEMO.[32] We can note that with solid market carbon prices[33], CCUS competitiveness could increase thanks to industrialization, and that it is certainly a technology that is needed. In the United States, Oil & Gas companies are strongly committed to developing this technology and the IRA provides subsidies. Europe is late (compared to the U.S.) in CCUS development; however, the EC has launched a consultation to state its vision.

Finally, China is making significant progress on CCUS development.[34] This is of the utmost importance as China is commissioning two large coal plants per week.[35]

Finally, as stated in 2022, Direct Air Capture is not a mature technology, since it consumes a lot of energy and because it is expensive.

32 https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/
33 In Europe, Emission Trading System (ETS) carbon price is around €90/t
34 www.globalccsinstitute.com
35 https://energyandcleanair.org/publication/china-permits-two-new-coal-power-plants-per-week-in-2022/#:~:text=A%20total%20of%20106%20GW,from%2023%20GW%20in%202021.

Nuclear:

Climate changes and energy sovereignty issues are triggering nuclear revival. In early 2023, at the initiative of France, the European Nuclear Alliance was created. It aims to bring together all the countries of Europe wishing to rely on nuclear energy, alongside renewables, to carry out their energy transition. In May, the 16 European countries participating in this alliance (Belgium, Bulgaria, Croatia, the Czech Republic, France, Finland, Hungary, the Netherlands, Poland, Romania, Slovenia, Slovakia, Estonia, Sweden, Italy, and the United Kingdom) announced that they will prepare a roadmap to develop an integrated European nuclear industry reaching 150 GW[36] of nuclear power capacity in the EU's electricity mix by 2050. They call on the European Union and international partners to consider the contribution of all affordable, reliable, fossil-free, and safe energy sources to achieve climate neutrality by 2050.

Nevertheless, actions must follow the announcements. ***Further, financing terms for new nuclear power plants have not yet been decided, including notably in France*** where there are ambitious plans to build six new EPR reactors and consider building a further eight.

36 100GW in 2023. As there will be nuclear plants decommissioning from 2023 to 2050 the new plants capacity to be built will exceed 50GW.

At the end of August 2023[37], in addition to EDF funding, the U.K. government announced that it has made available a further £341 million (€400 million) on the Sizewell C nuclear power plant. Sizewell C is expected to host two EPRs of 1.6 GW capacity each, like the Hinkley Point C plant, which is under construction. The construction of Sizewell C remains subject to a final investment decision and depends notably on the project financing as the U.K. government must raise £20 billion (€20.3 billion) of private finance through debt and equity before construction can start. To make the investment attractive to institutions (such as pension funds), the U.K. government has adopted the Regulated Asset Base (RAB) regulation[38] for the electricity to be produced by Sizewell C. In comparison with the CfD model used for Hinkley Point C, under RAB, construction risks would fall on the public (most likely as electricity consumers, but also as taxpayers). However, it will probably take until the end of 2024 to close Sizewell's construction funding.

37 https://world-nuclear-news.org/Articles/More-funding-for-Sizewell-C-preparations
38 https://www.lowcarboncontracts.uk/

1. ***Existing reactors have been operating safely*** as no important incident or accident happened since the 2011 Fukushima accident.

In 2023, there are about 440 nuclear power reactors operating worldwide with a combined capacity of about 390 GW.[39] They provide around 10% of the worldwide electricity needs. The 2022 IEA Net Zero Emissions by 2050 Scenario (NZE)[40] sees nuclear capacity increase to 871 GW by 2050. Out of the 60 power reactors currently being constructed, the vast majority is in Asia (China, India, and North Korea) and Russia has four reactors under construction.

» *Lifetime:*

The nuclear power plants lifetime should be linked only to its safety condition and price competitiveness. However, these technical and economic considerations are not considered by politicians that decide to close safe and competitive reactors. This was unfortunately the case in France with the closure of Fessenheim's two reactors in 2020.

After the Fukushima accident in 2011, the German Chancellor decided to phase out the country's 17 nuclear reactors. Accordingly, all have been stopped by mid-2023, including the three last ones that were provisionally kept open during the 2022-2023 difficult winter. This happens while Germany is increasing its renewable output and may be confronted with grid stability problems.

During the summer of 2023, two important lifetime extension decisions were announced. On the one hand, Belgium reached an agreement with operator Engie to extend the use of the country's nuclear reactors by 10 years after Russia's invasion of Ukraine prompted Belgium's governing coalition to rethink plans to rely more on natural gas.

Initially, Belgium was to have exited nuclear power entirely by 2025, but will now extend the lives of its two newest reactors, Doel 4 and Tihange 3, according to the agreement.

On the other hand, the French Nuclear Safety Authority issued a decision allowing for the continued operation of EDF's Tricastin 1 nuclear reactor in southern France. It is the first lifetime extension granted to a French reactor after 40 years of operation. These decisions will allow to keep the existing nuclear fleet while waiting for the new nuclear plant to be built.

» In addition, *reactor uprates*[41] provide immediate solutions to maintaining and increasing power capacity in existing reactors. Since 2001, globa net nuclear capacity has increased from 352.72 GW to 392.61 GW[42], an 11% increase, while the number of operational nuclear power plants has not increased significantly (438 vs. 442). Some of this is attributable to smaller reactors being replaced by larger ones, but most of the increase is due to improvements in existing reactors. These investments usually have a compelling payback for utilities as capital investment represents around 80% of the nuclear electricity cost. Uprates are relatively small investments leading to capacity increases ranging from 0.4% to 20%.

The French nuclear operator was prevented from increasing its fleet capacity by the 2015 law capping the total nuclear output at 63 GW. Thanks to the new 2023 law on "nuclear acceleration", this non-understandable constraint has been lifted and EDF is engaging in an uprating program.

39 https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx

40 'Net Zero Emissions by 2050 Scenario' (NZE), "maps out a way to achieve a 1.5°C stabilization in the rise in global average temperatures, alongside universal access to modern energy by 2030."

41 An uprate is any change that increases the power output of

42 https://sprott.com/insights/special-uranium-report-why-nuclear-power-plant-life-extensions-uprates-matter/

1. *New large reactors:*

Out of the 60 power reactors currently being constructed, the vast majority is in Asia (China, India, and North Korea) and Russia has four reactors under construction. Most of these constructions are progressing along the initial plant. This is not the case in western world.

» On July 31, 2023, the U.S. utility Georgia Power announced that the AP1000 Vogtle 3 was in commercial service. It becomes the 93rd reactor in the country. Unit 4 is expected to generate electricity in the first quarter of 2024 at the latest. They are seven years late and $17 billion over budget. Some of the key promises of Vogtle — like building modules offsite and shipping them for cheaper on-site assembly — did not materialize.

» In Europe, Finland's Olkiluoto 3 EPR (1600 MW) finally entered in service more than ten years later than planned and with a several billion Euro cost overrun. Olkiluoto 3 is the first EPR to enter service in Europe and the third in the world after the Taishan 1 and 2 plants in China. The French Flamanville 3 EPR should start operations in the first quarter of 2024. Similarly to Olkiluoto EPR, the delay will be 12 years and the cost overrun around €10 billion. (The project's cost at completion is estimated at €12.7 billion, more than four times the initial estimate of €3.3 billion). These examples ***illustrate the difficulty of building new large third-generation reactors in western countries.***

2. *SMRs:*

Development on small modular nuclear reactors (SMRs) is underway globally and is generating a lot of interest. SMRs promise technological advances that address key challenges in the nuclear power generation cycle, including project size, cost and financing, time to market, and location flexibility.

In 2021, after a nine-year construction, research and technological development, the China Huaneng Group Co.'s 200 MW Unit 1 reactor at Shidao Bay has started operations in Shandong province, using helium as the cooling fluid instead of water.

In 2019, the floating nuclear power plant Akademik Lomonosov was connected to the grid, generating electricity for the first time in Russia's far east.

There are currently four SMRs in advanced stages of construction in Argentina, China, and Russia. In addition, several existing and newcomer nuclear energy countries are conducting SMR research and development.

- *Design:* There is a large range of SMR designs in development (more than 70 different designs as of 2023). The most mature SMR concepts being proposed by vendors are evolutionary variants of Light Water Reactors (LWR) operating worldwide; these benefit from many decades of operating and regulatory experience. They represent approximatively 50% of the SMR designs under development.

  The other 50% of SMR designs corresponds to Generation IV reactors (Gen IV SMR) that incorporate alternative coolants (i.e., liquid metal, gas, or molten salts), advanced fuel, and innovative system configurations. While Generation IV-based designs do not have the same levels of operating and regulatory experience as that of LWRs, and additional research is still needed in some areas, they nevertheless benefit from an extensive history of past research and development.

  These reactors have advanced engineered features and are deployable either as a single- or multi-module plant. Some are classified as micro SMRs, producing as little as 10 MW, while many are designed for a capacity of about 300 MW.

- *Benefits:* Small modular reactors offer a lower initial capital investment and thus a reduced risk, greater scalability, and siting flexibility for locations unable to accommodate larger reactors. They also have the potential for enhanced safety and security compared to earlier designs. Their small size and modularity facilitate their adoption in regions and sectors where the use of large nuclear power plants is more limited.

- *Challenges:* The smaller size of SMRs implies that they don't benefit from economies of scale.

  To overcome this economic challenge, "series construction" will become an imperative. Factory fabrication also provides an environment of enhanced quality control that can reduce construction risks and enable the introduction of new manufacturing techniques. ***Some of these benefits*** have already been demonstrated in other industries but ***still need to be proven for SMRs.***

  At the same time, higher levels of regulatory harmonization are needed to support a global market, as well as a reduction in the number of designs proposed by vendors. Obtaining licensing agreements is potentially a challenge for SMRs, as design certification, construction, and operation license costs are equivalent to those of large reactors that generate much more electricity. In addition, the dispersion of SMRs could raise concerns on nonproliferation management.

Finally, due to their smaller size and deployment over larger areas; harnessing the same amount of electricity from SMRs than large reactors will require an increased number of grid connections (similar to wind or solar farms). This places additional demands on grid operators. They will encounter the same challenges in grid connection as dispersed wind or solar farms.

