We are *not on track* to meet the Paris Agreement's objectives. What should we do?

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Global Outlook

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This 2024 World Energy Markets Observatory outlook will be structured in three main paragraphs:

In the first paragraph, we will look at ***the energy markets developments in the last 12 months*** in the present very tense geopolitical situation: the energy prices "normalisation", the progresses in carbon free technologies implementation (nuclear electricity, intermittent renewables and their negative impact on grid balancing, storable renewables), the status of electricity consumption management, the storage solutions deployment and the green hydrogen reality.

In the second paragraph, we will ask ourselves ***what should be done to limit the rise in global temperatures:*** including technology deployment at scale, well fitted regulations adoption, company and citizens contributions, financing schemes improvements and disruptive technologies (including Generative Artificial Intelligence) impacts.

The last paragraph will be devoted to ***the energy sovereignty concern***s in the current context including relationship between Western economies and countries like China and Russia and the Western policies to produce domestically critical equipment.

We will end with a general conclusion.

I wish you a good reading.

Energy markets developments in the last 12 months

The year 2023 as well as the first half of 2024 were characterized by strong **geopolitical tensions:**

The continuation of the war in Ukraine, after Russia's unjustified invasion, combined with Russia's threat to use "special weapons" and the existence of nuclear reactors in combat zones is a matter of great concern.
An additional concern is linked to Israel's war against Hamas after the October 7,2023 massacre perpetrated by Hamas against the civilian Israeli population. There is a serious risk that it spreads beyond Israel, with Iran entering in the war. This could inflame the entire region that is rich in oil and gas. In addition, Houthi missiles against cargos in the Red Sea make this area unstable and forces tankers to go through the Cape of Good Hope, increasing logistics costs (as the tankers' journey is around 30 days compared to 22 days via the Suez Canal).
In Asia, tensions around Taiwan (which is home to around 70% of the world's foundries for electronic chip manufacturing[1]), with Chinese threats of taking over this territory by force are also a matter of concern.

In 2024, the result of the American election could have a significant geopolitical impact and slow down American policy in the fight against climate change.

1 https://www.statista.com/statistics/867223/worldwide-semiconductor-foundries-by-market-share/

European election results on June 9, 2024, showed centrist parties keeping their majority, but right-wing and far-right parties sceptical of the EU's "Green Deal" package gained seats and green parties experienced heavy losses.

The EU packages aimed at developing clean energy and cutting GHG[2] emissions should be hard to undo. But a more climate-sceptical EU Parliament could attempt to weaken those laws, since many are due to be reviewed in the next few years – including the EU 2035 phase-out of the sale of new combustion engine cars, which faces criticism.
The European Parliament will also have to negotiate a new, legally binding target to cut emissions by 2040 with EU countries.
The Labour Party, which came to power in the UK after the July 2024 elections, is committed to double onshore wind, triple solar power, and quadruple offshore wind by 2030. They pledge to invest in carbon capture and storage, hydrogen and marine energy. They aim at extending the lifetime of existing nuclear plants and completing Hinkley Point C. They recognize that new nuclear power will play an important role in helping the UK achieve energy security and clean power.
On the fossil fuels side, the freshly elected government ordered the immediate ban on new North Sea oil and gas licenses.

After the French elections in July 2024, there will be no majority in parliament and there is a risk of a standstill on legislation concerning France's energy transformation.

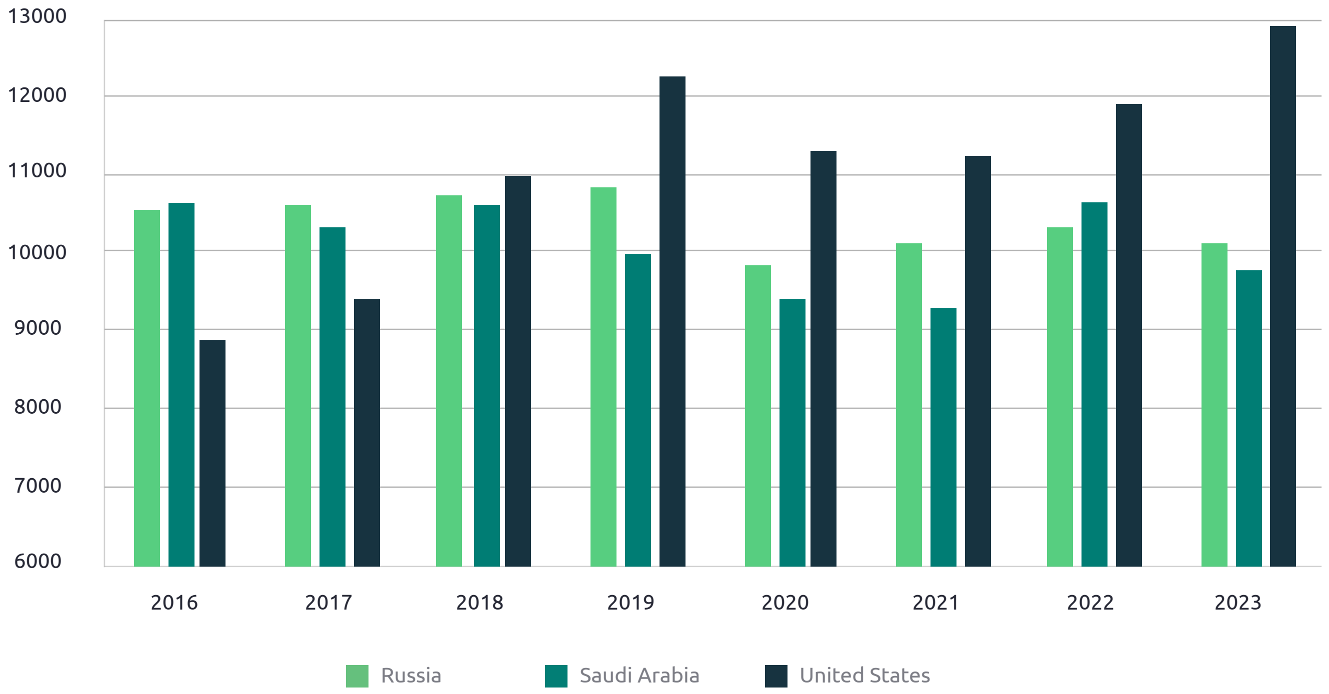
2 GHG: Green House Gases

Despite these tensions, **energy prices** have remained moderate. Between August 2023 and August 2024, Brent oil has traded between $74/bl and $93/bl, below what many OPEC+ members need to balance their budgets. This is reflecting the increase in USA shale oil production in a gloomy economic context and high interest rates. In June 2024, OPEC+[3][4] decided to extend most of its oil output cuts well into 2025 (cuts of 5.86 million barrels per day, or about 5.7% of global demand) without impact on oil price.

3 OPEC+ includes the members of OPEC (Organization of the Petroleum Exporting Countries) and allies led by Russia
4 https://www.reuters.com/business/energy/opec-seen-prolonging-cuts-2024-into-2025-two-sources-say-2024-06-02/#:~:text=OPEC%2B%20members%20are%20currently%20cutting,the%20end%20of%20June%202024.

FIGURE 1

The United States produced more Crude in 2023 than any country, ever



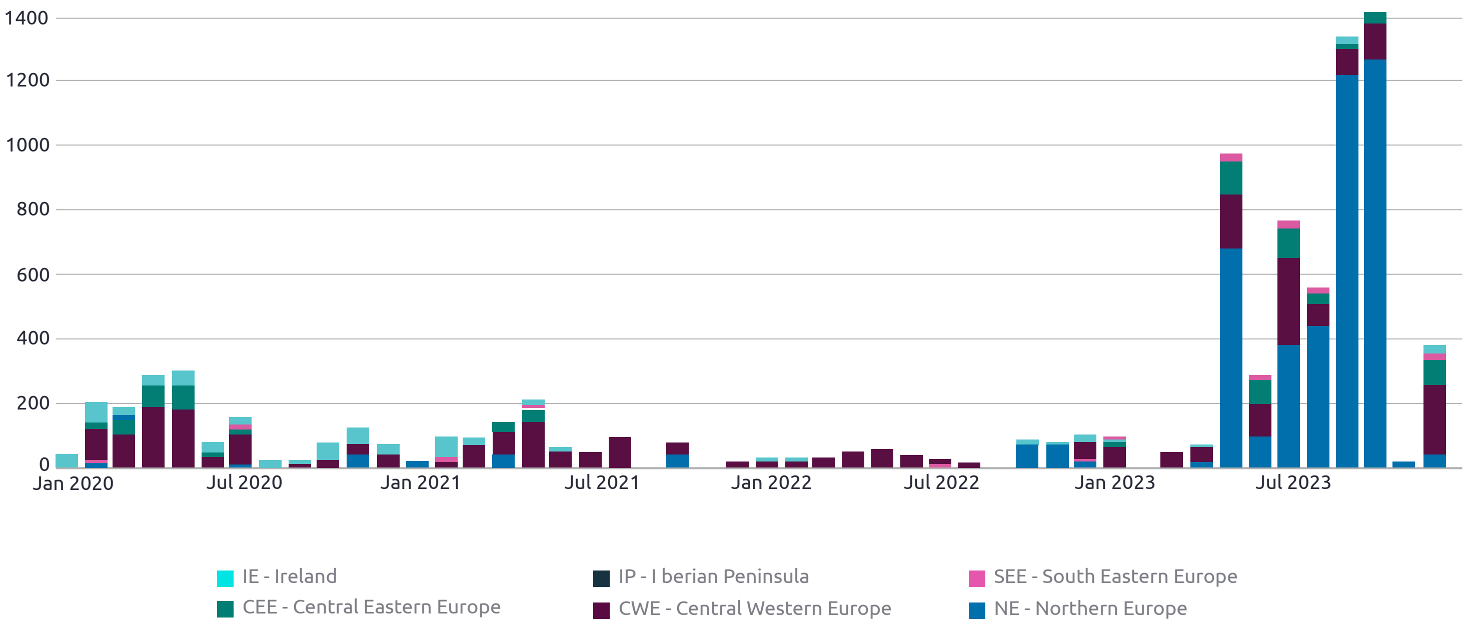
Source: U.S. Energy Information Administration, International Energy Statistics, Data as of Decemeber 31, 2023

The *electricity* market in Europe has turned upside down once again. In 2023, EU electricity spot prices returned to pre-crisis levels and the number of negative hours reached a record of 6870 in European markets, compared to 569 in 2022[5]. (see figure).

5 https://energy.ec.europa.eu/document/download/d48ec6b0-987f-4702-af0a-76bfb4fbce0c_en?filename=New%20Quarterly%20Report%20on%20European%20Electricity%20markets%20Q4%202023.pdf

FIGURE 2

Number of negative hourly wholesale prices in Europe



Source: ENTSO-E

This contrasts sharply with the energy crisis at the end of 2021 and 2022 when prices reached historic highs.
Electricity prices for energy-intensive industries in the European Union in 2023 were almost double those in the USA and China. Despite an estimated 50% price decline in the European Union in 2023 versus 2022, Energy Intensive Industries[6] in Europe continued to face far higher electricity costs compared with their American competitors. The price gap between energy-intensive industries in the European Union and those in the USA and China, which already existed before the 2021-2022 energy crisis, has widened. As a result, the competitiveness of EU Energy Intensive Industries is expected to remain under pressure.[7]

After a huge increase in 2021-2022, European *gas* prices returned to their pre-crisis level in 2023.
Thanks to the USA shale gas production, gas in this country is around five times cheaper than in Europe giving (as for electricity usage) a strong competitive advantage to USA firms.

After the unjustified invasion of Ukraine by Russia, the EU and other G7 countries-imposed sanctions on Russian oil and coal. Meanwhile Russia cut nearly all the piped gas that it exported to the EU.[8]
It seems that EU and G7 sanctions including embargo on Russian coal, oil and oil products have had a significant impact on the Russian oil and gas industries and on the related budgetary revenues that come from them.[9 10]

6 Energy Intensive Industries are: food, pulp and paper, basic chemicals, refining, iron and steel, nonferrous metals (primarily aluminium), and non-metallic minerals (primarily cement).
7 For example energy costs account between 20% and 40% of the total cost of steel production.

8 World Energy Market Observatory 2023 edition https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/
9 https://www.atlanticcouncil.org/content-series/russia-tomorrow/oil-gas-and-war/
10 https://energyandcleanair.org/russia-sanction-tracker/

In December 2022, the Price Cap Coalition countries[11] established an oil price cap mechanism on Russian seaborne crude oil and petroleum products. These countries operators are only allowed to provide maritime transport for Russian crude oil and petroleum products if these are sold at or below the relevant price caps.

The sanctions initially forced Russia to increase the discount on the price of its oil sold to attract new buyers and replace sales that previously went to Price Cap Coalition countries. The resultant losses were significant, with Russian oil export revenues falling by 14% (€ 34 bn) in the 12 months after the sanctions were implemented. The losses peaked at €180 million/ day in the first quarter of 2023, before shrinking to € 50-90 million/ day in the second and third quarters of the year.

On the gas side, the share of Russian pipeline gas member states imported fell from 40% of the total in 2021 to about 8% in 2023. In contrast, EU's LNG[12] imports from Russia have increased, by 37.7% between 2021 and 2023.[13] So when LNG is included the total share of Russian gas in the EU's total was 15% in 2023.

In June 2024, the Council adopted a 14th package of economic and individual restrictive measures against Putin's regime This package includes Russian LNG imports.[14]

Another way to cut Russia's export revenues further will be to drive down the oil price cap that is presently at $60/bl.

Also, the G7 countries should conduct a comprehensive critical oil-and-gas technology review. and impose embargos on them.