An illustration of these challenges is the NuScale SMR project development. It has long been named the most advanced company in the field of SMRs. Its design, composed of 50 MWe modules, is also the first to have received certification from the U.S. safety authority (NRC) in January 2023. However, at the end of 2022, the company announced a 53% increase in the SMR's target electricity price, driven by a dramatic 75% jump in the project's estimated construction cost, which has risen from $5.3 billion to $9.3 billion. The new estimate makes the NuScale SMR about as expensive (on a dollars-per-kWh basis) as the two-reactor Vogtle nuclear plants (see above), undercutting the claim that SMRs will be cheap to build.[43]

While SMRs will certainly contribute in the future to clean energy generation, it is likely that they will not contribute meaningful amounts in western countries, for another decade.

43 https://ieefa.org/resources/eye-popping-new-cost-estimates-released-nuscale-small-modular-reactor

- *Start-ups:* SMR development is proceeding in western countries with a lot of private investment, including small start-up companies. Out of the 83 SMR projects from many different players surveyed by IDTechEx[44], around 30% of the organizations involved are start-ups. The involvement of these new investors is positive, as it brings fresh financing to the nuclear industry, new ideas, and entrepreneurial management skills.

3. *Nuclear fusion breakthrough:*

Present reactors are based on fission nuclear reaction that split atoms to generate energy. A fusion reaction would force lighter atoms (for example deuterium) together to create heavier atoms. Both reactions generate carbon-free energy, but fusion avoids much of the radioactive waste that fission creates. Fusing atoms together requires extreme heat and pressure. Up until recently, the development was based on magnetic confinement (Tokamak), notably with the very large ITER[45] international project. Recently, fusion confinement triggered by laser has made a scientific breakthrough.

In December 2022, scientists at Lawrence Livermore National Laboratory in California achieved fusion ignition.[46] However, the efficiency of a potential fusion energy power plant remains to be seen as the reported fusion net gain required about 300 megajoules of energy input, which was not included in the energy gain calculation. This energy input, needed to power 192 lasers, came from the electric power grid. In other words, the experiment used as much energy as a typical household does in two days while the fusion reaction output was enough energy to light just 14 incandescent bulbs for one hour! ***So, a real break-even was not reached.***

Presently there is an appetite for funding nuclear fusion from governments and the private sector. For example, Germany, which has phased out its nuclear plants, announced in September 2023, that it will invest more than €1 billion in fusion research over the next five years. On the private sector side, entrepreneurs and start-ups are investing and getting public funding (from the Department of Energy, for example). Presently there are 39 companies in nuclear fusion[47] and this number is growing.

However, billions of dollars are needed before fusion can meaningfully contribute to our energy system.

Solar and wind power development must accelerate:

1. ***In 2022, investment in clean energy technologies48 has significantly outpaced spending on fossil fuels,*** triggered by affordability and security concerns. 2022 was a record year for renewable electricity capacity additions, with annual capacity additions amounting to about 340 GW.[49] Public policies in the United States (IRA), Europe, and China (14th Five-Year Plan) have pushed renewable energies and should continue in the future. The capacity of offshore wind farms is continuously increasing thanks to the wind turbine capacity increase. The development of the cable industry and floating offshore platforms enables the construction of very large offshore farms at a longer distance from the coast (which reduces local opposition).

   For example, the Seagreen[50] offshore wind farm in Scotland is expected to be fully operational during the summer of 2023 with 114 turbines and a total capacity of 1,075 MW. Its electricity will be exported via 19 kilometers of underground cables. The largest solar farms are in China, India, and the Middle East. The Golmud Solar Park in China is the world's largest

44 https://www.idtechex.com/en/research-article/the-future-of-nuclear-smrs-will-start-ups-disrupt-established-players/29374
45 https://www.iter.org/fr/mach/tokamak

46 https://theconversation.com/nuclear-fusion-breakthrough-decades-of-research-are-still-needed-before-fusion-can-be-used-as-clean-energy-196758
47 https://tracxn.com/d/trending-themes/startups-in-nuclear-fusion/__9FrsspZn9m17N8HDaicS29LcdRJCyceX3ICOmPdAn98

48 The report shows that investment in clean energy technologies is significantly outpacing spending on fossil fuels, as affordability and security concerns triggered by the global energy crisis strengthen the momentum behind more sustainable options.
49 https://www.iea.org/energy-system/renewables#tracking
50 https://www.power-technology.com/projects/seagreen-offshore-wind-farm/

solar farm with an installed solar capacity of 2.8 GW, generated by nearly seven million solar panels. Plans are to expand the site to reach 16 GW within the next five to six years. Despite those impressive achievements, renewable deployment must accelerate. Several factors can contribute to this needed acceleration.

2. ***Accelerating the permitting process,*** since it can be an obstacle to renewable energy projects by increasing delays and cost. To address the issue, the revised Renewable Energy Directive includes provisions that simplify permitting processes. In the U.K., the Simplifications Decree-Law for renewable energy, green hydrogen, and electricity grid entered into force on April 19, 2022[51]. In March 2023, France adopted the law on the acceleration of the production of renewable energies, the aim of which is to halve the deadlines for carrying out renewable energy projects. In 2020, wind, solar, as well as wood and hydro energies, represented 19.1% of country gross final consumption, which was below its EU target of 23%.

   The law is thus structured around four pillars:

   » Accelerate the procedures: In France, it takes, on average, five years of procedures to build a solar park requiring only a few months of work, seven years for a wind farm, and 10 years for an offshore wind power park – twice as long as its European neighbors.

   » Free up the necessary land, by mobilizing car parks, degraded land, and the edges of motorways to deploy photovoltaic panels.

   » Accelerate the deployment of offshore wind projects through less complex consultation procedures with local stakeholders and through field planning that would be carried out on the scale of a seafront.

   » Improve the financing and attractiveness of renewable energy projects.

3. ***Boosting innovation: The innovation goals for renewables are like those analyzed in the 24th edition of the WEMO.***[52]

   For PV solar technology, they aim to:

   - Increase the solar panels' yield[53], with innovative material such as perovskites.
   - Develop longer-lasting solar cells.
   - Develop solar cells printable onto flexible surfaces.
   - Implement solar panels that track the sun from east to west throughout the day.
   - Develop solar power plants that work at night.

   - Extend the surfaces covered by PV panels by installing them on rooftops and lakes (floating solar).

51 https://www.cuatrecasas.com/en/global/art/portugal-simplification-of-procedures-for-renewable-energy-projects
52 https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/

53 https://www.energymatters.com.au/renewable-news/latest-advances-in-solar-pv-technology-could-make-solar-panels-more-efficient-and-affordable/

For wind technology, innovations aim to:

- Increase wind turbines size: China Three Gorges Corporation announced that a 16 MW turbine had been successfully installed at the company's offshore wind farm on July 19, 2023. The behemoth is 152 meters tall, and each single blade is 123 meters and weighs 54 tons!
- Design wind turbines with innovative aerodynamic and structures.
- Use better materials, including advanced nanomaterials like graphene for turbine blades, and consider hybrid materials for wind turbine towers, combining both steel and concrete for enhanced durability and performance.
- Adapt oil offshore floating platform technologies to offshore wind, enabling the construction of wind farms further from the coast.

For both solar and wind there is a need to

- Recycle equipment.
- Improve operations, control, and maintenance; and
- Implement a data-driven approach, by developing advanced measurement systems and improving numerical prediction tools.

4. ***Improving wind and solar competitiveness:*** After years of impressive drops in cost, wind and solar levelized cost of electricity (LCOE) started to increase in 2021. In 2022, this trend continued. Like nuclear electricity costs, the initial capital investment accounts for the majority of solar PV and wind power plant generation cost (as operations and maintenance costs are very low). In late 2020, the prices of major inputs such as steel, copper, aluminum, and polysilicon began to rise sharply, as did freight and land transport costs, due to supply chain challenges and growing demand during the post-Covid-19 global economic rebound.

   During 2022, freight and commodity prices have fallen significantly below their peaks, but they remain elevated compared with 2020. For example, polysilicon price (where China has a dominant position) in Q1 2023 was 200% higher than the January 2020 average price. U.S. steel increased by 100% during the same period.

   These cost increases were not offset by cost reductions from technological innovation and, according to IEA54, the resulting LCOE increase for 2022 is estimated at 15-20% for these technologies. Except for China, many regions experienced cost increases, especially for offshore wind.

   In Europe55, between 2020 and 2022, LCOE onshore wind cost increased from €38/MWh to €50/MWh, solar utility scale farms cost rose from €48/MWh to €67/MWh, and offshore wind cost jumped from €101/MWh to €114/MWh.

   Although their costs continue to exceed pre-Covid-19 levels, solar PV and onshore wind remain the cheapest option for new electricity generation in most countries.

5. ***Overcoming industry difficulties and increasing sovereignty:***

   » Three recent events illustrate the wind sector difficulties.

   - On August 30, 2023, Denmark's Orsted[56], the world's largest offshore wind farm developer, announced impairments of €2.3 billion due to supply chain problems, soaring interest rates, and a lack of new tax credits, especially on U.S. offshore projects. In one year, production costs rose significantly, while the long-term electricity purchase prices offered by States have continued to fall. This situation makes operators dependent on subsidies. Part of Orsted's disappointment comes from a reduction in the expected subsidy for the establishment of its field off the North American coast.

54 iea.org/reports/renewable-energy-market-update-june-2023/will-solar-pv-and-wind-costs-finally-begin-to-fall-again-in-2023-and-2024.

55 https://www.woodmac.com/news/opinion/renewable-energy-costs-europe/
56 https://www.reuters.com/business/energy/denmarks-orsted-anticipates-730-mln-impact-us-portfolio-2023-08-29/

- In July 2023, Swedish utility Vattenfall[57] announced that it would stop development of its British Norfolk Boreas offshore wind project (1.4 GW) due to rising costs. Vattenfall President and CEO Anna Borg said that costs rose by 40% and she warned that Britain could struggle to meet its wind targets without improved incentives.
- In August 2023, Siemens Gamesa[58] booked a €2.6 billion loss in its fiscal third quarter due to higher-than-expected charges associated with its onshore turbines. The turbine company expects to record a total loss for the year of around €4.5 billion, reflecting lower profit contributions from the execution of its current order backlog mainly related to increased product costs. These challenges highlight a broader issue facing wind turbine manufacturers. They are actively investing in research and development to enhance the size of their turbines with the goal of reducing costs. However, they find it challenging to recover these R&D investments, as clients are demanding even faster cost reductions. Indeed, the latter (utilities and Oil & Gas companies) are bidding for new projects at continuously lower electricity prices to win. To secure their wind turbine procurement, European renewable companies are opening their supplier list to Chinese firms (Goldwind and Envision Energy, for example).
- According to Renewable Digital[59], five out of the 10 largest wind turbine manufacturers[60] are Chinese. *Governments, regions, and States in the U.S. and EU should either increase subsidiaries on wind projects or increase the allocated price to avoid bankruptcy of their domestic wind turbine companies, which would endanger their energy sovereignty.*

» While the U.S. government has limited the Chinese suppliers' access to the US by legislations such as the IRA, in Europe, the solar PV sector is totally dominated by Chinese suppliers. Now the EU is reacting by encouraging PV panels manufacturing in Europe.

In June 2023, the French President announced an investment of €700 million by Holosolis in a 5 GW production plant for photovoltaic solar cells and modules in France. This factory complements another 5 GW project with an investment of €1.5 billion over the entire solar module cycle, from the formation of ingots. In the medium term, new PV production capacity should reach 10 GW on French territory.[61]

However, China is dominant in polysilicon procurement. Its share of world's polysilicon production has grown from 30% to 80% in just one decade (2012-2021)[62] and should expand to 90% soon. Out of the top 10 polysilicon manufacturers in 2021, only two are situated outside of Asia: Wacker (Germany/United States, ranking 4th) and Hemlock (United States, ranking 9th). The remaining seven suppliers are based in China.

57 https://www.reuters.com/sustainability/vattenfall-halts-project-warns-uk-offshore-wind-targets-doubt-2023-07-20/
58 https://renews.biz/87372/siemens-gamesa-records-26bn-q3-loss/
59 https://renewables.digital/product/wind-turbine-manufacturers/
60 Vestas Wind Systems (Denmark), Siemens Gamesa (Spain),Goldwind (China), Nordex SE (Germany), General Electric Renewable Energy (France),Envision Energy (China),Zhejiang Yunda Wind Power (China),VENSYS Energy AG (Germany), Mingyang Smart Energy (China), HZ Windpower (China)
61 https://www.enerplan.asso.fr/industrie-solaire-une-ambition-enfin-a-la-hauteur-des-defis-en-france
62 https://www.solarpowerworldonline.com/2022/04/chinas-share-of-worlds-polysilicon-production-grows-from-30-to-80-in-just-one-decade/

Russia's invasion of Ukraine has opened the eyes for what it means to be dependent on a country for energy supply. Western governments should not make the same mistake with China.[63]

> *"It is high time to establish non-Chinese solar supply chains. China has demonstrated what the ingredients of success are: low electricity rates for power-hungry polysilicon and ingot production, loan guarantees for private investment, cost-efficient equipment manufacturing, and strategic foresight."*
>
> **Johannes Bernreuter**
> Founder and head · Bernreuter Research

Electricity storage development is of the utmost importance to balance electricity grids.

According to IEA, to reach climate change mitigation objectives, the world needs to triple the global installed capacity of renewable power by 203064 (mainly intermittent wind and solar).

In March 2023, the European Union members committed65 to sourcing 42.5% of their energy from renewable sources by 2030, with a potential top-up to 45%. This increasing share of intermittent renewable generation and the closure of "peaker plants" (powered by natural gas) that insure the grid balance at critical hours, is triggering an increasing need for electricity storage.

For example, in Australia, renewable energy sources supply about 27% of Australia's electricity generation, and at times up to 52%. Such rapid penetration of renewables is already posing significant challenges to grid stability with utility-scale energy storage becoming increasingly important. The recently drafted Australian Integrated System Plan (ISP) highlights challenges for energy storage in Australia.

They include:

- The need to triple the firming capacity that can respond to a dispatch signal, including utility-scale batteries, hydro storage, gas generation, smart behind-the-meter batteries, or virtual power plants (VPPs).
- By 2050, a National Electricity Market (NEM) without coal will require 45 GW/620 GWh of storage, in all forms.

1. ***Pumped storage hydropower (PSH)[66]:** Presently, the largest storage capacity is provided by PSH.* With more than 100 projects in the pipeline, International Hydropower Association (IHA)[67] estimates that PSH capacity is expected to increase by almost 50% – to about 240 GW – by 2030. The IEA has set a target of 420 GW of pumped storage worldwide by 2050. China leads installed PSH capacity with 50.7 GW, holding 30% of the world's total. For prospective capacity, China is the first country with 80% of the global projected capacity followed by Europe, Australia, India, and Northern America.

   An innovative project in Germany is studied by scientists. It consists of filling opencast lignite mines (at

63 Research: https://www.bernreuter.com/
64 https://www.iea.org/commentaries/tripling-renewable-power-capacity-by-2030-is-vital-to-keep-the-150c-goal-within-reach
65 https://www.reuters.com/business/sustainable-business/eu-reaches-deal-more-ambitious-renewable-energy-targets-2030-2023-03-30/#:~:text=Negotiators%20of%20the%20European%20Parliament,a%2032%25%20renewable%20energy%20share.
66 https://www.energy.gov/eere/water/pumped-storage-hydropower
67 https://www.hydropower.org/factsheets/pumped-storage

a depth of 500 to 300 meters) located in Rhineland and installing PSH. Feasibility studies with elaborated cost estimation are the next step.

2. *Batteries* offer a complement to creating a lower emission[68], more resilient grid. The world will need nearly 600 GWh of battery energy storage by 2030 to achieve net-zero emissions by 2050, according to estimates from the IEA.[69] In 2021, there was less than 60 GWh of battery storage capacity, hence *the need for a big acceleration of stationary batteries installations.*[70]

In 2021, about 25 GWh of battery energy storage system (ESS) capacity was added globally, which amounts to 10-15% of EV battery demand. Although the demand for ESS batteries is growing substantially—more than 100 GWh of new capacity has been announced for 2022-2024, the market is concentrated in just a few regions: the U.S. (mainly California), China, and Europe.

In China, for grid stability reasons, wind or solar farms will be connected to the grid only if they have stationary storage equivalent to about 5-20% of the total power generated. Some U.S. states have similar legislation.

With the higher renewable generation and its intermittency, curtailments of solar or wind generation will be more frequent.

Either these solar or wind farms are collocated with hydrogen electrolyzers[71] to produce hydrogen at near zero electricity cost, or this electricity is lost, thus destroying the value of investing in these farms. This is why the value of stationary storage is growing.

In August 2023, French utility company Engie has reached a deal, with an equity value of over $1 billion, to purchase Texas-based battery energy storage firm Broad Reach Power.[72] As part of the transaction, Engie will now own 350 MW of grid-scale battery assets in operation, along with 880 MW under construction and 1.7 GW of storage projects in the pipeline. U.S.-listed private equity firm KKR is set to acquire joint control of U.K. battery storage developer Zenobē in partnership with existing investor Infracapital, according to reports.[73] The deal totals $1.089 billion of investment.

This growth in ESS battery demand is ramping up at the same time as the need for EV batteries, meaning that both types of battery makers are seeking the same resources, such as lithium or cobalt (see above).

However, the specs for stationary batteries are not the same as for EV batteries. The latter can accommodate a lower energy density since weight and space constraints are not a concern.

ESS battery manufacturers are opting for lithium-iron-phosphate (LFP) batteries, which have a lower energy density compared to nickel-manganese-cobalt (NMC) batteries. However, this lower energy density is not a significant concern for ESS applications, especially considering that LFP batteries do not rely on nickel and cobalt, unlike NMC batteries.

It's worth noting that NMC batteries are still the primary choice for electric batteries.

» ***Technologies:*** Lithium-ion batteries are the best option for stationary storage today.

- Sodium-ion batteries are non-flammable (thus safer), have a longer life cycle, perform well in low temperatures and can be more sustainable due to their reduced use of critical materials. They also share a similar design to lithium-ion batteries, making manufacturing less of a challenge.
- The main drawback today is their relatively lower energy density compared to lithium-ion

68 They can be considered as "green" only if they are recycled.
69 https://www.iea.org/energy-system/electricity/grid-scale-storage#tracking
70 https://www.emergingtechbrew.com/stories/2022/04/19/batteries-beyond-evs-everything-you-need-to-know-about-stationary-storage

71 However, hydrogen transportation to the industrial consuming plants is usually not yet available expensive and probably ammonia plants will have to be built also as liquid ammonia is easier to transport.
72 https://www.engie.com/news/broad-reach-power
73 https://www.energy-storage.news/private-equity-firm-kkr-agrees-us1-billion-deal-for-uk-developer-zenobe-reports/

batteries (which is not a problem for stationary batteries). Ongoing R&D[74] aims at improving their performance to reach energy density similar to LFP batteries. Lower cost can be expected once production is scaled up. CATL[75], the world's largest battery-maker of Chinese origin, announced it plans to have a supply chain for sodium-ion batteries in place by 2023. Other early-stage battery technologies are being developed for stationary storage applications, such as: flow batteries, metal-air (notably aluminum-air) batteries, or liquid metal batteries using molten salt.

- Flow batteries[76]: A flow battery is a rechargeable battery in which electrolytes flow through one or more electrochemical cells from one or more tanks. Expanding the energy storage capacity of a flow battery is a straightforward process accomplished by increasing the volume of electrolyte stored in the tanks. The electrochemical cells can be electrically connected in series or in parallel, thus determining the power of the flow battery system. This decoupling of energy rating and power rating is an important feature of flow battery systems.

- However, the system is complex as it requires a pump and flow management system. Moreover, flow batteries have high costs at present.
- As a final consideration, many players in the flow battery industry have recently stumbled, including Imergy, Aquion, and ViZn. It is likely that only a few will be able to capitalize on the potential advantages of flow batteries.

» ***Recycling plays a vital role in ensuring the sustainability of batteries and electric vehicles (EVs).***

To achieve true sustainability, it is essential to recycle batteries, and simultaneously, ensure that the electricity used for recharging them comes from low-carbon sources.