2023 energy landscape at a glance

Global energy related GHG[15] emissions hit record high in 2023, despite rapid deployment of renewable energy.[16]

Primary energy consumption reached a record level of 620 exajoules (EJ) in 2023, compared to 537 EJ ten years earlier (a 15% increase). It grew by roughly 2% between 2023 and 2022.[17]

The world's demand for electricity grew by 2.2% between 2023 and 2022, roughly at the same pace as the global primary energy consumption while according to forecasts it should grow much quicker. While China, India and numerous countries in Southeast Asia experienced robust growth in electricity demand, Western economies posted substantial declines due to a weak macroeconomic environment which reduced industrial output. More than half of the electricity demand rise in 2023 was from five technologies: electric vehicles (EVs), heat pumps, electrolysers, air conditioning and data centres. The development of these technologies should fuel the future growth in electricity consumption.

In Europe: electricity demand in 2023 was lower than in 2005 as it reached its lowest level in 20 years!

This drop in consumption is linked, on the one hand, to the ongoing individual behaviours to control electricity consumption that began in 2022 under the pressure of very high prices and fears about the security of electricity supply (see WEMO edition 2023[18]). On the other hand, the European economy in general has been stagnant and the activity of the industrial sector, which accounts for 35% of the total electricity consumption,[19] has decreased.

The stagnation in electricity consumption and the non-increasing penetration rate of electricity consumption within the total energy mix in Western Countries ***reflect a significant delay in achieving the energy transition objectives*** as electricity is the privileged vector for decarbonized energies sources (wind, solar, hydro and nuclear)

11 Members of the Price Cap Coalition: Australia, Canada, the European Union, France, Germany, Italy, Japan, New Zealand, the United Kingdom, and the United States https://home.treasury.gov/news/press-releases/jy1796

12 Liquefied Natural Gas

13 https://www.google.com/search?q=russian+LNG+importation+in+EU&rlz=1C1ONGR_frFR1088FR1088&oq=russian+LNG+importation+in+EU&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIICAEQABgWGB4yCggCEAAYgAQYogQyCggDEAAYgAQYogTSAQoxNzUxNmowajE1qAIIsAIB&sourceid=chrome&ie=UTF-8

14 https://www.consilium.europa.eu/en/press/press-releases/2024/06/24/russia-s-war-of-aggression-against-ukraine-comprehensive-eu-s-14th-package-of-sanctions-cracks-down-on-circumvention-and-adopts-energy-measures/

15 GHG: Green House Gases

16 https://www.energyinst.org/statistical-review

17 https://www.statista.com/statistics/265598/consumption-of-primary-energy-worldwide/#:~:text=Global%20primary%20energy%20consumption%20reached,percent%20in%20comparison%20to%202022.

18 https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/

19 In2022, the EU Industrial electricity consumption accounted for 35% of the total electricity consumption. https://www.statista.com/statistics/265598/consumption-of-primary-energy-

In 2023, growth in solar and wind electricity resulted in 30% renewables share in global electricity generation for the first time[20] despite drought conditions that resulted in a fall in hydropower (that remains the main source of renewables).[21]

Combined with nuclear, the world generated almost 40% of its electricity from low-carbon sources in 2023. As a result, the CO_2 intensity of global power generation reached a new record low, 12% lower than its peak in 2007.

Despite these achievements and because of the fossil fuels consumption growth (1.5%), global energy-related CO_2 emissions[22] reached 37.4 bn tonnes - a 1% increase compared to 2022.[23]

The year 2023 was the warmest year since global records began in 1850 at 1.18°C above the 20th-century average of 13.9°C.
Regarding GHG emissions, the situation is contrasted between Western economies, where these emissions are decreasing and emerging economies where they are still increasing due to their economic development and fossil fuels usages (notably in China and India)

Advanced economy GDP[24] grew by 1.7% but emissions fell by 4.5%, a record decline outside of a recessionary period. This 2023 decline was caused by a combination of structural and cyclical factors, including strong renewables deployment, coal-to-gas switching in the USA, but also weaker industrial production in some countries, and milder weather.
Even though China is the solar and wind generation leader, its emissions grew around 565 Mt in 2023, by far the largest increase globally. Per capita emissions in China (8tCO_2eq/capita) are now higher that the global average (6,76tCO_2eq/capita).
In India, strong GDP growth drove up emissions by around 190 Mt however, per capita emissions remain far below the world average (2tCO_2eq/capita).
It is legitimate for developing countries to aim at increasing the standard of living of their growing population and hence an increase in energy usages. However, it is to be hoped that given the drop in the decentralized electricity production costs, local solutions will be implemented to allow a more sustainable development and global improvement of life conditions.
We must hope, but this is not the current trend, that these countries can conceive a way of life less energy-intensive than the Western model, while aiming to an equivalent quality of life.

20 https://ember-climate.org/insights/research/global-electricity-review-2024/#executive-summary
21 This shortfall in hydropower was met by an increase in coal generation.
22 Energy-related greenhouse gas emissions account for the majority of all anthropogenic emissions – about 80% in the USA and the European Union
23 https://www.iea.org/reports/CO₂-emissions-in-2023/executive-summary

24 GDP: Gross Domestic Product

2023 was marked by a renewed interest in **nuclear electricity** that provided about 10% of the world's electricity (about one-quarter of the world's low-carbon electricity).
Asia and notably China remained the main driver for nuclear power growth .[25]
Moreover, in August 2024, China has authorised 11 new nuclear reactors in $31bn worth of investment.
However, in 2023 the startup/closure balance was negative by 1 GW as reactors totalling 5 GW (gigawatt) of new nuclear capacity became operational while 6 GW were closed.
Thirteen years after the Fukushima accident, *Japan is returning its nuclear reactors to operation*. As of year-end 2023, 12 reactors have returned to commercial operation, with 8 reactors were planning for a restart. Another 5, have passed a government safety review, among them, the world's biggest nuclear plant Kashiwazaki-Kariwa[26] could restart in October 2024.However, in many locations, a nuclear plants restart is confronted to local opposition.
This nuclear revival helps Japan to decrease its LNG imports, meet its environment targets and decrease electricity prices.

The EU Nuclear Alliance launched early 2023 includes 12 countries[27] that intend to build new nuclear plants. In addition, other countries such as South Africa and Saudi, are launching tenders for new reactors.

25 In 2023, out of 59 reactors under construction worldwide, 22 are being built in China
26 With a capacity of 8000MW
27 Bulgaria, Croatia, Czech Republic, Finland, France, Hungary, the Netherlands, Poland, Romania, Slovakia, Slovenia and Sweden.

French government has announced a program to build 6 EPRs in a first step and then 8 more in a second step.
After more than 12 years of delay and an estimated cost of € 19 billion (compared to the initial budget of €3.3 bn), the French Flamanville 3 reactor should be connected to the grid in H2 2024. This would be the 4th EPR to enter in commercial service. The others, Taishan 1 and 2 in China and Olkiluoto in Finland, are operating at full power.
There is a lot of hope on SMRs (Small Modular Reactors) development. SMRs are smaller size reactors using the same processes and design as large reactors. They are usually light water-cooled reactors of 60MW capacity They are assembled by modules to reach on average a 600MW size (the average size of a coal plant).
Many projects are developed worldwide. Globally, there are more than 80 SMR designs at different stages of development across 18 countries. While countries such as the USA, UK, Canada, Japan, and the South Korea are actively developing their own designs, Russia and China connected their first SMRs to the grid in 2019 and 2021, respectively.[28]

28 https://energy.ec.europa.eu/topics/nuclear-energy/small-modular-reactors/small-modular-reactors-explained_en#:~:text=Globally%2C%20there%20are%20more%20than,in%202019%20and%202021%2C%20respectively.
29 https://www.eenews.net/articles/nuscale-cancels-first-of-a-kind-nuclear-project-as-costs-surge/
30 https://ieefa.org/resources/eye-popping-new-cost-estimates-released-nuscale-small-modular-reactor

We can acknowledge these benefits:

- ✓ Their smaller individual size will allow to manufacture in factories many components that would be assembled on site. Factory environment is far better to ensure a good quality of the equipment and thus of the plant.
- ✓ Thus, they should be quicker to build.
- ✓ Their smaller size allows to connect them to less robust grids.
- ✓ SMR heat transfer reactors which also provide district heating solutions represent an interesting solution because they have a better energy yield and relief the grids.

However, prerequisites for their massive deployment are:

- ✓ Cost competitiveness

End 2023, the USA first expected commercial SMR developed by Nuscale was stopped.[29] The project consisted of six 77MW SMRs, with a total capacity of 462 MW. It was supposed to come online in 2029. But the project experienced substantial cost overruns and delays. Initially, it had a target of delivering 40 years of electricity at $55 per megawatt-hour. However, the target price soared to $89/MWh due to a 75% increase in the estimated construction cost for the project, from $5.3 to $9.3 billion dollars.[30] Remarkably, the new $89/MWh price of power would have been around $120/MWh without IRA and DOE[31] $30/MWh subsidies.

31 DOE: Department of Energy

- ✓ To benefit from components industrialization, the same type of SMR design must be deployed at industrial scale in several different countries, hence, the needed cooperation between different National Safety Authorities.
- ✓ Miniaturization is not so easy. For example, in July 2024 the French Nuward governance body has decided to completely overhaul the design of its SMR, Specifically, the innovative idea of an integrated boiler (combining the reactor vessel and steam generators) used in submarine small reactors has been discarded in favour of a more traditional design.
- ✓ Acceptance procedures and local acceptance in many sites could be challenging (while in developed countries new large reactor are built on existing sites where grid connection exists, and local population welcomes nuclear facilities).
- ✓ Non-proliferation control of scattered nuclear material

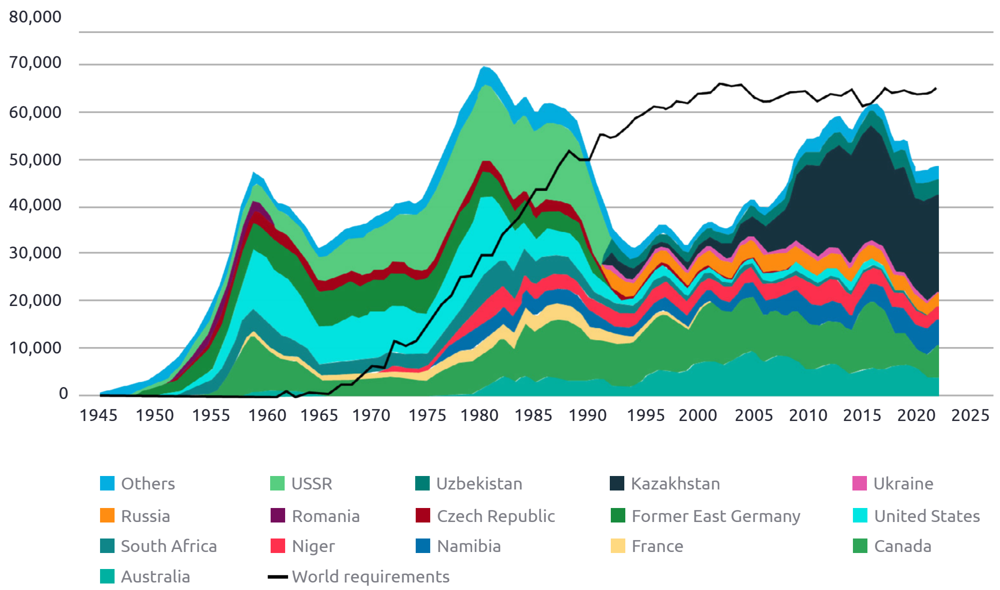
Hopefully, these challenges will be overcome and SMRs will be deployed alongside with large size reactors.

Uranium resources are better distributed around the world than those of oil or gas and nuclear electricity producers have large strategic stocks.
However, the price of uranium price increased significantly during the last three years[32] from 30$/lb[33] in June 2021 to 86$lb in June 2024 with a peak of 106$/lb in January 2024

This price increase is linked to new nuclear reactor construction programs announcements, and to the unstable situation in certain producing countries such as Niger. This country, where the former government was overthrown in July 2023, announced in June 2024, that it had withdrawn from the French nuclear group Orano its operating permit for the Imouraren deposit, one of the largest in the world.[34]

FIGURE 3

World uranium production and reactor requirements, 1945-2022, tU



As will be detailed below, the Advanced Modular Reactors projects based on breeder generation, will make it possible to produce around 100 more electricity with the same quantity of uranium than the reactors currently in service.
In addition, China is developing projects using thorium instead of uranium as the fissile element. Thorium is even more abundant than uranium in nature.
The availability of uranium resources is therefore not a concern in the medium term. In the short term, tensions could exist, particularly linked to the time needed to open new mines.[35]

32 https://tradingeconomics.com/commodity/uranium
33 Uranium price is expressed in $/U3O8 pound https://www.uranium.info/unit_conversion_table.php
34 Niger produces 5% of world uranium supplies but 15% of French supplies

35 https://www.scmp.com/news/china/science/article/3224183/china-gives-green-light-nuclear-reactor-burns-thorium-fuel-could-power-country-20000-years

Renewables

Intermittent renewables growth:

2023 was the 22nd year in a row that renewable capacity additions set a record.

Year on year, total renewable energy capacity increased by 14% with a larger capacity expansion of solar (32%) than wind (13%). Solar PV alone accounted for three-quarters of renewable capacity additions worldwide.

China commissioned as much solar PV as the entire world did in 2022, while its wind additions also grew by 66% year-on-year.

The wind offshore sector has encountered difficulties:[36] In 2023 global wind offshore installed capacity amounted to 73 GW[37] out of which 34 GW are in Europe (which was the first region to instal offshore wind turbines) 31 GW in China[38] and 3 GW in the USA (which is catching up).

In 2023 large offshore wind turbine manufacturers were confronted with operational and financial difficulties. While this crisis impacted European players as Vestas, Siemens Energy or Vattenfall, it had large consequences in the USA.

Big companies such as Ørsted, Equinor, BP and Avangrid, cancelled contracts or sought to renegotiate. Pulling out meant the companies faced cancellation penalties ranging from $16 million to several hundred million dollars per project.

It also resulted in Siemens Energy, the world's largest maker of offshore wind turbines, anticipating financial losses in 2024 of around $2.2 billion.

These cancelled projects capacity amounted to more than 12 GW in the USA, around half of the capacity in the pipeline.

There are a few reasons for these difficulties:

- To win large wind offshore farms projects, offshore wind operators (Utilities, Oil companies, Investment funds) have put price pressures on their suppliers. To sell their equipment, these suppliers have lowered their prices, and they were thus unable to amortize their R&D costs.
- Added to this, there were difficulties linked to regulations and the post-Covid crisis. In the USA and in Europe, the process to obtain all the permits and approvals for a wind offshore project, takes years. The post-COVID crisis and the war in Ukraine resulted in high inflation, high interest rates, logistics issues that increased costs of commodities (like steel or copper) as well as construction and capital costs. However, there were no price renegotiation clauses in the contracts agreed by the operators before the Covid crisis, hence, the choice of turbine suppliers or future operators to renounce these contracts and pay penalties rather than incur even more important losses.

36 https://www.npr.org/2023/12/27/1221639019/offshore-wind-in-the-u-s-hit-headwinds-in-2023-heres-what-you-need-to-know
37 https://www.statista.com/statistics/
38 https://www.offshorewind.biz/2023/06/30/china-now-has-31-gw-of-offshore-wind-installed-country-on-track-to-hit-wind-and-solar-targets-five-years-early-report-says/#:~:text=China%20Leads%20in%20New%20Offshore%20Wind%20Capacity%20Second%20Year%20in%20Row&text=The%20total%20capacity%20of

- In addition, an old American legislation from 1920 "the Jones Act" prevents ships to operate in USA waters unless they are built, operated, and staffed by American companies. In the USA, there are presently no Wind Turbine Installation Vessel able to ship turbines of around 250m length. Hence, wind turbine manufacturers, had to use barges which are expansive.

Remediation measures are underway in the USA, which should make the projects more attractive. Thus, the new contracts will allow price renegotiations, the regulatory process should be streamlined, and the IRA provides for federal incentives in the form of tax credits.In addition, companies, as Dominion Energy of Virginia, are constructing their own American ship.[39]

President Biden's objective is to have 30 GW of offshore wind power in 2030 (It compares to a 60 GW target in the EU). However, because of the above-mentioned issues, the present forecast is only at 15GW.

39 This 472-foot vessel will be able to transport wind turbine components domestically and avoid unnecessary costs and delays

Intermittent renewables impact on the grid:
The power grid plays a fundamental role to a successful energy transition.
As recently pointed out by Tatsuya Terazawa, Chairman and CEO of the Institute of Energy Economics of Japan "Without transmission, No transition"

Intermittent renewable costs are increasing with their penetration rate
Additional costs linked to grid balancing issues must be added to the LCOE[41] to make a fair comparison between intermittent renewable generation costs and dispatchable generation costs. According to Lazard 2024 report[42] after an increase between 2021 and 2023, wind and solar LCOE[43] averages in the USA remained stable in 2024.
However, with higher penetration rates in the electricity mix the timing imbalance between customer demand and renewable electricity production is increased. As such, the optimal grid balancing solution is to complement new renewable energy technologies with a "firming" resource such as energy storage or dispatchable generation technologies. The renewable costs must include this externality, more precisely the "firming" resource generation cost.

40 https://eneken.ieej.or.jp/en/chairmans-message/chairmans-message_202401.html
41 LCOE: Levelized Cost of Electricity. See definition: https://corporatefinanceinstitute.com/resources/valuation/levelized-cost-of-energy-lcoe/
42 https://www.lazard.com/research-insights/levelized-cost-of-energyplus/
43 LCOE: Levelized Cost Of Electricity

While in Europe, the nuclear generation (which is dispatchable technology with no GHG emissions) helps to balance the missing renewable generation, in the USA Combined Cycle Gas Turbine is the most used firming generation source despite its GHG emissions.

The incremental cost of firming intermittent electricity varies regionally depending on the rate of renewable source penetration and the grid operating rules. According to Lazard report, this additional cost varies in the USA from 56% of the LCOE (PJM TSO[44]) where renewable penetration is 7% to 200% of the LCOE (CAISO[45]) where renewable penetration is 52%

44 PJM Interconnection coordinates the movement of electricity through all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.
45 CAISO: California ISO

FIGURE 4

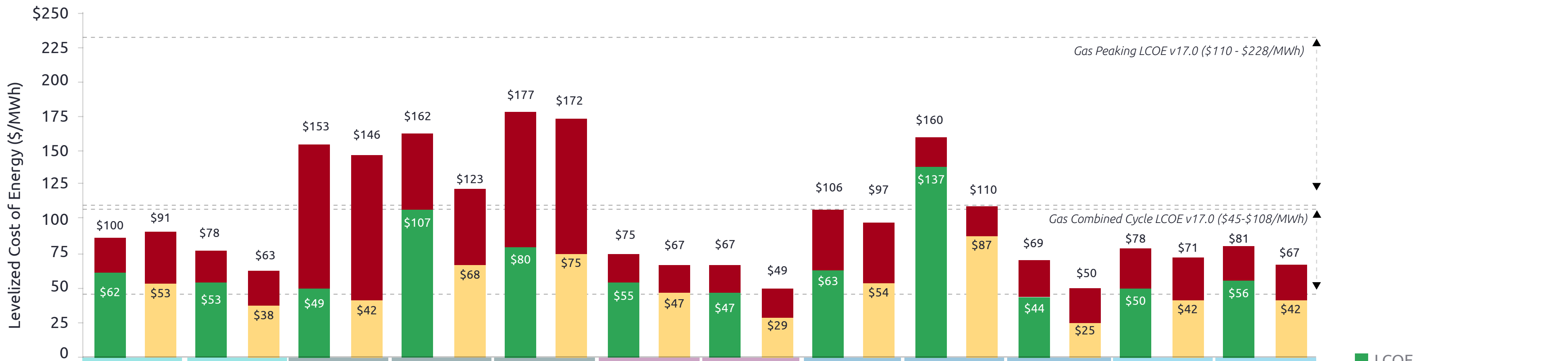
LCOE including levelized firming cost ($/MWh)

Growth of intermittent renewables (solar and wind) penetration rate in electricity generation is also increasing grid stability problems that translate into **difficulties to stabilize the power system frequency.**

Some Countries or Regions with high shares of variable renewable generation are establishing minimum requirements for system inertia that helps enhance the power system's resilience during disturbances.[46]

Additionally, various countries including the United Kingdom, Ireland and Australia have been introducing measures such as fast frequency response and similar services that stabilise the power system rapidly after disruptions.

Battery storage systems can provide such services for grid stability while enhancing system flexibility (see below).



	MISO		CAISO			SPP		PJM			ERCOT	
	Solar	Wind	Solar	PV+Storage	Wind	Solar	Wind	Solar	PV+Storage	Wind	Solar	Wind
ELCC	39%	26%	8%	51%	14%	57%	19%	42%	72%	21%	38%	25%
Capacity Factor	18%	34%	23%	23%	23%	21%	39%	18%	18%	42%	23%	33%
Resource Penetration	6%	25%	52%	52%	20%	1%	58%	7%	7%	7%	21%	44%

46 A property typically provided by conventional generators with spinning rotors that helps enhance the power system's resilience during disturbances. Wind and PV solar that don't need turbines cannot provide this stabilizing feature

The duck curve[47]: As more solar capacity comes online, grid operators in sunny regions as California have observed a drop in power load in the middle of the day when solar generation tends to be highest. This dip is followed by a steep rise in the evenings when solar generation drops off. This load pattern is called the "duck curve". As solar capacity continues to grow, the midday dip in load is getting lower and the following rise is getting stiffer, presenting challenges for grid operators. This situation has created a large blackout in California during the 2020 summer. Since then, the State has adopted a plan to build dispatchable generation plants (i.e CCGTs[48])

Curtailment: When those services don't exist or are insufficient, grid operators have curtailed renewables and sometimes nuclear generation.
In 2023, PV and wind generation curtailment has increased in many European countries, notably in Germany where it reached 8%. The main reason is that grid expansion did not keep pace with offshore wind growth (located in the North of Germany) and geographical consumption location (in the South of Germany).[49]

In the EU, variable renewables penetration is expected to reach in 2028, more than 50% in seven countries, (90% in Denmark). Although EU interconnections help integrate solar PV and wind generation, grid bottlenecks will pose significant challenges and lead to increased curtailment in many countries.

47 https://www.eia.gov/todayinenergy/detail.php?id=56880
48 CCGT: Combined Cycle Gas Turbine
49 In Germany wind offshore generation is located in North sea while electricity demand is mainly in the South of the country

In the USA, wind electricity curtailment was in 2022 at an average of 5.3%(increasing over the last years).
China has tried to limit curtailment of renewable energy to 5%.[50] However, it can be larger: for example, curtailment for Huaneng Power International, a major state-owned generator, rose to 7.7% in Q1 2024 from 3.1% in 2023.
Moreover, in a survey of six provinces' ability to absorb distributed solar [51], China's energy regulator found five provinces expected to have to impose restrictions on new renewable projects in 2024.

Consequences on new projects profitability: Renewables and nuclear being energy generation with a very high capex proportion in the kWh final cost, frequent episodes of curtailment (meaning hours with no revenue while cost have already occurred) negatively impacts their profitability. This lowered Return on Investment questions the attractiveness of new constructions.
For renewables, the question arises less because they benefit from subsidies of various kinds ("Contract for Difference", tax exemption, subsidies, etc.)[52] while it arises in Europe for new nuclear plants constructions.
Given the grid balancing problems related to intermittent renewable energies such as solar and wind, nuclear dispatchable electricity (see above) and *storable renewable energies development* should be accelerated.
First **hydropower**:[53] It remains the largest renewable source of electricity, generating more than all other renewable technologies combined. It provides a range of electricity grids services, such as storage and flexibility to balance solar and wind intermittency.
Pumped Storage Hydropower (PSH) provides more than 90% of all stored energy in the world. It can store months of electricity consumption, while batteries allow only a few hours.
The more variable renewable electricity (solar and wind) is developed the more pumped hydropower will be required to provide grid balance.
In 2023, global hydropower fleet grew to 1,416GW. Conventional hydropower capacity grew less than previous years by 7.2GW to 1,237GW, while pumped storage hydropower grew by 6.5GW to 179GW.
Capacity increases are going on an average at about half the rate they need to be on the pathway to net zero.

50 https://www.reuters.com/business/energy/chinas-blistering-solar-power-growth-runs-into-grid-blocks-2024-05-22/
51 https://www.reuters.com/business/energy/chinas-blistering-solar-power-growth-runs-into-grid-blocks-2024-05-22/
52 These subsidies, paid by the end customer or the taxpayer, have enabled the development of wind and solar electricity generation, they should now be removed as they distort the electricity markets functioning.

53 Hydropower https://www.hydropower.org/publications/2024-world-hydropower-outlook

Historically, hydropower has been funded by state or intergovernmental actors, but their ability to put more resources into the sector is limited. If the build rate of hydropower is to double, then private investment is needed so that annual capital flows can also double, from $65 billion to $130 billion. Beyond technical and financing challenges, policies and market mechanisms must ensure that investment in sustainable hydropower is attractive.

"Green heat"

Heating and cooling for residential and commercial buildings and for the industry accounts for about half of the global final energy consumption. It is the largest source of energy end use, ahead of transportation (30%), and is responsible for more than 40% of global energy-related CO_2 emission. In 2021, fossil fuels' share in heat generation was around 75%.[54]

Despite remote-controlled heating and cooling systems that enable savings, the global energy demand for cooling is expected to increase by 45% by 2050, compared with 2016 levels.[55] One reason for this is rising standards of living in developing countries; another is that global temperatures will probably rise. Cooling solutions are predominantly powered by electricity.

To decarbonize heating a mix of sustained solutions should be implemented: electricity, solar hot water, biomass, geothermal resources.

- Electrification of heating by using ***heat pumps***, is strategic for decarbonising heating and cooling. However, it will not suffice. For example, in Irena pathway to achieve the 1.5°C target by 2050, heat pumps installations are forecasted to increase by 14-fold from 2023 to 2050 which is not realistic. This scenario bets also on large wind and solar developments which is also questionable notably because of grid balancing issues (as described above).
- ***Solar domestic hot water*** constitutes an interesting source of decarbonization on one side and energy storage on the other side. France was a pioneer by offering, for more than 30 years, to residential customers, night-day rates which favour the heating of water during off-peak hours for its use during peak hours.
- Use of "green heat" coming from ***biomass***, used notably in district heating systems (burning urban waste) and geothermal energy.

54 https://www.irena.org/Innovation-landscape-for-smart-electrification/Power-to-heat-and-cooling/Status#:~:text=The%20share%20of%20fossil%20fuels,95%25%20of%20global%20heating%20demand.