- EV batteries no longer suitable for vehicles: When an EV ultimately retires (or crashes), its battery pack can be reused for stationary storage. For example, the Mobility House (Zürich) already earns ~€1000 per EV battery pack per year by selling ~13 services from stationary or parked EV battery packs to the electricity grid in several European countries.
- Recycling: Interest and investment in lithium battery recycling have grown in recent years as critical materials needs are exploding (see above) and carbon emissions from metals need to decrease. New legislations, such as the European battery passport, are making recycling compulsory.

74 They can be considered as "green" only if they are recycled.
75 https://www.iea.org/energy-system/electricity/grid-scale-storage#tracking
76 https://www.emergingtechbrew.com/stories/2022/04/19/batteries-beyond-evs-everything-you-need-to-know-about-stationary-storage

Prior to recycling, batteries are collected, sorted, and dismantled. Then plastics and metals will be separated. Metals are crushed, producing "black mass" which is a powder containing a mixture of cathode and anode materials. It is made up of many metals such as copper, manganese, cadmium, lithium, cobalt, etc., and contains recoverable metal oxides. The objective is to separate each metal from this mass and remove toxins from the material to avoid contaminating the metals. The purer the metal, the better it can be recycled. For this purpose, two techniques are used: pyrometallurgy and hydrometallurgy.

"Black mass" is on the verge of becoming a raw material in its own right. The S&P Global[77] launched regular pricing of this material in 2023.

Car manufacturers are becoming more and more interested in black mass[78], with BMW, Ford, and Mercedes announcing partnerships for the development of battery recycling projects.

Specialists in metals and chemistry are doing the same. In May 2023, Glencore joined forces with the Canadian Life Cycle to process black mass and create the largest European battery recycling center.

77 https://press.spglobal.com/2023-08-29-S-P-Global-Commodity-Insights-Launches-First-of-Kind-Daily-US-Black-Mass-Price-Assessments
78 https://www.lesechos.fr/finance-marches/marches-financiers/la-black-mass-nouvel-or-noir-de-la-transition-energetique-1973527

The sector has a few challenges – first and foremost that of profitability.

The economic viability of recycling plants will be negatively impacted by the increased usage of LFP batteries, which makes metal recovery less profitable. At the current market price, a NMC battery contains approximately $10,000 of metals per ton of battery cells. Conversely, the value of the metals in an LFP battery is only $4,000 per ton.

- The carbon footprint of an electric battery must consider the footprint of mining. Recycled material has a much lower carbon footprint. The carbon footprint of a ton of aluminum is between 4 and 15 tons of CO_2 while the carbon footprint of recycled aluminum is 5 to 25 times lower.
- According to S&P Global forecasts, recovery will represent approximately 15% of the global supply of lithium, 11% of nickel, and 44% for cobalt in 2030. Thus, recycling would significantly reduce the risk of shortage linked to these metals' rapid increase needs. According to Energy Transition Commission models[79], lithium consumption will be 30% higher than global supply in 2030, but with an emphasis on recycling and efficiency, the gap can be reduced to 10%.

79 https://www.energy-transitions.org/publications/material-and-resource-energy-transition/

- Recycling facilities: In 2022, Redwood Materials[80], the battery recycling company founded by a former Tesla executive, announced that it will build a massive $3.5 billion facility in South Carolina that would produce 100 GWh of cathode and anode components annually. The DOE acknowledges that the U.S. needs to expand its battery recycling capabilities to meet growing demand for EVs, and to lower the cost of EVs. In February 2023, it committed $2 billion in a new, conditional loan to help Redwood Materials build out its battery recycling campus.

Batteries costs:

Thanks to the scaling up of electric vehicle production and to the construction of mega factories, battery costs have fallen dramatically in recent years. However, after more than 10 years of decreases, the volume-weighted average price for lithium-ion battery packs has risen to $151/kWh in 2022, a 7% increase from the previous year in real terms. Battery costs increase is notably linked to high lithium prices. Higher adoption of less expensive chemistries like LFP was overtaken by the rising cost pressure on batteries. BloombergNEF[81] anticipates that average battery pack prices will not decrease in 2023.

80 https://www.theverge.com/2022/12/14/23509031/redwood-materials-ev-battery-recycling-factory
81 https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/

Battery production:

In 2022, the world added 102 gigafactory projects to the ten-year pipeline, with a total capacity of 3.1 TWh. In 2022[82], $131 billion in battery production investment was pledged, a 24% increase over the previous year; 74% of these investments are in China.

By 2030, thanks to these investments, worldwide lithium-ion batteries manufacturing will grow by more than five times.

China has a leading position in batteries manufacturing, followed by Europe, the U.S., South Korea, and Japan.[83]

China produces three-quarters of all lithium-ion batteries and is home to 70% of production capacity for cathodes and 85% for anodes. Over half of lithium, cobalt, and graphite processing and refining capacity is in China. South Korea and Japan have considerable shares of the supply chain downstream of raw material processing, particularly in the highly technical production of cathode and anode material.

Due to the extent of its investment in new capacity, China is expected to remain the leading producer by the end of the decade. According to estimates, ***China should produce 69% of the world's lithium-ion batteries by 2030.***

There are already 125 battery gigafactories[84] operating in China, more than ten times the combined number in Europe and North America. China also has twice as many plants in planning or under construction.

Outside China, the race is on to build bigger and better battery facilities, especially in South Korea, another major manufacturer of EVs.

The U.S. is the region with the second largest number of gigafactories currently in operation, with many of these clustered around a newly emerging "battery belt" in the Midwest and South, close to the Tesla plants in Texas and California. Driven by its decision to ban the sale of combustion engines after 2035, Europe is catching up. 60% of all new cars sold in 2030 are expected to be battery electric vehicles, rising to a 100% share by 2035. This regulatory push, combined with climate-conscious policies, has led to significant investments in Europe's battery industry.

82 https://evmarketsreports.com/300-billion-in-new-lithium-ion-battery-gigafactories/
83 https://www.iea.org/reports/global-supply-chains-of-ev-batteries

82 The term 'gigafactory' was coined by Tesla to mean a battery factory capable of producing batteries on the gigawatt-hour scale of capacity

Currently around 50 Li-Ion batteries factories have been planned in Europe[85], although only a handful of these are currently operational. One of the best known of these is Swedish battery manufacturer Northvolt, which started operations in May 2022. The factory is expected to ramp up to a total capacity of 60 GWh per year.

Poland, Hungary, Germany, France, and Sweden are emerging as key players.

Except for lithium supply, Europe could achieve self-sufficiency in battery cells, meeting 100% of its Li-ion battery cell demand by 2027.[86]

While Europe's progress is promising, there are potential challenges. Notably, IRA U.S. subsidies and ITC Canadian subsidies[87], to attract investments in clean power and green infrastructures, are luring European battery manufacturers away from Europe. For example, Northvolt is concluding a $5.3 billion deal to build a new battery plant near Montreal.[88]

85 https://www.transportenvironment.org/wp-content/uploads/2023/03/2023_03_Battery_risk_How_not_to_lose_it_all_report.pdf
86 https://evmarketsreports.com/300-billion-in-new-lithium-ion-battery-gigafactories/
87 IRA for the US and Canada Infrastructure Bank Act
88 https://www.bloomberg.com/news/articles/2023-06-29/northvolt-is-near-deal-with-canada-on-5-3-billion-battery-plant?in_source=embedded-checkout-banner

Hydrogen:

1. ***Hydrogen production technologies:*** At present, nearly all hydrogen production worldwide is grey hydrogen that is produced from methane or coal through natural gas reformation or coal gasification. It emits high volumes of GHG. Blue hydrogen refers to hydrogen derived from fossil fuels but where reforming/gasification plants are coupled with carbon capture facilities. It is classified as low-emitting hydrogen. However, it is not an emission-free hydrogen production route. In fact, the lowest possible emission intensity of blue hydrogen, will be ~30% that of grey hydrogen produced with natural gas.

   Green hydrogen refers to hydrogen produced by water electrolysis with green electricity. This process does not emit GHG. By mid-2023, the EU finally recognized[89] that nuclear electricity produces green hydrogen. With this decision, Europe is aligned with all other regions in the world.

   Green hydrogen is considered a crucial solution to decarbonize 'hard-to-abate' sectors (which represent around 25% of the global economy).

2. ***Green hydrogen goals:*** As part of their net zero roadmaps, many countries and regions have set up *ambitious goals* for clean hydrogen production in the coming decades. For example, in September 2022, the U.S. DOE identified opportunities for 10 Mt/y of clean hydrogen production by 2030 and 50 Mt/y by 2050.

   In May 2022, the EU announced[90] its target of reaching 20 Mt/y of renewable hydrogen use by 2030; in March 2019, the Ministry of Economy, Trade, and Industry of Japan (METI) targeted a "one-fourth cost" for water electrolysis equipment – from $1,500/kW installed capacity to $380/kW by 2030.

   In 2022, more than 1,000 projects have been announced globally, of which 795 aim to be commissioned by 2030. Total announced investments through 2030 have increased by 35% in the first eight months of 2023 – from $240 billion to $320 billion.

   The global green hydrogen market is poised to grow at a CAGR of 55% from 2023 to 2032 (from $4 billion in 2022 to $332 billion by 2032).