55 https://www.irena.org/Innovation-landscape-for-smart-electrification/Power-to-heat-and-cooling/Status

Geothermal is a sustainable and reliable energy resource[56] that is widespread over the globe.
This underground heat resource has a wide range of temperatures depending on the reservoir's depth and the locations.
For low temperature subsurface resources (wells up to 500m depth), a geothermal heat pump can be used to increase heating and cooling system's efficiency.
Medium temperature geothermal resources are used for industrial processes and in district heating distribution systems.
The deep and high temperature resources (wells up to 5000m depth) can be used for both heat and electricity dispatchable generation.
Geothermal power plants can provide both energies with a capacity factor of more than 80%.
Moreover, the hot salty water, or geothermal brine, which is pumped to the surface, can also yield lithium
Between 2021 and 2022, the global weighted average LCOE of ten newly commissioned geothermal projects fell by 22% to $56/MWh which is comparable to wind or solar farms LCOEs.
However, the initial cost capital cost is high with an installed cost of $3478/kW.[57] Also, operation and maintenance are considerably more complex compared to solar or wind and require a high level of experience.[58]

56 https://www.irena.org/Publications/2023/Feb/Global-geothermal-market-and-technology-assessment
57 In 2023 the capital cost for U.S. nuclear power ranged between $13952/kW and $8475/kW https://www.statista.com/statistics/654401/estimated-capital-cost-of-energy-generation-in-the-us-by-technology/
58 Between 2021 and 2022, the global weighted average levelized cost of electricity (LCOE) of ten newly commissioned geothermal projects fell by 22% to $0.056 kWh.

Electricity generation from geothermal energy has grown at around 3.5% annually, reaching a total installed capacity of approximately 16 GWe[59] in 2021. On the other hand, geothermal deployment for heating and cooling grew at an average rate of around 9% annually between 2015 and 2020 to reach 107 GWth[60] in 2020. The relatively low growth could be attributed to factors such resource's location, drilling equipment availability, permitting delays and high upfront capital.

In the USA, in 2023 geothermal provided 3.7 gigawatts (GWe) (1%) of electricity in the USA, mostly from hydrothermal resources in California, Nevada, and Utah. Assessments[61] indicate that with present technologies a potential of 18 GWe could be deployed in 2050.
In the EU, low temperature geothermal energy is currently used in just 2 million of the 100 million home heating systems, and it generates only 0.2 % of the total electricity consumed.
According to the Implementation Working Group for geothermal[62] with today's technology, 25 % of the European population could cost-effectively deploy geothermal heating.
Geothermal power plants could provide up to 10 % of Europe's power demand. Furthermore, the geothermal industry could become a key player in the production of sustainable lithium made in Europe.

59 GWe: GW of electricity generation
60 GWth: GW of thermal generation. One needs roughly 3 GWth to generate one GWe
61 https://iopscience.iop.org/article/10.1088/2753-3751/ad3fbb
62 https://setis.ec.europa.eu/implementing-actions/geothermal_en

As a conclusion, geothermal resource can provide sustained heat and dispatchable sustained electricity. This resource needs to be better exploited. This is why, in January 2023, the European Parliament adopted a resolution calling for a European strategy on geothermal energy. It calls for mapping geothermal assets, launching an industrial alliance on geothermal energy, and the introducing a harmonised insurance scheme to mitigate financial risk.

Demand side management

Demand-Side Management (DSM) such as direct load control, demand response, and energy efficiency has been used for decades to lower costs, increase usages efficiency, improve the grid balancing and increase security of electricity supplies.

- **DSM** has become more complex because of decentralized electricity production growth, leading to increased bidirectional flows and greater network balancing needs. Contrary to California in 2020(see above) it is thanks to its demand response and energy flexibility programs that ERCOT[63] the Texas grid operator avoided blackouts in June 2023.
  These programs provide financial incentives to energy consumers to reduce demand during times of electricity grid stress or shift consumption to times of day when grid pressures and power prices are lower. Demand response payments were 20 times higher that year, rewarding those who participate in the programme.[64] However, these spendings are negligeable compared to what a blackout would have cost.
- **Technical devices** as smart meters, increased sensors on networks and at customers' premises and more sophisticated management algorithms improve the demand management situation.
- **Sharing consumption data**, within the limits authorized by law, should make it possible to develop services allowing better electricity grid management and significant savings for the community. For example, better management of congestion on the network could help avoid the construction of new lines.
- On the economic side, **time of use tariffs** if well explained and well understood and adopted by customers[65] help manage the demand and reduce customer bills.
- Customer demand is influenced by economic aspects such as price increases or **psychological biases**, such as a perception of shortage risk. These factors were important in explaining the drop in electricity consumption in Europe over the winter of 2022-2023. This economic sobriety was maintained the following winter.

Also, all economic conservation campaigns launched by utilities or public authorities must consider human aspects at the risk of unpleasant surprises (rebound effect[66]).

Electricity storage

Different electricity storage technologies are available. Their performance and cost depend on the storage scale and duration. For large storage capacity and long durations Pumped Hydro Storage (if geography allows) and Diabatic Compressed-air energy storage (CAES) are the best options.[67] However, diabatic CAES is not a zero-emission technology, since it uses fuel such as natural gas in the discharge cycles.

63 ERCOT: Electric Reliability Council of Texas
64 https://www.enelnorthamerica.com/insights/blogs/demand-response-2023-texas-heatwaves

65 It is the fear that customers would not understand these variable tariffs that prevented the EU to make them mandatory
66 https://blog.rexel.com/en/a-world-of-energy/the-rebound-effect-the-hidden-face-of-energy-efficiency/

67 https://www.pnnl.gov/sites/default/files/media/file/ESGC%20Cost%20Performance%20Report%202022%20PNNL-33283.pdf

FIGURE 5

Total installed storage cost comparisons

Batteries Energy Storage Systems (BESS) have their value mostly in short-term balancing of the grid (1 to 4 h time scales). Thanks to electrical cars development, stationary battery performances and costs are improving quickly.

Stationary batteries demand is set to grow in line with the increasing percentage of intermittent renewables connected to the electricity grids. For example, in the EU roadmap they would reach more than 65% share in the electricity mix by 2030 as the need for flexibility in the electricity system will increase significantly in all EU countries, reaching 24% of total EU electricity demand in 2030.[68]

Some Institutes[69] predict that annual stationary storage deployments will grow at a CAGR[70] of 30% from 2023-2033 to reach a capacity exceeding 2 TWh. To reach these optimistic predictions, big improvements are needed in policy frameworks, technology and profitability.

68 https://energy.ec.europa.eu/topics/research-and-technology/energy-storage/recommendations-energy-storage_en
69 https://www.idtechex.com/en/research-report/batteries-for-stationary-energy-storage-2023-2033/905
70 CAGR: Compound Annual Growth Rate

Clear policy frameworks are starting to be implemented in some countries as China, Australia where state-level storage incentives are key drivers for their high historical and forecasted BESS[71] installation growth.

In certain Chinese regions, association of PV and batteries is compulsory to connect new solar farm to the grid.
Several USA States have energy storage and renewables mandates. With more states announcing new battery storage targets, and expanding older targets (such as New York), this trend is expected to continue and will be a key driver for USA BESS growth. Let's note that the cost of PV farms with BESS are significantly higher than without batteries[72] but better services is provided.

Batteries technical improvements: stationary battery storage improvements include the extension of their life cycle; their size and physical footprint reduction, cost decrease, limited use of critical metals and easy recycling.

Over the past decade, Li-ion batteries have become an increasingly important stationary energy storage technology. LFP and NMC[73] chemistries are the most popular in storage application. A shift towards LFP for grid-scale batteries is witnessed because of lower costs, better safety properties, and longer life cycles.[74]

The grid-scale market is leaning towards longer duration of battery storage to accommodate growing volumes of renewable energy capacity on electricity grids.
Li-ion may not be well suited to long-duration storage in future, whereas Redox Flow Batteries(RFB)[75] can store more than 10 hours of energy. However, this technology is still in its early stages, with grid-scale proof-of-concept projects starting to emerge. For instance, in 2022, Sumitomo Electric brought one of the world's largest vanadium RFBs online in Japan.

Batteries manufacturing: Worldwide battery mega factories are mainly installed in Asia, with a dominant position for China where over 80% of global lithium-ion battery production takes place. Europe has succeeded in attracting battery factories built by European or Chinese or other Asiatic firms. However, some European battery manufacturers are encountering technical problems notably linked to the anode[76] graphite[77] quality and the factory yield.

Batteries profitability increase: it will of course benefit from battery costs decrease[78] and if it is the case of electricity prices increase that allow quicker amortisation of the "renewable plus batteries" systems.

Similarly to renewable costs, Li-ion battery costs have decreased in a spectacular way in the ten last years. In 2021 and 2022, very high prices for critical materials (Lithium and Graphite) have resulted in cost growth. In 2023 and H12024, the decrease in these critical metals price notably Lithium (that decreases by 80% in H1 2024 from its 2022 peak.), have resulted in significant costs decrease.[79]
However, at the same time electricity prices have significantly fallen, erasing part of the cost decrease benefits.
Presently BESS are considered unprofitable in spot market trading cases, especially in the day-ahead market. According to AEPIBAL,[80] in the current markets first BESS entrants have between 6 to 8% project IRR.[81] These values are low for this type of business model (high merchant risk and new technology) so additional revenue streams such as peak shaving and other ancillary services are needed to reach an acceptable profitability level. In regions where there are capacity markets[82] and/or subsidies, the BESS projects IRR will be improved.

71 A Battery Energy Storage System (BESS) is a system that uses batteries to store electrical energy. They can fulfil a whole range of functions in the electricity grid or the integration of renewable energies https://flex-power.energy/school-of-flex/battery-energy-storage-system-bess/
72 For example, in California the LCOE cost of PV farm is more than doubled: from $49/MWh without BESS to $107/MWh with BESS
73 LFP: Lithium-Fer-Phosphate, NMC: Nickel Manganese Cobalt
74 The same shift is happening for EV batteries

75 See WEMO 2023
76 Anodes are made in graphite that is imported at 100% from China
77 Graphite is imported from China(see below)
78 Grid-scale battery costs can be measured in $/kW or $/kWh terms. Thinking in kW terms is more helpful for modelling grid resiliency. A good rule of thumb is that grid-scale lithium-ion batteries will have 4-hours of storage duration

79 The average 2024 price of a BESS 20-foot DC container in the U.S. is expected to come down to US$148/kWh, down from US$180/kWh in 2023 and $270/kWh in 2022 according to Clean Energy Associates https://www.cea3.com/cea-blog/bess-prices-in-us-market-to-fall-a-further-18-in-2024
80 https://aleasoft.com/revenue-stacking-the-solution-for-battery-viability/
81 IRR: Internal Rate of Return
82 https://www.nrg.com/insights/energy-education/electricity-markets-what-s-the-difference-between-a-wholesale-en.html

Hydrogen

Green hydrogen allows long term electricity storage in fuel cells, but its usage is focused at achieving industrial and transportation sectors decarbonization.
Global hydrogen use reached 95 Mt in 2022, a nearly 3% increase year-on-year, low-emission hydrogen[83] accounting for just 0.7% of total hydrogen demand

By the end of 2023, China's installed electrolyser capacity reached 1.2 GW – 50% of global capacity[84] – with another new world record-size electrolysis project (Kuqa plant, 260 MW), which started operation. This Kuqa plant operated by Sinopec is expected to produce 20,000 tonnes of low-carbon hydrogen per year.

The conditions for the green hydrogen development are:

- **Technology improvement:** in 2023 and early 2024 low emission hydrogen production in Europe and China encountered difficulties linked to malfunctioning electrolysers. Even alkaline, the most advanced technology (50% of current production), had unexpected failures when the electrical load rate was in below 40%. Unfortunately, this means that today electrolysers cannot use directly over abundant green electricity as the latter is available intermittently.
  It is because of the poor function of the John Cockerill electrolysers, that the French, Masshylia green hydrogen megaproject, from TotalEnergies and Engie has been revised downwards.[85]
  At this stage, most manufacturers encounter similar difficulties. Other problems are linked to increase of the size of the electrolysers, which is evocative of the problems encountered by other young industries.
- **Lowering low emissions hydrogen costs** is essential for its development.
  In 2023, grey hydrogen[86] LCOE varied between \$0.98-\$2.93/kg; for green hydrogen it was between \$4.5-\$12/kg.[87]

  In Europe, TotalEnergies has launched a call for tenders for 500,000 tonnes of renewable hydrogen for use in its refineries. The price obtained was €8/ kg.[88] However, thanks to subsidies this was an acceptable price.[89]
  Cost reduction should come from the drop in the price of low-carbon electricity and the reduction in the capital and operational cost of electrolysers.

  ✓ ***The cost of electricity used:*** After the huge drop of renewable costs these last ten years, wind and solar electricity generation costs decrease will be limited, and costs from new nuclear plants are higher than that of existing ones.
  However, with the increase of the intermittent renewable rate in the electricity mix, the number of hours when this electricity is curtailed will increase. If electrolysers plants are collocated with renewable plants, they could use this free electricity and green hydrogen cost would decrease significantly. Unfortunately, today electrolysers have difficulties to operate with a variable electricity load[90] that also reduces their lifetime.

  ✓ *The cost of electrolyzers drop* could come, as for renewables and batteries, from mass production but presently the large electrolyzers plants have difficulties, and the market is not yet there (see below).
  The difficulties of green hydrogen cost decrease are confirmed by "Futurible" study mid-March, 2024[91] that concludes that cost reductions are insufficient to significantly narrow the competitiveness gap with grey hydrogen.

83 Low emission hydrogen is produced by water electrolysis using either electricity produced by renewables (green hydrogen) or nuclear electricity.
84 In 2023, 50% of world's hydrogen installed capacity was in China, 25% in Europe and 10.5% in the U.S.