3. ***2022 achievements:*** In 2022, global green hydrogen production capacity grew by 44% compared to 2021[91] to reach around 100 kT/year. It is still very small compared to the 120Mt of total hydrogen production.[92]

   » The largest green hydrogen projects in the world[93] are in Saudi Arabia, China, Australia, and Europe. In 2023, two large renewables-based hydrogen projects started operations in two Chinese provinces: Xinjiang (developed by Sinopec) and Inner Mongolia (developed by Three Gorges Corporation). Their combined annual hydrogen production capacity is 30 kT/year.[94]

   Both projects will utilize solar photovoltaic power to electrolyze water and produce green hydrogen. According to the nation's broad decarbonization plan, Inner Mongolia and Xinjiang will be developed into giant solar PV and wind power hubs. Sinopec's project, located in Xinjiang, is a pilot to construct an entire value chain for green hydrogen: renewable power generation, hydrogen production from water electrolysis, hydrogen storage, hydrogen transportation, and hydrogen utilization by refining

89 By mid-2023, the EU finally recognized that nuclear electricity produces low carbon hydrogen. By this decision Europe is aligned with most countries in the world.
90 REPowerEU plan

91 https://www.greencarcongress.com/2023/02/20230222-globaldatah2.html#:~:text=In%202022%2C%20green%20hydrogen%20production,data%20and%20analytics%20company%20GlobalData.
92 https://www.irena.org/EnergyTransition/Technology/Hydrogen#:~:text=Hydrogen%20is%20produced%20on%20a,of%20a%20mix%20of%20gases

93 Largest green hydrogen projects: NEOM Green Hydrogen Project in Saudi Arabia, Sinopec's Ordos Green Hydrogen Project in China, FFI ad TES green hydrogen project in Germany, Plug Power Green Hydrogen Plants in Finland, Western Green Energy Hub (WGEH) in Australia.
94 https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/063023-two-green-hydrogen-projects-totaling-30000-mtyear-of-capacity-start-up-in-china#

facilities. Sinopec's aim to produce more than 2 Mt/year from 2025 and is developing a giga-scale electrolysis plant in Inner Mongolia.

These announced large-scale renewable hydrogen projects deepen China's role as a renewable energy giant.

- *Infrastructure deployment* is progressing and is critical to ensuring that (low-cost) clean hydrogen supply matches demand. Committed investments in hydrogen infrastructure have grown from about $5 billion to about $7 billion, of which more than three-quarters are in Asia.
- *Electrolyzers manufacturing capacity:* Electrolyzers are a critical technology to produce low-emission hydrogen from water electrolysis.[95] According to OEM statements, electrolyzer[96] manufacturing capacity has reached nearly 9 GW/year in 2022. Future electrolyzer capacity is forecasted at 230 GW in 2030, which is very ambitious. However, a bigger significant acceleration is needed to get on track with the NZE 2050 IEA Scenario[97], which requires installed electrolysis capacity to reach more than 550 GW by 2030.[98]

  As in all green electricity equipment, China is reaching a dominant position in electrolyzers. Among the 307 MW capacity added in 2022, 224 MW were contributed by China and 83 MW were added by the rest of the world.[99]
- *For fuel cell manufacturing,* the total global capacity stated by OEMs stands at 12 GW in 2022, with Japan and South Korea as the largest supply markets.
- *Total investments* increased by 35% from May 2022 to January 2023 ($320 billion in direct investment between now and 2030, up from $240 billion). However only 9% of total investments have reached final investment decision (FID). These investment announcements are spread globally, with Europe leading on announcements, while North America leads with committed investments ($10 billion). Europe ($7 billion) and China ($10 billion) However, China is catching up with giant projects.

4. ***Green hydrogen cost:*** At present, grey hydrogen cost is in the range of $1-2/kg (the lower range being in the U.S. where gas is cheap). The cost of green hydrogen is in the range of $4-6/kg. To make green hydrogen competitive, its cost should decrease very significantly (to $2/kg).

   CRU projections[100] find that, even for green hydrogen production facilities in very favorable renewable energy locations, ~$2/kg is already a stretch goal for 2050. This cost level projection assumes halved renewable power costs[101] and a 75% reduction in electrolyzer system CapEx. In addition to this, costs associated with an electrical grid or renewables connection (~$0.7/kg additional cost) as well as hydrogen storage, compression, and distribution (~$0.8/kg additional cost) must be added. Taking these costs into account, the total green hydrogen cost to a typical end-user is expected to exceed $3/kg in 2050. Most countries exhibit green hydrogen costs above blue and grey hydrogen costs by 2050.

   If carbon prices (that penalize grey and blue hydrogen costs) are very high, green hydrogen could become competitive with grey and blue hydrogen by 2035.

   At present, China developers claim that with, very cheap solar and wind electricity in certain provinces (such as Xianjian and Inner Mongolia), combined with

95 https://www.iea.org/news/promising-signs-in-electrolyser-manufacturing-add-to-growing-momentum-for-low-emissions-hydrogen
96 https://hydrogencouncil.com/en/hydrogen-insights-global-project-funnel-gains-momentum-across-value-chain-and-geographies/
97 https://www.iea.org/reports/global-energy-and-climate-model/net-zero-emissions-by-2050-scenario-nze
98 https://www.iea.org/energy-system/low-emission-fuels/electrolysers#tracking
99 https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/063023-two-green-hydrogen-projects-totaling-30000-mtyear-of-capacity-start-up-in-china#
100 https://sustainability.crugroup.com/article/energy-from-green-hydrogen-will-be-expensive-even-in-2050
101 In 2022 and 2023 these costs have increased (see above)

collocation of renewables and hydrogen electrolyzers, hydrogen production cost is as low as $2/kg.

5. ***Innovations:***

   a. *Electrolyzers:* Australian researchers have developed a "capillary-fed electrolysis cell" producing green hydrogen from water at 98% cell energy efficiency compared to 75% (or less) for existing electrolyzer technologies. This technology could increase green hydrogen cost-competitiveness.[102]

   b. *Methane pyrolysis* is a process that uses heat to split methane into hydrogen and solid carbon. Unlike conventional methods of hydrogen production, methane pyrolysis produces hydrogen without any carbon emissions.

   Methane pyrolysis is a two-step process. In the first step, methane is heated to a high temperature (around 900°C) in the absence of oxygen. This causes the methane molecules to break down into hydrogen gas and solid carbon. In the second step, the solid carbon is collected and can be used for various applications.

   One of the main challenges of this new technology is the high temperature required for the process, which can lead to significant energy consumption.

   Additionally, the technology is still in the early stages of development and needs further research and development to scale up to commercial levels. However, it has the potential to become a mainstream solution for zero emissions hydrogen production.

   c. *White hydrogen,* also known as natural hydrogen, is hydrogen gas that is naturally generated within the earth's crust through water-rock reactions.[103]

   There is growing interest in white hydrogen given its abundance, renewability, and low carbon footprint.

   However, the scientific community is still working to understand the mechanisms behind its generation, accumulation, and migration. Achieving cost-effective methods for extraction and distribution on a large scale is also a critical challenge. Finally, just like any resource, the extraction of white hydrogen could have potential environmental impacts.

   There is a long way to go before white hydrogen can be used on a commercial scale.

102 https://www.uow.edu.au/media/2022/breakthrough-opens-door-to-low-cost-green-hydrogen.php

103 https://energyadvicehub.org/what-is-white-hydrogen/

d. *Innovative projects* overcoming the negative economic impact of green hydrogen's higher cost are underway in Europe:

» *GravitHy*[104] : The steel sector is responsible for 8% of global energy demand and 7% of CO_2 emissions from the energy sector and must become more sustainable. To support the transition to lower GHG emissions, an industrial group[105] gave birth to GravitHy. This company aims to reduce the GHG impact of metallurgy by producing and using green, low-carbon hydrogen to produce direct reduced iron (DRI). The DRI can either be used directly at the plant or exported.

The extra cost of green hydrogen is only around €1/ton which is negligeable compared to the cost of an EV Mercedes, for example. If the latter is powered by green electricity, it can be marketed as a "real green car"!

» *FertigHy*[106] : In June 2023 an industrial group[107] announced the creation of FertigHy, which plans to build and operate several large-scale, low-carbon fertilizer projects. The first plant will be built in Spain and produce more than one million metric tons per year of low-carbon nitrogen-based fertilizers from 100% renewable electricity and green hydrogen. Its construction is planned to start in 2025. The agriculture sector alone is responsible for 13% of the EU's total greenhouse gas emissions. By localizing fertilizer production in Europe, the FertigHy project is also answering to the recent challenges of the EU and global food security due to supply chain disruption[108] and global uncertainties in the natural gas supply.[109]

E-fuels:

Another way to use green hydrogen is its conversion into synthetic fuels, or e-fuels, by reaction with "green" CO_2.

E-fuels are not yet commercially available. So far there are only very few demonstration plants worldwide. Around 60 new e-fuel projects have been announced through 2035, of which only 1% have been secured with a FID.

The ramp-up of the e-fuel market is being hampered by high costs and a lack of visibility on the market demand. The pilot plant in Chile (Haru Oni which was inaugurated in December 2022) would deliver costs of around €50/liter of e-fuel, which is one hundred times more than the typical wholesale price of fossil gasoline (around €0.50/liter).

The industrial ramp up of e-fuel should lead to production cost decreases. However, this production increase depends heavily on the speed of the global demand increase.

With e-fuel quotas in air and shipping traffic, politicians have a lever to accelerate the e-fuel market ramp-up. One of the initial large-scale applications of e-fuels could be in the aviation sector, which, apart from biofuels, has limited options for mitigating its GHG emissions.[110]

104 https://gravithy.eu/
105 EIT InnoEnergy, Engie New Ventures, Plug, Forvia, Primetals Technologies and the Idec group
106 https://fertighy.com/
107 EIT InnoEnergy, RIC Energy, MAIRE, Siemens Financial Services, InVivo and Heineken

108 Around 40% of EU potash is imported from Russia and Belarus
109 Gas is used as both a raw material and an energy source to power the fertilizer's production process

110 The electrical plane is not yet a commercial option

For example, the EU reached a political agreement in April 2023 on the aviation sector emissions regulation, ReFuelEU.[111] The new rules will require fuel suppliers at EU airports to blend sustainable aviation fuels (SAF) with kerosene in increasing amounts from 2025. It mandates a minimum SAF supply at EU airports of 2% by 2025, 6% by 2030, 20% by 2035, and up to a maximum of 70% by 2050. Of these amounts, 1.2% in 2030, and 5% in 2035 must be e-fuels, increasing to 35% by 2050.

Triggered by this regulation, some projects were announced in France during the summer of 2023. EDF announced that it would mobilize €700 million together with Holcim and IFPEN to build a plant to produce e-kerosene for Air France KLM.[112] At the same time, Engie announced its participation in the France KerEAUzen project, a synthetic fuel production unit for air transport and green chemistry.[113]

According to a study published by the ICCT[114,115], that assumes low CO_2 costs, a combination of technologies that gives lowest green hydrogen cost and mid-level future cost reductions assumptions, e-kerosene is not projected to be cost-competitive with fossil kerosene before 2050.