85 The plant should now not exceed 40MW of capacity instead of the planned 120MW.
86 Grey hydrogen is produced by gas -methane- reforming
87 https://about.bnef.com/blog/green-hydrogen-to-undercut-gray-sibling-by-end-of-decade/
88 According to Patrick Pouyanné April 2024 Ryad economic forum
89 If a refinery uses green hydrogen and replaces its grey hydrogen not only will it avoid paying emission rights but it will get EU CO_2 emissions free allowances that it can trade.

90 It seems that they cannot function if the electricity input is below 40% of the nominal input.
91 https://www.futuribles.com/hydrogene-bas-carbone-perspectives-de-deploiement-a-lhorizon-2050/

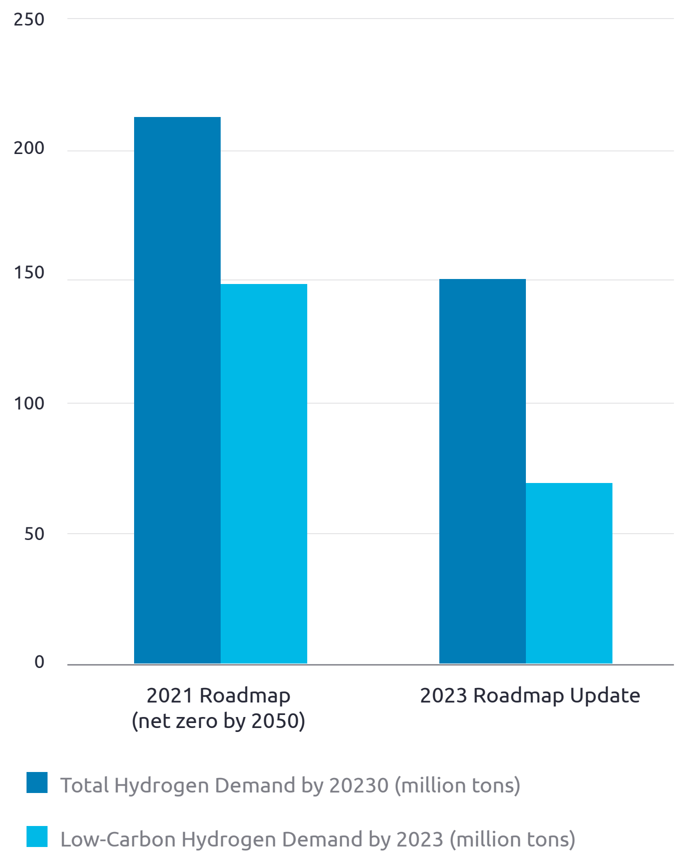
To narrow the cost difference between low emission hydrogen and grey hydrogen, authorities in the USA and EU are implementing various subsidies plans. In the USA, under the IRA (Inflation Reduction Act) legislation, renewable hydrogen producers can receive up to $3/kg of low emission H2 produced during 10 years after production start.
The European Commission should offer subsidies to renewable hydrogen producers in the form of a fixed premium (between €1.7 and € 2.5/per kg of hydrogen produced) for 10 years after production start. In addition, producers of green hydrogen will receive free CO_2 emission allowances that they can trade.
Contrarily to EU the subsidies structure under the IRA, does not involve lengthy, burdensome, and uncertain application processes.

- ✓ *__The availability of low-carbon electricity__* is an important condition for low-carbon hydrogen development .
  The last IEA study published early 2024,[92] forecasts a 35% lower global renewable electricity capacity[93] dedicated to hydrogen production, than a year ago.
  As mentioned in the previous WEMO[94], renewables electricity development in Europe is behind objectives and moreover, more renewable electricity is needed to replace Russian gas.

Green hydrogen manufacturing outside Europe, for example in countries like Morocco that are very sunny, and its shipping to Europe is seriously considered to fill the renewable electricity availability gap.
However, countries like Morocco need green electricity for their growing domestic energy and freshwater demand. Moreover, hydrogen long distance transportation to Europe is complex (see below).
Nuclear electricity could also power electrolysers. In this case, new reactors construction program should be accelerated or the existing reactors lifetime of should be extended to 80 years (see above). With the present nuclear industry dynamics in Western countries, it will be a slow decision process.

FIGURE 6

Total hydrogen demand by 2030, comparing 2021 and 2023 forecasts



Source: IEA Hydrogen review 2021, and 2023

92 https://www.reuters.com/business/energy/iea-lowers-renewables-forecast-clean-hydrogen-2024-02-01/
93 By 2028
94 https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/

- **Solving transportation issues:** Hydrogen is the smallest molecule and very inflammable in contact with air. Hydrogen transportation security has to be carefully assessed.
  - ✓ ***Long distances hydrogen transportation*** as liquid at very low temperature (-273.15°C) has a very poor energy efficiency.[95] It is possible to transform green hydrogen in green ammonia and transport it. At destination, ammonia would be reconverted into hydrogen. However, ammonia is a corrosive molecule, and two conversions processes are inefficient.

    Research on hydrogen transportation in Zeolite has been pursued for years.[96] Also, new technologies are emerging as the one developed by Hydrogen Storage Research Group in Australia to transport this very small molecule as a powder, which is safer and cheaper than other methods.[97] This is not yet available at an industrial scale.
  - ✓ ***Mid distances hydrogen transportation by pipeline is possible.*** Gas network operators that are aware that natural gas consumption is falling, are getting ready to transport hydrogen in their existing pipes. We can cite the Hydrogen European Backbone initiative, a network of 5 corridors for the import of hydrogen into Europe and its transport within Europe.

95 To obtain 1l of liquid hydrogen containing 2.4 kWh, it is necessary to spend 4.8 kWh https://www.h2-mobile.fr/dossiers/lh2-hydrogene-liquide-definition/#:~:text=Un%20litre%20d'hydrog%C3%A8ne%20liquide,au%20total%204%2C8%20kWh.
96 https://www.researchgate.net/publication/269478417_Zeolite_as_material_for_hydrogen_storage_in_transport_applications
97 https://www.mining.com/project-to-turn-hydrogen-into-a-powder-for-easy-export-gets-a5-million-in-funding/#:~:text=The%20HSRG%20research%20team%20is,be%20reused%20to%20transport%20hydrogen.

Using gas pipelines dedicated to natural gas to transport hydrogen, requires adaptations because hydrogen is a smaller molecule than methane with different physical and chemical properties. The concerns are related to the weakening of the tubes by hydrogen if the operating conditions lead to a large amplitude of pressure. It is also necessary to ensure the tightness of the infrastructures. Ultimately the objective is to circulate in the pipes 10% of the consumption planned for 2030, or 10 million tonnes.

- **Creating a large enough market demand:** Increasing hydrogen production only makes sense if there is sufficient demand. Thus, there is a need to develop hydrogen usages. For example, the replacement natural gas by green hydrogen allows to decarbonize industries that are otherwise difficult to decarbonize, such as chemistry, steel and fertilizers.

  Let's cite the two European projects initiated by InnoEnergy:
  On one hand, GravitHy dedicated to speeding up the decarbonization of the steel industry (responsible for approximately 8% of the global CO_2 emissions),[98] and on the other hand FertigHy[99] that aims to produce, low-carbon fertilisers for European farmers.[100]
  However, these usages are probably not sufficient for green hydrogen production mass development. The transportation market (car, lorries or ships) conversion to hydrogen would significantly increase the demand. However, green hydrogen fuelled vehicles must be competitive compared to electrical vehicles whose costs are decreasing thanks to batteries improvements.

98 https://gravithy.eu/
99 https://fertighy.com/
100 The agriculture sector alone is responsible for 10% of the EU's total greenhouse gas emissions

Projections

The previous analysis shows that *low emissions hydrogen development should be much slower than previously expected* for cost reasons, technical problems, difficulties in long distance transportation and lack of demand.

Manufacturers have announced plans for further expansion, aiming to reach 155 GW/year of manufacturing capacity by 2030, but only 8% of this capacity has at least reached FID.[101]

The SISYPHE study[102] shows a huge gap between the EU objectives and the low-carbon hydrogen demand projection in Europe by 2040. The low emission hydrogen demand projected by the study is thus 2.5 million tonnes in 2030 and 9 million tonnes in 2040, a huge gap with the objectives set by the European Commission of 20 million tonnes per year by 2030!!

Moreover, in its July 17,2024 report the European Court of Auditors has stated that "2030 EU goals for renewable hydrogen production and demand were overly ambitious"[103]

As a *conclusion, the growth in low-carbon hydrogen production has been "oversold" in Europe* both by politicians and by the industrial companies involved. Governments should review their unrealistic objectives at the risk of spending precious subsidies not for the right technology and creating stranded assets.

101 FID: Final Investment Decision
102 https://www.cea.fr/presse/Documents/CEA-etude-hydrogene-sisyphe.pdf This projection is based on the reality of projects committed and on the vision of some 70 European manufacturers questioned about their potential needs into hydrogen
103 https://www.eca.europa.eu/en/news/NEWS-SR-2024-11

As the above analysis shows, **the energy transformation is falling behind schedule**

We can give a few more examples:

- ✓ *The penetration of electric cars has slowed,* and some countries such as the UK have pushed back the date of banning the sale of internal combustion cars from 2030 to 2035.
- ✓ *Big oil companies, we are returning to more realistic and less proactive positions* concerning Oil and Gas exploration. They now acknowledge the need to continue to develop new fields to cope with the existing fields depletion (even with unchanged or decreasing oil consumption).

This means that the objectives of the energy transformation, as announced by many countries, are too optimistic and too close in time.

Indeed, this transformation impacts not only the production and use of energy but also the way of living of our fellow citizens. It also reduces their purchasing power, which is a key area of concern that emerges in all opinion polls.

The objectives of the Paris Agreement will very likely not be met (barring a major crisis as the Covid pandemics or as a global war) by 2030.

Today the forecast is for an increase of 3°, even 3.5° by 2050 in global temperature with the disastrous consequences that we know about.

The question that must be asked is:

What should be done to limit the rise in global temperature?

What should be done to limit the rise in global temperature?

Current technologies would make it possible to get closer to the objectives of the Paris agreement *if they were deployed at scale.* Of course, *research must continue in disruptive technologies* even if it is for a horizon further than 2030.
Let's first analyse the conditions of deploying at scale present technologies before analysing some disruptive energy related technologies and generative AI impact on the sector.

Scaling up existing technologies requires industrialization efforts, sound regulations (including simplified and accelerated procedures) faster and greater funding and stronger public acceptance.

Existing technologies deployment acceleration:

Wind and solar power are developing rapidly with photovoltaic solar production dominating. However, this development is not fast enough compared to the COP 28 objectives as confirmed by the June 2024 IEA report.[104] Analysed policies, plans, and estimates of almost 150 countries reveal an intention to install nearly 8,000 GW of renewables worldwide by 2030, representing 70% of the required(11000GW) amount to achieve the tripling goal by 2030 agreed at the COP 28. Moreover, governmental targets that are usually too optimistic are rarely met.

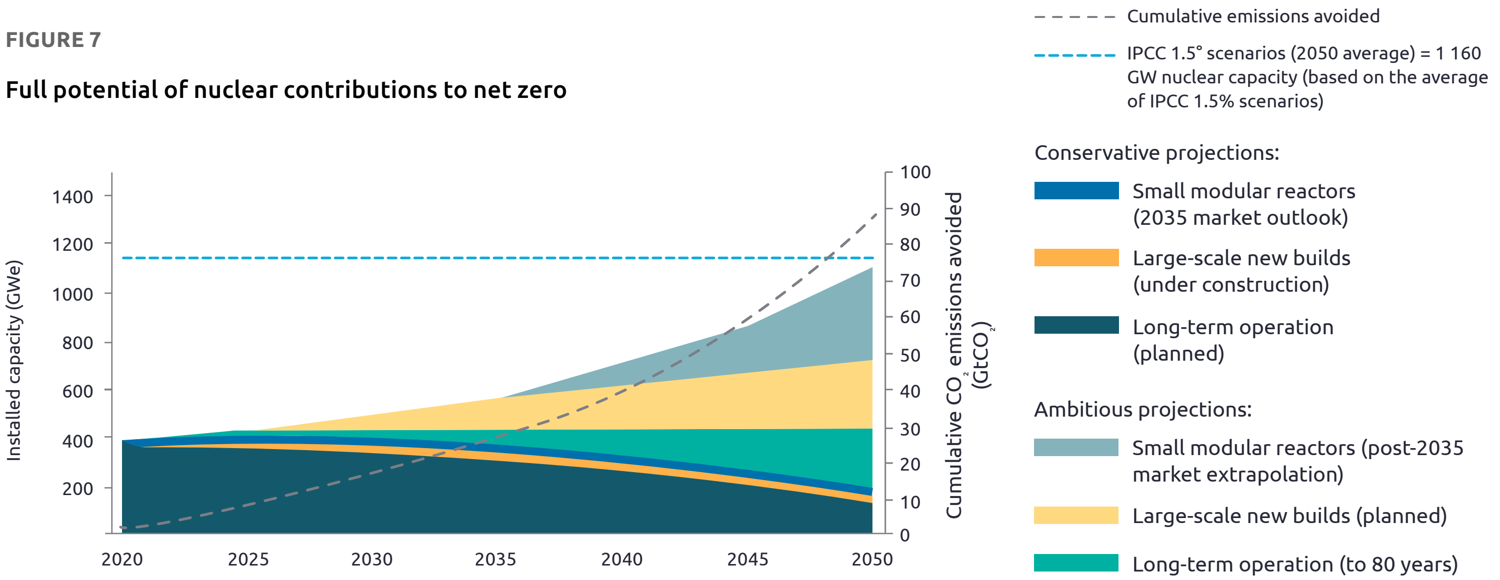
104 https://www.pv-magazine.com/2024/06/06/iea-urges-countries-to-accelerate-renewables-deployment/#:~:text=A%20new%20report%20from%20the,decade%2C%20as%20agreed%20at%20COP28.