111 https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2389
112 https://www.lesechos.fr/pme-regions/pays-de-la-loire/edf-veut-produire-du-e-kerosene-pour-air-france-klm-1957692
113 lesechos.fr/industrie-services/energie-environnement/biomethane-e-kerosene-engie-officialise-ses-projets-au-havre-en-presence-delisabeth-borne-1964888
114 ICCT International Council on Clean Transportation
115 https://theicct.org/publication/fuels-us-eu-cost-ekerosene-mar22/

The digital revolution:

It is closely linked to the energy and climate transitions. On one hand, the use of digital technology is an energy transition enabler.

On the other hand, the increased use of digital technology, big data, and artificial intelligence (AI) are major consumers of electricity.

1. ***The use of digital technology impacts all steps of the electricity value chain:***

- Digital twins make it possible to better design, operate, maintain, and dismantle power plants. This is why EDF implemented the Switch[116] program that tracks data over the entire nuclear power plant lifecycle.
- Blockchain guarantees transactions between operators (for example, in electricity trading).
- Smart meters improve interaction between customers and the electricity network. Thanks to dedicated applications, these meters, which give real-time consumption information, should promote energy control. They make it possible to set up dynamic tariffs needed for demand side management that contribute to network balancing.

116 https://www.capgemini.com/fr-fr/actualites/communiques-de-presse/edf-dassault-systemes-et-capgemini-signent-un-partenariat-pour-la-transformation-numerique-de-lingenierie-nucleaire-dedf/

- Smart grids: The smart meter and other sensors on smart networks capture a lot of data. Organizing and analyzing this data makes it possible to better anticipate network congestion and other grid balancing issues. This is increasingly important with the development of intermittent renewable electricity generation.
- The use of supercomputers increases the reliability of weather forecasts. This, in turn, improves the production forecast of renewable energies (such as wind and solar).
- In the building industry, the generalization of building information model (BIM) will allow new construction to be better designed and therefore more efficient in terms of energy consumption and GHG emissions. Better organized, better coordinated, and therefore more quickly completed projects will also consume less energy.
- In the transportation sector, the impact of digital tools, such as teleconferences, on energy consumption was demonstrated during the confinements linked to the Covid-19 pandemic. Communication and remote working tools have made it possible, in certain professions, to maintain activity while avoiding transport. Post Covid-19, these tools continue to reduce travel.

» *Electricity consumption linked to digital technology* can be broken into:

- Transit and storage of data: Progress made in these technologies led to a reduction by a factor of 7 in energy consumption per gigabyte transported.[117] But traffic has increased[118] faster than the drop in unit consumption, resulting in an increase in the share of digital consumption within the overall electricity consumption.
- Data centers, housing IT equipment such as data storage servers and redundant power supplies, generate significant heat as a byproduct of their operations, nearly equivalent to the energy they consume They require energy-consuming cooling. At the global level, this energy represented between 200 and 900 TWh[119] in 2019.
- Supercomputers, boasting computing power measured in exaflops, are essential for tasks like developing artificial intelligence models and demand substantial power resources. For instance, the Fugaku supercomputer has a power supply requirement of approximately 38 MW.
- Crypto assets[120] also require substantial energy consumption. This is due to blockchain technology and data mining for cryptocurrencies. In 2022, the global electricity consumption related to crypto assets was between 120 and 240 TWh, volumes which exceed the total annual consumption of countries such as Argentina or Australia.
- Everyday equipment: Nearly 30 billion pieces are connected to the network, including computers, televisions, tablets, smartphones, and other everyday equipment. Their combined consumption represented a total of more than 150 TWh in 2022. In addition to this daily life equipment, there is the Internet of Things (IoT) equipment. Its consumption in 2020 was estimated at more than 60 TWh. Forecasts show an increase in efficiency, which will make it possible to partially compensate for the increase in the number of devices. Indeed, the number of these control objects should increase from 7 billion in 2020 to more than 20 billion in 2030.

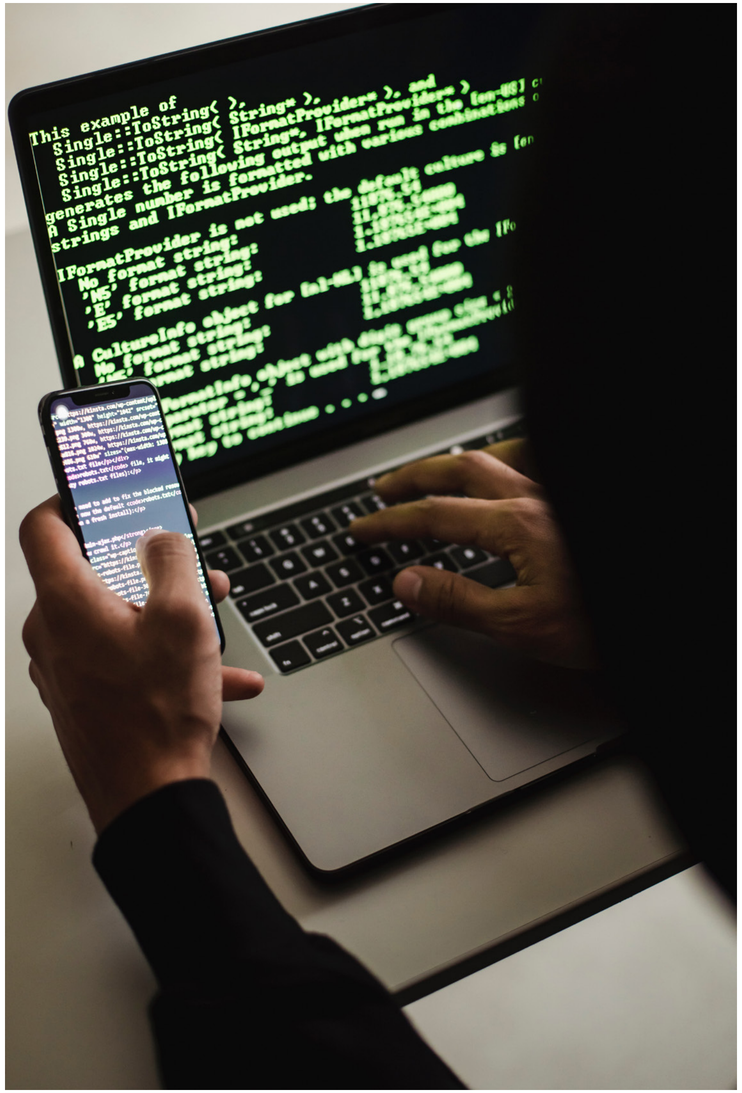
117 Between 2015 and 2020
118 The annual growth rate of network users was estimated by CISCO at +6%, representing a forecast of 5.3 billion users in 2023.
119 The methodologies for metering the energy consumption of these centers are not standardized, resulting in very different results.
120 Crypto assets are a digital representation of value that you can transfer, store, or trade electronically.

2. ***The solutions:***

- The first incentives to demonstrate *"sobriety"* have been introduced. This includes encouraging individuals to disconnect their equipment when not in use, as well as urging professionals to avoid generating unnecessary traffic.
- These include the management of all auxiliary consumption required for data processing, such as reducing energy consumption associated with server and switch cooling. A commonly used indicator in data centers is power usage effectiveness (PUE), which is the ratio between the total energy consumed and the energy consumed solely by the information processing equipment. It appears that Google's equipment average PUE of 1.10 is the current low asymptote. Significant energy savings can be obtained by optimizing data transfer protocols, as well as system architectures.
- Another important avenue of optimization is that of the physical architectures of microprocessors. The considerable increase in etching fineness, which has gone from 10 µm to 3 nm[121] in fifty years, and the subsequent miniaturization have had a drastic effect on reducing consumption.

All these actions make it possible to significantly reduce unit consumption. This is imperative to compensate for the expected strong growth in traffic.

To conclude, it is necessary to emphasize that the increased use of digital technology entails significant risks, such as those associated with cyberattacks and the misappropriation of data, for commercial or even criminal purposes.



121 A µm is equal to 0.001 mm, a nanometer(nm) is equal to 0.001 µm.

R&D funding:

In 2022, investment in energy innovation rose . Public spending on energy R&D grew by 10% in 2022 (estimated at $44 billion), with 80% devoted to clean energy. For listed companies in energy-related sectors, data shows a similar rise in R&D budgets in 2022, while early-stage venture capital investment into clean energy start-ups reached a new high of $6.7 billion.

However, due to higher cost of capital, the situation has reversed in Q1 2023 with very weak growth-stage funding.[123]

In addition, private equity funds started, by mid-2022, to withdraw from start-up funding and many innovative small companies have financial difficulties. This is worrying when considering the needed clean technologies progress that often originate from start-ups.

Electric grids:

As mentioned above, a successful energy transition requires a major expansion of electricity grids. According to the REPowerEU strategy, the goal is to double the proportion of energy demand covered by electricity, increasing it from the current 25% to over 50% by 2050. Hence, an additional supply of about 4,000 TWh would be necessary, the equivalent of Europe's current total electricity consumption in 2019.

Part of the electrification increase is driven by heat waves; a further uptake from 110 million cooling units in 2019 to 275 million units in 2050 is expected. These devices, as well as additional distributed renewable energy sources put the distribution grids at the center of the current transition.

Distribution system operators are continuously enhancing the resilience of their grids through various approaches. These include expanding the deployment of sensors to gather more data, implementing smart meters, improving forecasting techniques, adopting demand-side management strategies like increased energy efficiency, implementing intelligent EV charging solutions, and enhancing storage capacity.

On the transportation grid, it is necessary to develop new flexibility levers, such as rapid frequency adjustment, improved forecasting systems, intraday markets, and virtual power plants. Moreover, TSO/DSO coordination on data exchanges must be improved.

As described above, implementation of digital technologies is key to making grids smarter and increasing their resilience. Overall, it is estimated that European distribution system operators require about €400 billion[124] of additional investments by 2030 to maintain and modernize electricity grids and to connect distributed clean generation.

Critical industrial equipment for energy transition must be available. This includes electrical cable with proper copper procurement, inverters for solar farms, edge loggers at the factory floor, which provide operations and maintenance related data, and silicon carbide power transistors to control both the charging of electric batteries on the grid and their injection of electricity when the vehicle is not used.