In addition to the acceleration conditions set out above, there is a need to solve offshore wind turbines technical problems, resolve the grid balancing problems that arise when the penetration rate of intermittent renewables is high and ensure that sovereignty issues will not disrupt these technologies deployments (see below).

Nuclear electricity: The 90 pathways for the 1.5°C scenario considered by the IPCC require on average *nuclear energy capacity to triple* and to reach 1 160 gigawatts of electricity by 2050.[105]

FIGURE 7

Full potential of nuclear contributions to net zero



105 https://www.oecd-nea.org/jcms/pl_90816/the-nea-small-modular-reactor-dashboard-second-edition

To meet this ambitious target a few things must happen:

- ✓ lifetime extension (up to 80 years) of existing nuclear power plants,
- ✓ large-scale plants new builds acceleration
- ✓ SMRs deployment at scale

Source: https://www.oecd-nea.org/jcms/pl_90816/the-nea-small-modular-reactor-dashboard-second-edition

The main prerequisites for this successful development are:

- ***Delivering nuclear projects on time and on budget.*** Simplify design and do not start the construction phase before the detailed design is approved.
  As mentioned above, this has been a challenge in Europe and in the USA, less so in China, UAEs and probably Russia.
- ***Demonstrate the SMR economic competitiveness***[106] their local acceptance and the strict control of the nuclear materials scattered on multiple sites.
- ***Unlocking access to significant amounts of capital*** at competitive rates.
  Governments that support nuclear expansion should provide access to financing. It is not always the case, for example, in France, the financing of the first 6 EPR construction, forecasted at €6.4 bn, is not yet assured.
  However, the European Investment Bank has included nuclear power financing in its June 21, 2024, document that outlines its investment strategy for the period 2024-2027.[107]
- ***Ensuring a healthy and resilient supply chain***. While the nuclear industry benefits from an international nuclear supply chains built up over 70 years, new nuclear technologies such as SMRs will require changes to use factory production instead of on-site construction.
- Building and maintaining public confidence.
- Ensuring a skilled white collars and blue collars workforce.

Carbon Capture and Storage (CCS[108]) is considered as one of the solutions to decarbonize hard to abate industries (mainly gas and coal fired plants, cement and steel industries). Deploying massively CCS is also key for countries as China that accounted in 2023 for 95% of the world's new coal power construction. It is part of the country critical technologies[109] to reach their objective of peak carbon emissions by 2030.
The USA has been the first region to push CCS development supported by Oil and Gas majors. The federal government has provided financial support for those projects and more recently IRA has significantly boosted annual funding.[110]

- ***Full scale CCS clusters are actively developing.***
  In the USA,15 CCS facilities are currently operating. Together, they have the capacity to capture about 22 million tons of CO_2 per year, or 0.4 percent of the USA's total annual emissions. An additional 121 CCS facilities are under construction or in development.

China has nearly 100 CCS projects in operation or under construction, with over half already operational, according to incomplete statistics. These projects have a combined CO_2 capture capacity of 4 million tonnes and an injection capacity of 2 million tonnes per year.
EU commission is pushing to expand CCS capacity from current projects totalling 4 million tonnes per year[111] to 100 million tonnes per year by 2030. Consistently, European governments are actively introducing regulations to grow the CO_2 storage capacity by a factor of 100 by 2030.
The Northern Lights project in Norway is building the world's first opensource CO_2, transport and storage infrastructure. Once the CO_2 is captured from its source, it will be liquefied and transported by custom designed ships, injected, and permanently stored 2,600 metres below the seabed of the North Sea.

- ***Financing:*** CCS projects are a multibillion capital projects, which under present conditions, have a IRR in a range of a medium to high single digit. In the USA, DOE funding and

106 It is the cost overruns and delays of Nuscale, SMR (the first in in Western) world that led to its construction cancellation https://www.eenews.net/articles/nuscale-cancels-first-of-a-kind-nuclear-project-as-costs-surge/
107 https://www.sfen.org/rgn/bientot-de-largent-public-europeen-pour-financer-le-grand-carenage/

108 https://www2.deloitte.com/fr/fr/pages/explore/climat-developpement-durable/carbon-capture-and-storage.html
109 https://www.carbonbrief.org/china-responsible-for-95-of-new-coal-power-construction-in-2023-report-says/
110 https://www.cbo.gov/publication/59832#:~:text=Status%20of%20Carbon%20Capture%20and,under%20construction%20or%20in%20development

111 Which has taken Final Investment Decisions)

subsidies under the IRA 2 and IIJA 3 (Infrastructure Investment and Jobs Act) are aimed at meeting the potential demand. While the first CCS projects are receiving significant government subsidies, scaling up the next wave will require private investments.
The UK has designed an investable CCS business model by implementing the Regulated Asset Base (RAB) approach on the whole infrastructure. Emitters in the UK, Netherlands and Denmark receive local subsidies to cover the gap between CO_2 capture costs and the EU ETS price.
To enable CCS development, more Contracts for Difference or subsidies should be introduced across Europe to support the emitter business cases.

- ***Cross border CO_2 transport and storage*** (i.e., London Protocol) should be enabled to allow emitters to access ideal storage locations, as well as to promote competition among developers and mitigate storage underutilisation risks through access to a wider pool of emitters.

Sound and predictable regulations:

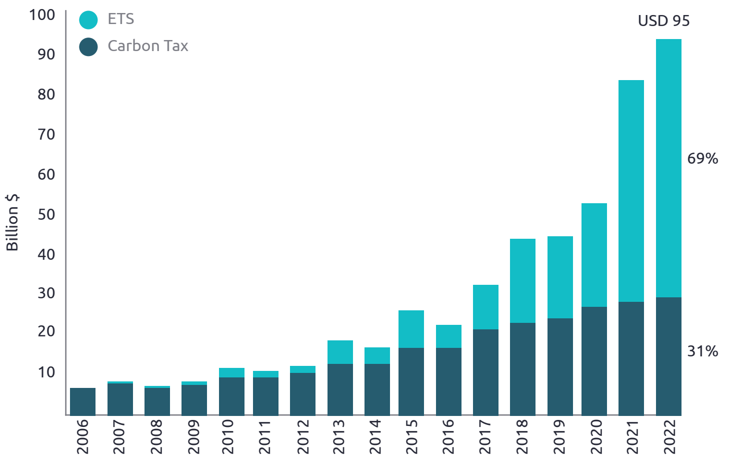
They are important levers to implement energy transition policies. Stable and predictable regulations are key for investors in sustained energy installations to decrease their risks and increase their return on investments.

Before looking into details into some legislations, let's note that too many regulations are slowing down the energy transition. For example, many Western countries have passed laws to remove their numerous regulatory obstacles to the installation of wind farms. The objective is to decrease the permitting duration, by lowering the number of local consultations and their duration while preserving a democratic process.
Also, some regulations have negative secondary effects. For example, in France there are costly regulations on refurbishing flats to increase isolation and decrease their energy consumption. This seems good, however, some flat owners, that cannot afford these refurbishing costs, prefer not to rent their flats thus reducing the offerings for rent in a market that is already tense.

Carbon pricing coverage should be extended, and prices increased:
As stated by IPCC[112] researchers, our planet temperature increase is directly linked to anthropogenic GHG emissions. Carbon taxes aimed at GHG emitters is a virtuous measure. However the range of sector covered needs to be large enough, the prices high enough and the revenues generate need to be invested only in climate transition projects.

FIGURE 8

Evolution of global revenues by type of carbon price: ETS and Carbon tax". Graphs source: World Bank



Source: https://www.ciat.org/wp-content/uploads/2023/08/Grap03.png

In 2024 there were worldwide 75 carbon pricing instruments (Emission Trading Systems-ETSs- or carbon taxes) in operation in 89 jurisdictions covering around 24% of global greenhouse gas emissions.[113] The prices ranged between 0.46 to 167$/t$CO_2$e. These taxes generated $104 billion in government's revenues. However, only 1% of global GHG emissions were covered by a direct carbon price.[114]

112 IPCC: Intergovernmental Panel on Climate Change
113 https://www.homaio.com/post/eu-ets-revenues-what-do-the-member-states-use-the-proceeds-for#:~:text=The%20rules%20on%20EU%20ETS%20revenues%20use,-The%20European%20Law&text=Yet%2C%20most%20countries%20are%20using,for%20climate%20and%20energy%20purposes.
114 In 2017, a report by the High-Level Commission indicated carbon prices need to be in the $50-100 per ton range by 2030 to keep a rise in global temperatures below 2C. Adjusted for inflation those prices would now need to be in a $63-127 per ton , the World Bank report said.

In addition, in some large emitting countries, such as India (the third largest emitter), there is no system in place, and in China (the largest emitting country), the present system is on a voluntary basis.
Set up in 2005, the EU ETS is the world's first international emissions trading system. It covers greenhouse gas emissions from around 10,000 installations in the energy sector and manufacturing industry as well as aircraft operators.
From 2024, it also covers emissions from maritime transport and incineration of municipal waste
In 2022 in Europe, 90% of the auctioning revenues(€30bn) were redistributed to member states. The remaining 10% of the proceeds go to the innovation fund and the modernisation fund. Member state spent only an average of 76% of these revenues for climate and energy purposes in a vast range of programs.[115]
As part of the 2023 revisions of the ETS Directive, a new emissions trading system named ETS2 was created.[116] It will cover new sectors mainly from fuel combustion in buildings, road transport and additional sectors and become fully operational in 2027. Although it will be a 'cap and trade' system like the existing EU ETS, it will cover upstream emissions. The ETS2 cap will be set to bring emissions down by 42% by 2030 compared to 2005 levels.

EU ETS prices have been decreasing from a maximum of €100/t to €70/t (in August 2024).
On October 1st, 2023, the Carbon Border Adjustment Mechanism (CBAM) a tool to fight carbon leakage[117] entered into application in the EU for a transitional phase until 2026. In this phase, CBAM will only apply to a limited number of goods imports: cement, iron and steel, aluminium, fertilisers, electricity and hydrogen. EU importers of those goods will have to report on the volume of their imports and the greenhouse gas (GHG) emissions embedded during their production, but without paying any financial adjustment. As of 2026, importers will need to buy and surrender the number of "CBAM certificates" corresponding to the GHGs embedded in imported CBAM goods.
It is much too early to assess the effectiveness of this very complex innovative tool.

As a conclusion, carbon emissions rights allocations systems associated with emissions trading systems are a good way to incentivize Companies to invest in decarbonization projects. However, they should have a much larger coverage both on sectors and geographies and the emission prices should be higher.

A limitation on these high prices is that, at the end of the day, industrial companies will pass their extra costs to their end customer by increasing the price of their goods endangering customers and citizens acceptance of the energy transition.

115 https://www.homaio.com/post/eu-ets-revenues-what-do-the-member-states-use-the-proceeds-for#:~:text=The%20rules%20on%20EU%20ETS%20revenues%20use,-The%20European%20Law&text=Yet%2C%20most%20countries%20are%20using,for%20climate%20and%20energy%20purposes.
116 https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/scope-eu-emissions-trading-system_en

117 The phenomenon where industries relocate their operations to regions with less stringent emissions regulations, potentially increasing global emissions.

Circular economy is essential:

Currently, only 7.2% of used materials are cycled back into the economies after use. This has a significant burden on the environment. If current trends were to continue, we would need three planets by 2050!

A circular economy is essential for fighting climate change.[118]

Countries and regions (USA, EU, Australia...) have or are adopting laws to implement such a circular economy.

Circular economy allows to reduce material use, redesign materials and products to be less resource intensive, and recapture "waste" as a resource to manufacture new materials or equipment's. Moreover, by extracting critical metals (from used products) and reusing them, countries increase their sovereignty.

Examples can be given for the energy sector:

- The EU Digital Product Passport (DPP) is designed to provide a digital record of products throughout their lifecycle. In 2026, batteries, that use a lot of critical metals, will be the first product category to be legally required to comply with DPP.
- By reusing metals from recycles batteries, security of supply is enhanced as dependence on mining countries and other suppliers is decreased. It's why Europe will require new batteries to contain at least 6% recycled lithium and nickel by 2031, and the state of New Jersey made it illegal to discard EV batteries in landfills.
- Battery recycling plants are being built near batteries Gigafactories in China but also in Europe, for example in Dunkirk in France.
- Extending solar panels lifetime beyond 20-30 years by appropriate maintenance or selling used solar panels on secondary markets.
- If safety allows, extending nuclear plants lifetime to 80 years or beyond.
- PV solar panels recycling to recover raw materials. According to the International Energy Agency, 70% of the photovoltaic sector's silver needs could be covered by recycling, the coverage rate being 20% for silicon and copper.
- Recycling the carbon fibre contained in windmill blades and reusing it in other equipment's.

There are many challenges in implementing a circular economy, among them: the redesign of products and processes, the availability of recycling and repairing infrastructures and the consumer behaviours. This in-depth transformation of our economies will take a long time, but it has started.

More public and private financing

Global investment in the energy transition hit a new record of $1.8 trillion in 2023, up 17% on the previous year.[119] These clean energy investments come in addition to $1.05 trillion investments in fossil fuel[120] as a dual economy (renewables and fossil fuels generation) will remain for at least a decade. This creates a financial burden on citizens.