One can mention new catalysts to improve the energy efficiency of industrial installations. Also, membranes have the potential to become a key element of the energy transition.
They can be used as electrolytes in membrane-based fuel cells and electrolyzers to produce hydrogen, as separators in lithium batteries, in thermoelectric and electrokinetic energy conversion etc. Some membrane technologies are already being applied in industries at a large scale, while others remain in the early stages of development.

123 Growth-stage funding requires more capital than early stage but funds less risky innovation.

124 Growth-stage funding requires more capital than early stage but funds less risky innovation.

Increased financing, proper regulations, and good citizen behaviors are critical for achieving climate goals:

In previous WEMO Outlooks we performed a thorough analysis of climate regulations and citizen behaviors. This year, we shall concentrate on financing issues.

As stated above, progress in clean technologies is promising. However, a huge acceleration of their deployment is needed. This was acknowledged by the G20 Heads of State (responsible for around 80% of GHG emissions) at their September 2023 meeting. They pledged to triple global renewable energy capacity by 2030.[125]

According to Irena[126], investment in renewable energy in 2022 was at a historic high, amounting to $500 billion. However, these investments represented less than one-third of the investments needed each year to stay on the 1.5°C pathway.

How to focus public investments[127]

In the 2000's, **the marginal abatement cost emerged** as a measurement and decision-making tool. It is simply the cost of an intervention that will reduce greenhouse gas emissions by one ton.[128]

It was adapted to climate policies concentrated on marginal changes.

However, since the Paris Agreement, the aim is to reduce emissions to almost zero in 2050. Thus, one cannot ignore hard-to-abate emissions. The challenges are no longer to identify low-cost opportunities, but to avoid all emissions at the lowest cost possible.

The problem is complex given:

» That each measure cannot be considered individually since they interact with one another. For example, emissions reductions from an electrical vehicle depend on the carbon content of the electricity used.

125 https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/090923-g20-leaders-pledge-to-support-tripling-of-global-renewables
126 https://www.irena.org/Publications/2023/Feb/Global-landscape-of-renewable-energy-finance-2023

127 https://www.i4ce.org/en/proper-use-abatment-cost-streer-transition-climate/
128 As seen before, the carbon emissions on the life cycle that have to be considered.

- That there is the question of the velocity of the energy transition. It is not possible, for example, to wait until all electricity is decarbonized to start deploying electrical vehicles. The industry and users need time to adapt to these changes. So, there is a need to start earlier even if the marginal cost of abatement is high.
- The variability in technologies' availability and associated costs. However, technologies costs depend also on demand. High demand pushes for innovative efforts and deep tech research. Also, larger production volumes push prices down. This was the case of solar, wind, and battery technologies whose costs decreased year-over-year during the last ten years. If there were no political decisions to subsidize and deploy them, they would have kept a high abatement cost.

These public investment policies aimed at accelerating technology maturity could be reproduced in critical industries where scale effect leads to cost decrease. For example, electrolyzers are well suited to this approach.

A more comprehensive, albeit intricate, approach involves shifting the focus towards long-term strategies. These strategies consider sector interactions and technological advancements with the aim of minimizing the overall cost of the transition, rather than solely concentrating on marginal costs. These examples demonstrate that public financing modeling of zero carbon is very complex, hence the lack of economic coherence between climate change-related policies.

Also, side effects can be damaging : for example, French regulation on building isolations (that forbid renting apartments that don't comply with isolation rules), could result in scarcity of housing to rent. Owners of apartments that would need to invest significant amounts to continue to rent them could opt not to do so. Housing is already a critical issue for residents of France.

Private financing

Companies across all sectors of the global financial system have pledged their support to climate goals. It is the case for the Glasgow Financial Alliance for Net Zero[129], a global coalition of leading financial institutions committed to accelerating the decarbonization of the economy. It has more than 550 members, including many of the world's largest banks, insurers, asset managers, and asset owners. They have all committed to support the transition to a net zero global economy.

129 https://www.gfanzero.com/

Also, to respond to growing demand for investments that are focused on climate solutions, asset managers are launching more funds. The number of climate-oriented funds has grown at a 7% annual rate since 2016, with 113 such funds starting in 2022. The amount of capital raised for such funds reached $75 billion in 2022, a 29% increase from the previous year.

However, private capital flows to green projects are still far too small. A recent study by the Rockefeller Foundation and BCG found that the needs are exceeding current flows by 66%.[130]

130 https://www.bcg.com/publications/2023/asset-owners-can-supply-push-in-climate-finance

Enterprises

They are committing to limit their carbon footprint. For example, the Science-Based Targets initiative (SBTi) that was created in 2015, at the same time as the Paris Agreement's signature, has become an international reference. It provides tools to help set decarbonization objectives for companies. These objectives are "aligned with science" and compatible with limiting global warming in 2030 to +1.5°C.[131]

By the end of 2022, the cumulative number of companies with science-based targets validated by the SBTi represented 34% of the global economy by market capitalization. SBTi has taken note of the difficulties of decarbonizing the company value chain, and therefore tolerates that part of the emissions (related to scope 3) is not subject to reduction objectives.[132]

More and more companies include climate change related KPIs in the variable and long-term remunerations of their managers. Beside public policies, enterprise commitments are an efficient way to increase climate change achievements.

Finally, to be efficient and fair, all investments or regulations should be examined according to three criteria:

sustainability,
security of supply,
and affordability.

131 Compared to the pre-industrial era
132 https://www.climatepartner.com/en/scope-1-2-3-complete-guide

Adaptation measures:

As analyzed previously, present climate mitigation actions and policies are not sufficient to be on the right trajectory to meet the Paris Agreement objectives. ***Climate adaptation*[133] *action need to be implemented urgently.***

A comprehensive risk assessment must be conducted, and equipment and infrastructure need to be adapted to address the consequences of climate change This must be done at all stages of the lifecycle (design, construction, operations, and maintenance) as well as across the electricity value chain (electricity generation, transmission, and distribution).[134,135]

As will be detailed below, these risks are related to exceptional events triggered by climate change.

Thermal power plants must be adapted to exceptional hot weather.

For thermal power generation (including nuclear power), the temperature increase of cooling water decreases their efficiency. In addition, in the case of an exceptionally hot climate, the plants that collect their cooling water from rivers, must lower their generation output to preserve natural live-in rivers.

This question has been tackled at the design level with closed water circuits and air coolers reducing the amounts of water used. Now that sea corrosion consequences are mastered, nuclear plants, for example, can be built along the seashore.

The experience of the exceptionally hot summer in France in 2003 led to a vast program of modifications to better cope with extreme heat waves. The cooling units of power plants were resized, and operating practices were reviewed.

Moreover, temperature rise is expected to increase electricity demand for cooling in many countries, which will become a driving factor for generation capacity additions.

Finally, lessons learned from incidents or accidents must lead to modifications. In France, all nuclear plants have been retrofitted to take into account the lesson learned from the 2011 Fukushima accident (emergency diesels, onsite water reserves). The EPR design has also been revised.

Renewables' main resource is directly linked to climate variables such as precipitation, temperature, irradiation, or wind.

1. ***Hydropower,*** **like other infrastructures, is starting to experience negative impacts due to climate risks:**

» Water availability and hydropower generation are affected by changes in hydrological patterns and extreme weather events.

» Change in rainfall patterns[136] can impact river flows and water levels, thus affecting production. The main risks are related to flooding and intense rain, which can pose a significant risk to dam safety.

» Higher air temperature would increase evaporation, reducing water storage and power dam output.

» Changes in the ice melting patterns can alter the seasonal inflow of water to dams that rely on snowfall or glaciers. A study published in the journal Water[137] about flood and drought risk to hydropower dams found that by 2050, 61% of all hydropower dams would be in river basins at "very high or extreme risk for droughts, floods or both". According to studies, the global impact of climate change on hydropower generation is not significant (0.9-2.4%) but can be important locally.

To manage the changing climate, asset owners are using more advanced weather and water forecasting technologies to help increase project resilience.

» *Design:* To mitigate the consequences of flooding, installations are fitted with flood discharge systems to cope with extreme flow rates. If needed, these flood discharge systems are increased. For example, EDF has invested in new discharge systems on 60 dams in

133 Climate adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage caused.
134 https://www.iea.org/reports/power-systems-in-transition/climate-resilience
135 https://www.eurelectric.org/in-detail/climate-adaptation/

136 https://www.sciencedirect.com/science/article/pii/S1364032119306239
137 https://www.iea.org/reports/power-systems-in-transition/climate-resilience

recent years. In the U.S., the Biden administration's infrastructure bill earmarked $500 million over five years to fund dam safety projects.

- *Operations:* Asset operators, such as EDF, carry out daily weather monitoring in 1,100 measurement stations to anticipate any out-of-the-ordinary weather events. In addition, exceptional rains can have an impact on the dam's safety. If a dam breaks, the impact on populations is huge (see above example regarding the Kakhovka dam break following the Russian bombing).

2. ***Wind power is also impacted by exceptional weather events.***

- Changes in wind speed can reduce generation (as turbines cannot operate in very high or very low winds). Also wind turbine output is greatly affected by wind speed, as the energy provided by the wind is the cube of wind speed.
- Ice on turbine blades can affect performance and durability.
- Rising sea level could damage offshore turbine foundations in low-lying coastal areas, as well as onshore turbines in coastal locations.
- Some turbines, especially the bigger and taller ones, will have to be redesigned and safety margins should be increased.

Globally, changes in wind energy output can range from ±12% depending on the region.

3. ***Solar energy:***

Climate change impacts on solar generation has received less attention than that of wind or hydropower. Solar PV installations are usually smaller with lower capital costs and a shorter lifetime (around 20 years) than hydro or wind. This reduces the importance of climate impacts.

The available projections are uncertain: depending on the model and assumptions, differences in results can be substantial. One study[138] suggests a global reduction in direct normal irradiation of 5%. The biggest output increases are expected in Europe (up to 10%), while the greatest reductions are expected in Africa (up to 10%).

Other climate change-related events, such as fires or sandstorms, have an impact on solar generation. The smoke produced by the huge fires in Canada in May 2023 reduced solar generation by 30% in impacted regions.

138 Huber I, Bugliaro L, Ponater M, Garny H, Emde C, Mayer B. Do climate models project changes in solar resources? Sol Energy 2016;129:65–84. https://doi.org/ 10.1016/j.solener.2015.12.016.

Transmission and distribution networks:

Electricity network damages have a large impact on electricity supply, and hence customer satisfaction.

- Climate change impacts on transmission and distribution networks are important and result in higher electricity losses, a decrease in transfer capacity, and physical damages.
- Intense and concentrated rainfall leads to high water levels and even floods. If coupled with storms and winds, restoration is even harder.
- Heatwaves cause loss of load due to reduced grid capacity and overheating of transformers.
- Wet snow can cause icing and snow sleeves.

The key dimensions of an electricity network's climate resilience are robustness and speed of recovery.

1. ***Enhancing robustness involves both physical investments and the utilization of digital tools***

    - Investments: TSOs are investing each year to adapt and reinforce the network. For example, pylons are built with specific materials in wind-exposed regions and their foundations are reinforced in stressed climate areas.[139]

      Vegetation management is important to avoid the risk of contact between trees and overhead conductors. In California, where wildfires are a major threat, good forest maintenance is crucial.

      Underground transmission and distribution cables, which require a higher upfront investment and higher maintenance costs than overhead lines, can significantly reduce damage from climate impact and save recovery costs.

    - Digital tools: TSOs and DSOs are improving their forecasting tools and meteorological alerts to predict extreme climatic events. They have digitized their inspection regime using aerial Light Detection and Ranging (LiDAR)[140] and drone footage image processing technology.

2. ***Recovery: The speed of reconnection is very important for customers.***

    Physical damage to energy networks can result in interruptions in service to customers.

    TSOs and DSOs have human forces and specific tools (such as temporary generation) to deal with the potential damage that threatens the network. As soon as a storm is forecasted, network operators deploy special teams ready-to-go on-the-ground.

    The deployment of smart meters allows for the localization of customers experiencing power outages and enables a quicker response.

    Technological innovations that allow for remote reconfiguration of networks can help reduce the number of customers affected by faults.

Studies suggest that the benefits of resilient electricity systems outweigh the costs in most scenarios, especially when considering the increasing impacts of climate change. According to the World Bank, if the actions needed for resilience are delayed by ten years, the cost will almost double.[141]

139 https://www.sia-partners.com/en/insights/publications/grid-resilience-climate-change

140 Lidar : which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges. It is well suited for topographic surveys of vegetation or hard access zones

141 https://www.iea.org/reports/power-systems-in-transition/climate-resilience

Conclusion and recommendations

To achieve the decarbonization objectives of our economy, **world electricity consumption will have to quadruple** from ~28,000 TWh in 2022, to as much as ~110,000 TWh by 2050, with over 75% of this supplied by wind and solar.

Security of supply concerns, prompted by Russia's unwarranted invasion of Ukraine in February 2022, have boosted renewable electricity production. This renewable energy not only offers a clean source of power but, under specific circumstances, also contributes to domestic electricity generation. **2022 was a record year for renewable electricity capacity additions**, with annual capacity additions amounting to about 340 GW. In 2022, investment in clean energy technologies has significantly outpaced spending on fossil fuels.

However, **this growth is far below what is needed to achieve net zero carbon in 2050** as global renewable capacity should grow by 2400 GW over the 2022-2027 period (i.e., an annual average growth of 480 GW). This amount is equal to the entire power capacity of China today.

Nuclear electricity output, which has finally been recognized under certain conditions by the EU as green energy, **will have to increase.** To achieve net zero by 2050, projections show that total nuclear energy capacity will need to triple by 2050.[142]

142 https://www.oecd-nea.org/jcms/pl_83775/government-industry-conference-to-chart-the-nuclear-energy-path-to-net-zero#:~:text=To%20achieve%20net%20zero%20by,priority%20in%20several%20NEA%20countries.

It will be necessary to extend the life of existing reactors and build new reactors. In the western world, construction times for large reactors are very long (around 15 years) and budgets are often more than tripled compared to initial forecasts. SMRs raise hope, but their promises have yet to be confirmed.

The expansion of electrical grids is linked to growing electrification and the need to connect more decentralized means of production (solar and wind farms, SMRs, etc.). They should grow from the current 75 million kilometers of transmission and distribution to over 200 million kilometers by 2050. Their construction (especially overhead lines) arouses local opposition, which extends delays and costs. The instantaneous balance between an increasingly intermittent supply and a demand which may experience peaks linked to extreme climatic events must be ensured. Networks are becoming smarter with more stationary storage, sensors, and intelligent exploitation of large masses of data. **Without these adaptations, networks will become the Achilles heel of the energy transition.**

The digital revolution is a facilitator of the energy transition but also a source of electricity demand growth. In 2022, the total electricity consumption related to crypto assets[143] is estimated between 120 and 240 TWh/year, volumes which exceeds the annual consumption of countries such as Argentina or Australia.

All this equipment must be sustainable, which requires the analysis of their carbon footprint over their lifecycle. Batteries must be recycled. Recycling facilities are already being built in China and Europe. The recycling industry will be boosted by legislation. For example, in Europe by 2030, all batteries will have to use a minimum of 12% cobalt, 85% lead, 4% lithium, and 4% nickel coming from recycled sources.

The 2021-2022 crisis was a wake-up call in Europe regarding the security of energy supply. Legislation, such as the IRA in the U.S. and RepowerEU in Europe, aims to help these regions reclaim their **sovereignty** over equipment, metals, rare earths, and industrial installations related to the security of electricity supply. These legislations also aim at reshoring, in their territories, critical equipment production.

After years of impressive cost decreases, **wind and solar LCOE[144] started to increase** in 2021. In 2022, this trend has continued. These cost increases were not offset by cost reductions from technological innovation and, according to IEA, the resulting LCOE increase for 2022 is estimated at 15-20% for these technologies.

Wind equipment manufacturers need to recuperate the higher cost of manufacturing products and amortize their R&D costs. However, they cannot as they are pushed by their clients (that are bidding for new projects at continuously lower electricity prices) to decrease costs even more. Some manufacturers are in a difficult financial position and utilities are opening their suppliers list to Chinese manufacturers.

Europe's solar power industry is in a precarious situation as solar PV prices reached record lows due to China manufacturing excess capacity and fierce competition. As for offshore wind, European companies' bankruptcies, would hurt the EU's goal of reshoring policy.

The emergence of a **hydrogen economy** is happening even if there are still challenges over low-carbon electricity availability and green hydrogen cost decrease. What usage should be prioritized (hard-to-abate sectors versus mobility) is still unclear. More than 1,000 projects have been announced globally, of which 795 aim to be commissioned by 2030. Total announced investments through 2030 have increased by 35% in the past 8 months – from $240 billion to $320 billion.[145]

China has a dominant position in clean technologies (including nuclear) both by its domestic investments and by its position in the international market. The country spent $546 billion in 2022 on investments that included solar and wind energy, electric vehicles, and batteries. That is nearly four times the amount of U.S. investments, which totaled $141 billion. The European Union was second to China with $180 billion in clean energy investments.

143 Crypto assets can be defined as a digital representation of value or rights which may be transferred and stored electronically, using distributed ledger technology or similar technology.

144 LCOE: Levelized Cost of Electricity

145 https://hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf

It is also becoming a leader in the production of green hydrogen, thanks to the installation of significant electrolyzer capacities in provinces such as Inner Mongolia, which have a very low cost of producing renewable electricity.

It plans to develop CCUS, which is crucial because China is commissioning two large coal-fired power plants per week.

Despite this progress, the world is not on the right climate trajectory. The main obstacle is linked to the **difficulty of adapting our economy quickly.** Citizens are slow to change their lifestyles, local oppositions are slowing down the installation of carbon-free electricity production capacities, and new industries lack skills while there is unemployment of workers in industries that are disappearing. Finally, the cost of these actions for citizens is significant as they must spend more money to comply with legislations. In Europe, people will have to buy an EV after the internal combustion cars ban (in 2035) or to insulate their houses to be able to rent or sell it.

Financing is also lacking. Even if investments in renewable energy in 2022 reached an unprecedented high – at$ 500 billion– it represented less than one-third of the average investment needed each year to stay on the 1.5°C pathway. Climate tech funding dropped in 2023, but is resilient compared to other sectors, especially in EVs and batteries technologies.[146] It is critical for Europe to unlock funding to scale up the deployment of innovation to avoid losing this new industrial revolution battle and being squeezed between the U.S. and China.

Each investment decision should be taken regarding its impact on sustainability and energy sovereignty as well as affordability for citizens.

Adaptation measures are necessary for all electricity production, transport, and distribution equipment. The return time on these investments is indeterminate. Beyond compliance with regulations (for example the ban on building in seismic or flood zones) the control authorities should require the implementation of these adaptation measures. This is what the French Nuclear Safety Control Authority did by requiring new investments in nuclear reactors to take into account the feedback from the Fukushima accident. The multitude of actors (governments, local authorities, energy producers, infrastructure operators, network concessionaires, etc.) makes the implementation of these adaptation measures complex.

146 https://www.cleantechforeurope.com/publications/cleantech-q2-briefing-2023 and CTVC https://www.ctvc.co/climate-tech-h1-2023-venture-funding/).

The year 2023 was full of uncertainties:

Firstly, the evolution of the conflict in Ukraine, where all options are open, creates a high level of uncertainty. Moreover the savage agreesion of Hamas terrorists in Israel could generate instabilty in the Middle-East which is a large oil and gas producing region

Secondly, inflation remained high, despite lower energy prices and supply chain improvements. To curb this inflation, central banks have increased interest rates, triggering increased food prices and precariousness that could be a source of social conflicts. While the economic slowdown could have negative consequences on employment, it has the positive consequence of slowing energy consumption and therefore keeping prices at reasonable levels.

The winter 2023-2024 presents itself in Europe under better circumstances than the previous winter. However, mild temperatures and sustained energy savings remain key to having a non-eventful winter.

“Finally, I wish to recall that in the combat against climate change, each of us has a role to play as a consumer, citizen, political authority, or business employee.

However, despite all the human efforts, nature is still present, and events such as big volcanic eruptions or huge fires contribute to increasing GHG emissions.”

Colette Lewiner
Paris, October 24, 2023

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