According to different institutions (World Bank, IEA) around $3.5 trillion a year of capital investment will be needed on average between now and 2050 to build a net-zero global economy.[121] This is equivalent to around 1.3% of the average annual global GDP over the next 30 years.

118 https://climatepromise.undp.org/news-and-stories/what-is-circular-economy-and-how-it-helps-fight-climate-change
119 https://about.bnef.com/blog/global-clean-energy-investment-jumps-17-hits-1-8-trillion-in-2023-according-to-bloombergnef-report/
120 https://www.iea.org/reports/world-energy-investment-2023/overview-and-key-findings
121 https://www.energy-transitions.org/keeping-1-5c-alive/financing-the-transition/

In developed economies there is still a gap in financing the energy transition.
In the USA and EU new laws have been passed to reduce this gap.

- In the USA, the Inflation Reduction Act (IRA) aiming at combatting climate change through a series of tax incentives, grants, and loans for clean energy was passed in August 2022, channelling nearly $400 billion in federal funding into clean energy. Since then, around 300 major clean energy projects have been announced creating around 103,900 new jobs. They amount to nearly $121 billion in capital investment. However, according to an August 2024 report,[122] nearly 40% of major manufacturing projects are delayed. The uncertainty of policies during the election year coupled with deteriorating market conditions and slowing demand have led the manufacturing companies to alter their plans.

- In 2023, the EU climate investments grew by 9% in 2022, reaching €407 billion.[123] However, to meet the Green Deal objectives, the Region faces an additional €620 billion clean investment gap each year until 2030.[124] It is to be seen if the net zero Industrial Act adopted early 2024, will be as effective as IRA to attract private financing.

However, the present tense geopolitical situation has pushed many Western countries to increase their military budgets. There are fears that these increases will come at the expense of budgets dedicated to the fight against climate change.

- Two forms of financial flow are required for the energy transition: capital investment, and subsidies.
These flows will come from public (20 to 40%) and private (60 to 80%) funds.
Public financing comes mainly from taxes or from obligations as emission certificates (providing $104bn in 2023). Whatever tax types (directly to citizens or consumers or to companies that pass them to their own customers), it is the citizen/customer who will pay. This burden added to often tight personal income is negatively impacting citizen energy transition acceptance (see below). Hence, most financing will have to come from private financial institution or companies.

Public subsidies enhance the energy transition projects Return on Investments as has been seen for at least a decade, on solar and wind generation projects.

Also, firm date bans, for example on the sales of internal combustion engines (e.g., by 2035 in Europe), create a demand and attracts investments.

In contrast, very volatile electricity (and gas in a lesser way) spot markets don't give a clear signal for investments. In early 2024 the combination of low electricity prices in Europe with a decrease of the emission certificates prices has lowered the appetite for energy and carbon savings projects.
The 2023 EU electricity market reform has finally recognized the need for long term investments in the electricity sector. It aims at giving long term electricity prices signals by encouraging PPAs and accepting "guaranteed sale prices" with systems as CfD or RAB .[125] Even so, it is extremely difficult to attract private funds to finance large projects as nuclear plants.

122 https://www.ft.com/content/afb729b9-9641-42b2-97ca-93974c461c4c
123 https://www.unpri.org/policy/implementing-a-2040-climate-target-for-a-competitive-and-just-european-greendeal/12242.article#:~:text=The%20EU%20faces%20an%20investment,for%20the%20net%20zero%20transition.
124 https://www.i4ce.org/wp-content/uploads/2024/02/European-Climate-Investment-Deficit-report-An-investment-pathway-for-Europe-future_V1.pdf

125 PPA: Power Purchase agreement, CfD: contract for Difference, RAB:

Developing economies: At the COP 28, the growing gap between the needs of developing countries for adaptation efforts and action to mobilize and provide support to protect people from climate extreme has been pointed out. To be specific, that growing gap to fund the climate transition equates to the difference between the $100 billion annually committed by donor countries[126] and the more than $2.4 trillion needed per year.[127]

In addition, some analysts pointed out that rich countries are overstating their contributions to the $100 billion pledge, because a portion of their climate finance flows back home through loan repayments, interest, and work contracts. In addition, around 20% of the loans are at market-rate interest which is not the norm for climate-related and other aid projects, which usually carry low or no interest.[128]

It has also to be verified that receiving countries are using these funds for energy transition projects.

Also, closing coal mines, polluting plants (as coal fired plants) or small coal fuel furnaces will generate an economic cost and job losses.

Subsidies to offset these costs in middle- and low-income countries (excluding China) may therefore be essential and could amount to around $0.3 trillion a year by 2030.

126 in 2022 developed countries provided and mobilised a total of $115.9 billion in climate finance for developing countries, exceeding the annual $100 billion goal for the first time
127 https://blogs.worldbank.org/en/ppps/laser-focused-bridging-climate-finance-gap-cop28#:~:text=To%20be%20specific%2C%20that%20growing,COP28%20President%20Dr.
128 Reuters report May 23, 2024

In conclusion, during the last years, in developed countries, there was noteworthy progress in financing energy transition. However, the needs of developing countries (that will become the larger GHG emitters) are not well addressed and despite donor countries efforts, there is a huge gap between the needs and the financing commitments. Fixing these financial issues is a key success factor for achieving Paris accord climate objectives.

Enhanced companies and citizen's contributions:

Companies: One must salute the efforts of many companies that are committing on a trajectory to reduce carbon emissions by 2030 as it is an important operational step on the 2050 net-zero trajectory. Beyond the personal convictions of their leaders, these commitments are taken by companies under pressure from the rating agencies and proxies and from their employees that want to work for environmental conscious Companies.

Scopes 1,2, 3 are measuring GHG[129] emissions over different perimeters.[130] Most companies are mastering scopes 1 and 2 emissions. It is less the case for scope 3 emissions that are all emissions a firm is responsible for, but which happen outside of its walls. Scope 3 emissions calculation requires wide-scale collaboration along the value chain raising concerns around lack of information, data quality and confidentiality, Generative AI could provide help in those calculations.

129 The GHGs included in the framework are carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulphur hexafluoride (SP6), and nitrogen trifluoride (NF3) They are measured in CO_2 equivalent
130 Scope 1, Scope 2, and Scope 3 is a classification system for greenhouse gas (GHG) emissions a firm is creating through its operations, energy usage, and the wider value chain.

Achieving these GHG emissions reduction targets are more and more often part of the short- and long-term compensation incentives for employees, which increases the probability that they will be met.

There remain two important points of vigilance: the quality and taxonomy of emissions data which are generally not measured but established from public data and the methodology for measuring the reduction achievements where there are too many tools and indexes (e.g. SBTI, Carbon Trust.. start-ups). Agreeing on one common tool would allow comparability between companies from a same sector and between sectors.

Citizen's attitudes: In Western countries, citizens are conscious about the damage that climate change could cause and the need to fight against this change. However, their attitude can change when energy transition measures result in extra spending (for example to buy an electric car instead of the existing internal combustion car) or if they hinder their activity. This was evident in France at the beginning of 2024 when the farmers' demonstrated against Brussels' measures concerning agriculture, particularly the ban on certain pesticides.

In response, the French government has undertaken to plead in Brussels for the modification or removal of these regulations. Another example concerns the ban on the sale of internal combustion vehicles from 2035. Several political parties are committed to pushing back this date.

Understanding global climate phenomena and their issues is complex and there is great confusion. Indeed, the scientific and financial knowledge of our fellow citizens is not sufficient to allow them to form their own opinion and very often scientists are not listened to. Explanations are given by certain institutions or companies, but this is insufficient, and often political statements add to the confusion.

Many product sellers claim that their products are environmentally friendly, which is not verified. On this side we must salute the recent European Commission's proposal for a Directive on Green Claims that aims to prevent companies from misleading consumers with false environmental claims. The proposed directive sets minimum requirements for the substantiation, communication, and verification of explicit environmental claim.

To conclude this paragraph, let's quote the French author Albert Camus ***« Mal nommer les choses c'est ajouter au malheur du monde »*** *which means "Naming things wrongly is adding to the world's misfortune"!*

Albert Camus
French philosopher and author

Be prepared for disruptive technologies deployment after 2040

Nuclear advanced technologies

Fusion is often considered as the energy source of the future because its fuel can be extracted from seawater. It would produce no carbon emissions and only relatively short-lived radioactive waste.

Most government-funded efforts have focused on magnetic confinement machine called tokamaks, such as the international €20bn cost ITER project under construction in France. However, this huge project is undergoing a major setback: in June 2024 it has announced an €5billion extra cost and a 10 year delay.[131] The first plasma is now planned for 2035 and the start of deuterium-tritium operation in 2045!

A more promising technology is based on laser confinement. In December 2022, researchers at Lawrence Livermore Laboratories in the USA have ignited an inertial confinement nuclear fusion reaction that produced a net return on energy.[132]

Many national programs have been announced by governments to catalyse the establishment of this new industry.[133] There has also been an exponential increase in the establishment of private laser fusion companies.

The Chinese government's current five-year plan makes research facilities for fusion projects a priority for the country's science and technology. China could be spending $1.5bn each year on fusion, almost double what the USA government allocate in 2024 for this research.

A lot of developments on laser and photonics technology, deuterium-tritium targets manufacturing, large supply chain for lasers and photonics construction needs to occur before commercial deployment can take place. Nuclear fusion will also require appropriate and comprehensive monitoring by safety authorities.[134] Finally funding is crucial as for example building an ignition-scale machine for a credible ignition experiment by the 2030s will cost around $2.5billion.

It is doubtful that all these challenges will be overcome on a short enough timescale to support the fight against climate change by 2030.

In the meantime, promising **Generation IV nuclear reactors** could be built by 2030-2040.
Let's recall that during World War II, to propel submarines, the American company, Westinghouse developed light water nuclear reactors LWR.[135] This technology was then scaled up and adopted by many European (including Russia) and Asia countries that built PWRs[136] or BWRs[137]. This technology represents most of the Generation II reactors that are operating presently. Following nuclear incidents and a few accidents, increased safety features were included in Generation III reactors as the EPR(Europe), AP1000(USA), VVER 1200(Russia) or Hualong One(China).

Other technologies that were developed in the U.S. DOE, the French CEA National laboratories and the Russian Kurchatov Institute were not (for various reason) deployed at large commercial scale. Presently, these technologies are considered again to build reactors, but unlike previously, the industrial deployment is focused on small modular reactors called AMRs (Advanced Modular Reactors)

It is to prepare for these Generation IV reactors deployment that thirteen countries[138] created in 2001, the Generation IV International Forum (GIF) seeking to develop the research necessary to test the feasibility and performance of fourth generation nuclear reactors. The GIF has selected six reactor technologies[139] for further research and development. These technologies are often those developed since the 80's and 90's in the National Laboratories mentioned above. Their designs include thermal and fast neutrons, closed and open fuel cycles. The reactors range in size from very small to very large.

131 https://www.newscientist.com/article/2437314-is-the-worlds-biggest-fusion-experiment-dead-after-new-delay-to-2035/
132 https://www.photonics.com/Articles/Nuclear_Fusion_Drives_Laser_Development/a68807
133 These include the U.S. IFE S&T Hubs (IFE STAR) and the UK's fusion energy roadmap, and Germany has published its Memorandum on Inertial Fusion Energy.

134 https://www.polytechnique-insights.com/en/columns/energy/nuclear-fusion-the-true-the-false-and-the-uncertain/
135 Using French research done by Frédéric Joliot Curie
136 PWR: Pressurized Water Reactors

138 Argentina, Australia, Brazil, Canada, China, France, Japan, Korea, Russia, South Africa, Switzerland, the United Kingdom and the United States), as well as Euratom.
139 These 6 technologies are: the gas-cooled fast reactor (GFR), the lead-cooled fast reactor (LFR), the molten salt reactor (MSR), the sodium-cooled fast reactor (SFR), the supercritical-water-cooled reactor (SCWR) and the very high-temperature reactor (VHTR).

Depending on their respective degree of technical maturity, the first-Generation IV systems are expected to be deployed commercially around 2030-2040. They have advantages compared to the present LWR. For example, fast neutron and breeder technologies allow in principle, to extract almost all the energy contained in uranium, decreasing fuel requirements by a factor of 100 compared to today. Molten salt reactors don't need water cooling that create rivers heating (especially with potential increasing temperatures) and hence limit the nuclear plants electricity output.

Combined with start-up innovative spirit and new private and public funding these AMRs could fuel a real nuclear renaissance.

In the USA, the ADVANCE[140] Act that passed Senate agreement in June 2024 and that should go shortly to President Joe Biden for signature, is notably aimed at accelerating the licensing and creating new incentives for AMRs.
TerraPower (sponsored by Bill Gates) has developed a 345 MWe sodium-cooled fast reactor with a molten salt-based energy storage system. The construction of the first plant (Natrium) has started in June 2024 in the USA.

140 Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy

Space-Based Solar Power (SBSP)[141]
Sunlight is, on average, more than ten times as intense at the top of the atmosphere as it is at the surface of the Earth. Moreover, at a sufficiently high orbit sunlight would be available on a continuous basis. This would lift fundamental limitations that solar panels have on Earth as they can only generate power during the daytime and much of the sunlight is absorbed by the atmosphere during its journey to the ground.

Space-based solar power would be transformed into electricity via photovoltaic cells in geostationary orbit around Earth. The power would then be transmitted wirelessly in the form of microwaves to dedicated receiver stations on Earth, which convert the energy back into electricity and feed it into the local grid.

Technological advancements have made the concept of SBSP more feasible as the space launches cost has decreased, and the photovoltaics cells performance has improved.
However, there are challenges. A big one is the efficiency of the microwave beam. It spreads out when the wave progresses so that the receiving antenna on the surface must be huge (many square kilometres), which limits where to build them.

141 https://www.esa.int/Enabling_Support/Space_Engineering_Technology/SOLARIS/Space-Based_Solar_Power_overview

Another important challenge is the high initial costs of launching solar panels and other necessary materials into space. Also, building large structures in orbit and maintaining them is complex and expensive.

In early 2023, the European Space Agency launched the SOLARIS program, starting with a technology development and feasibility analysis that aims to enable the Agency to decide, by 2025, whether to continue with a program of large-scale development and use of space-based solar power.

On the opposite, in January 2024, NASA[142] released a report that concluded that generating power from orbit was too expensive, especially compared with solar power made on Earth.[143]

White hydrogen[144], also known as natural hydrogen, is found in the earth's subsurface along tectonic plates, both underwater and on the surface. Deposits have been discovered on every continent and in many countries around the world, but scientists are reluctant to estimate the quantities of natural hydrogen available. It is therefore impossible to say what share white hydrogen could supply in a few years' time.

142 National Aeronautics and Space Administration
143 https://www.scientificamerican.com/article/nasas-hopes-for-space-solar-power-are-looking-dim/
144 https://www.alcimed.com/en/insights/white-hydrogen/

As opposed to oil or natural gas production, continuous production would be possible for white hydrogen thanks to a rapid regeneration time of 10 years. Its production emits very little CO_2 compared with grey hydrogen that is extracted from natural gas.

The projected cost of extracting white hydrogen, €0.5/kg to €1/kg, would be competitive with grey hydrogen cost. In addition, helium is often a co-product of natural hydrogen, and its market price ranges from €30 to €70/kg. This co-product should make natural hydrogen deposits even more profitable.

Only one company is currently exploiting a white hydrogen deposit in Mali.
Industrial groups in the energy sector as well as players in the Oil & Gas industry and numerous start-ups, are present at the early stages of development, mostly by obtaining exploration permits. Australia is very active in this field, with over 35 permits already completed.
If presently, the industrial exploitation of natural hydrogen is not a reality, it could become one around 2030.[145]

Generative AI: Since 2022, generative Artificial Intelligence (ChatGPT, Gemini, Perplexity, Mistral..) has become available to a large public and is raising both hopes and concerns.
While the generative AI technology applies to a much broader scope than the only energy sector, it will have a major impact on it.

145 https://www.rystadenergy.com/news/white-gold-rush-pursuit-natural-hydrogen

This impact has two facets: it helps optimize energy resources and combat climate change, but the current algorithmic choices require computation and data centres consuming a huge amount of energy and water.

- **On the positive side** let's note:

✓ ***Complex modelling ability:*** As AI makes it possible to analyse, correlate, and generate a lot of data, it can improve complex situations modelling.
Electricity consumption modelling is indeed complex. Consumption depends on temperature, season of the year, activity, prices, self-consumption and customer's behaviours that are influenced by economic situations, fears on prices increase or risks on security of supply, among others.
Better forecasting electricity consumption and finer optimization scenarios will help to improve grid balancing.

Another example is processes modelling for example, for electrolyser plants to improve hydrogen production.

✓ *__Strong forecasting ability:__* For example, weather forecasting: Google DeepMind Graph Cast model delivers 10-day weather predictions at unprecedented accuracy in under one minute. This helps to better forecast sun and wind power generation and thus to better balance the grid, with much lower processing power than currently used by weather super calculators.
A second example is provided by the city of Zurich. By integrating AI into the management of its public lighting and thanks to traffic forecasts, it managed to reduce its energy consumption by 70%, by switching lightening on only when it was needed.

✓ *__Energy consumption reduction:__* At Google, reducing energy usage has been a major focus over the past 10 years. It has built its own superefficient servers, invented more efficient ways to cool its data centres and invested heavily in green energy sources.
In five years, it improved by 3.5 times the computing power out of the same amount of energy.
A breakthrough was achieved by applying DeepMind's machine learning to Google data centre. It resulted in lowering the amount of energy used for cooling by up to 40% .[146]

On the negative side:

✓ *__Huge consumptions:__* As AI makes it possible to analyse, correlate, and generate a lot of data, it can improve complex situations modelling.
Chat GPT 3 training would have emitted around 502 tonnes of CO_2, which is the equivalent of what 56 French people emit for a year. Each single query generates, only for computation, around 5g of CO_2.
More generally, Microsoft increased its greenhouse gas emissions by 30% between 2020 and 2023 due to 16 infrastructures for artificial intelligence (which were not always installed near decarbonized electricity sources).

Today data centres consume around 1% of global electricity, or 194 TWh. So far, the increase in the number of calculations has been nearly offset by gains in energy efficiency. As a result, data centre's consumption increased by only 6% between 2010 and 2020.

If AI keeps its current trend, this consumption should grow significantly.
The energy required to run AI tasks is already accelerating with an annual growth rate between 26% and 36%. This means that by 2028, AI could be using more power than the entire country of Iceland used in 2021!

The AI lifecycle impacts the environment in two key stages: the training phase and the inference phase. In the training phase, models learn and develop by digesting vast amounts of data. This training phase is very intensive, and usually performed several times to adjust the meta-parameters of the algorithms. Once trained, they step into the inference phase, where those models are applied to solve real-world problems. The consumption of each request is much smaller (equivalent to a few grams of CO_2), but the number of requests can be massive.
At present, the environmental footprint is split, with training responsible for about 20% and inference taking up the lion's share at 80% for large public systems. As generic AI models gain traction across diverse sectors, the need for inference and its environmental footprint will escalate.

146 https://deepmind.google/discover/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-by-40/

✓ ***How to master this consumption evolution?***

» More parsimonious, eventually targeted use of generative AI is needed as well as the optimization of the type of model used.

» It is already possible to optimize some core elements in the models. With the re-usability of neural network infrastructure choice, and the data centre location (where the energy mix is less carbon-intensive), GHG emissions can be divided between 100 and 1,000 times.

» Improvements can also be made to microprocessors and cooling so that they consume less energy and to algorithms so that they become more efficient and require less data and computing power for training.

» Research is emerging about other actionable steps that can be taken today to align AI progress with sustainability. For example, capping power usage during the training and inference phases of AI models presents a promising avenue for reducing AI energy consumption by 12% to 15%, with a small trade-off on time to finish tasks with GPUs expected to take around 3% longer.

In data centres, the objective is to reduce the PUE (Power Usage Effectiveness) through various technologies (see WEMO 2023[147]) through the development at scale of innovative cooling methods such as immersing servers in an oil bath or direct cooling of the chips themselves. Microsoft Azure and Google Cloud aim to achieve a PUE below 1.125 or 1.120, which means that their energy efficiency will be greater than 89%.

Conclusion: Adaptation measures

From the previous analysis one can conclude that the world is not on the right trajectory to meet the Paris agreement objectives. Besides mitigation measures that were outlined above, politicians, public services and Companies must also demonstrate realism by launching adaptation measures to combat the negative effects of climate change which will be inevitable (see WEMO 2023[148]).

147 https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/

148 https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/

In the current geopolitical context, energy sovereignty is a major concern

In recent years, various events have changed the Western countries energy doctrine and led them to strengthen their energy sovereignty.

In 2020-2021, the health crisis linked to Covid 19, and the resulting lockdowns, slowed down global trade. This has led to a desire to develop national production to shorten supply chains.

In 2022, **Russia's** unjustified invasion of Ukraine, highlighted Europe's dependence to Russian gas (especially certain countries like Germany). Russia has gradually reduced and almost stopped its gas supplies via pipelines to Europe.

To deal with this crisis, European countries have encouraged their citizens to reduce their energy consumption[149]; they have diversified the origin of their gas supplies and accentuated the transition to renewable energies.[150]

As a measure of retaliation, the Europeans and Americans have launched embargoes against Russia, particularly on coal, oil (see above) and more recently the American embargo on Russian enriched uranium.

149 Fear of electricity or gas cuts and high prices have led to drops in consumption of around 10%
150 WEMO 2023 https://www.capgemini.com/insights/research-library/world-energy-markets-observatory/
151 https://www.sfen.org/rgn/uranium-enrichi-orano-valide-le-projet-dextension-de-georges-besse-2/

In May 2024, the USA President Joe Biden signed a ban on Russian enriched uranium even though the country imports around 20% of its needs from Russia. The law unlocks about $2.7 billion in funding to build out the USA uranium fuel industry. The European Company, Urenco has already decided to increase its New Mexico plant capacity by 15% from 2025 and the French Orano is looking at building an enrichment plant in the USA. In Europe, missing Russian supplies will be met thanks to the extensions of Urenco enrichment plant in the Netherlands (by 15% from 2027) and Orano plant in France[151] (by 30 % from 2028).

Natural uranium and SWU[152,153], prices have increased.[154] However, this price increase has little impact on the final cost of nuclear electricity because the enriched uranium cost represents only 5 %[155] of the total nuclear electricity generation cost.

China: during his term, President Trump launched an economic war against China to try to curb its economic dominance notably in the clean technologies.

Indeed, China has become by far the world's largest producer of hydroelectric, wind and solar power thanks to its massive deployment of renewable capacities (see above).

152 Separative Work Unit (SWU) is a unit that defines the effort required in the uranium enrichment process
153 In 2023, the average price paid by the Civilian Owners/Operators was $106.97 per SWU up 6% from 2022. https://www.eia.gov/uranium/marketing
154 https://www.eia.gov/uranium/marketing/
155 https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull59-2/5920405_corr.pdf

- ✓ China accounted for more than half of all new renewable capacity installed last year.
- ✓ It is building the biggest number of large nuclear reactors[156], it has already one SMR in operation and is building both SMRs and AMRs,[157,158]
- ✓ in 2023, it has installed half of the world's electrolysers to produce hydrogen,
- ✓ It is for a few years already the largest batteries and EV manufacturer.
- ✓ More recently it has launched plans to install CCS facilities which are badly needed as the country is burning increasing volumes of coal and gas.

156 China is on pace to add as many as 10 reactors a year and may surpass the United States' total nuclear capacity by 2030.
157 https://www.ans.org/news/article-5861/chinas-new-linglong-one-reactor-just-one-piece-of-nuclear-expansion/
158 https://www.reuters.com/world/china/china-starts-up-worlds-first-fourth-generation-nuclear-reactor-2023-12-06/

By mid-2024, China's energy administration has declared that it will meet its 2030 renewable energy targets by the end of 2024.[159]

With such industrial development and exportation capacities, China is increasing year after year its dominance on the energy sector. Let's analyse this in more detail.

On the equipment side, for example, China has a PV Solar panels production capacity much larger than its own needs. It produces around 80 to 90% of key elements of the PV solar global chain as wafers and cells. For 2024 analysts expect China to add 500-600 GW of PV module production capacity, while it should install around 260 GW of new capacity.[160] This will result in a significant overcapacity that will be sold notably in Europe (as the USA supply only 1% of their imports directly from China[161])[162] threatening the existing domestic manufacturers.[163]

Tariffs and embargos: since a few years, to protect their domestic industry, Western countries (especially the USA) have voted tariffs on Chinese equipment.

In 2024, the USA tariff rate on solar cells increased from 25% to 50%. This tariff increase aims to counter China manufacturers to sell in the USA solar cells at discounted prices inhibiting the development of domestic solar cell capacity.
A recent illustration of USA manufacturers difficulties is SunPower, that in August 2024 filed for chapter 11 bankruptcy and is winding down its operations[164]
Moreover, the USA administration has raised import tariffs on battery cells from China used in electric vehicles and energy storage systems. In 2024, tariffs for electric vehicle battery cells will increase to 25%, with energy storage tariffs increases following in 2026.

On June 12, 2024, following an anti-subsidy investigation, the European Commission disclosed that it would provisionally impose import tariffs ranging from 27.4% to 48.1% on electric vehicles (EVs) from China. This comes a month after the USA announced that their own tariffs on Chinese EVs would rise to an unprecedented 102.5 %. In August 2024 Canada followed by imposing 100% tariffs on China-made electric cars.[165]

However, these measures will have a limited effect:

- ✓ Solar cells: the direct USA import of solar cells from China is less than 1% and Chinese solar panel enter the USA market though other countries supplies (notably through India).
- ✓ For energy storage, while a tariff increases to 25% for cells is notable, it may have its impact softened by expected price reductions. In the 2023 summer, battery cell prices in China ranged from $120/kWh to $130/kWh but were expected to drop to $40/kWh or less in 2024 summer. A 25% tariff on a battery price around $40/kWh, results in an increase of just $10/kWh. This increase remains modest compared to the overall price reduction of around $80/kWh.

The question is whether to fight against the massive arrival of Chinese clean equipment's (which contributes to the energy transition cost decrease) or try to find alliances.

159 China On Track To Meet 2030 Renewable Energy Targets By The End Of 2024
A new report from the China Renewable Energy Engineering Institute (CREEI) research body has stated that the country is likely to meet its 2030 renewable energy targets, an impressive 6 years ahead of target. This is for the most part due to incredibly quick growth in the solar and wind sectors which was apparent in 2023 and continues throughout 2024.
By the end of 2024, China is expected to add 260GW of renewable energy capacity, after previously adding just over 300GW in 2023. This meant that last year, China provided 60% of all global renewable energy
160 It installed 300GW in 2023
161 https://www.japantimes.co.jp/business/2024/02/06/companies/us-solar-indian-china/
162 https://ember-climate.org/insights/research/china-spare-solar-climate-energy-opportunity/#supporting-material
163 https://climateinsider.com/2024/03/15/unpacking-chinas-solar-panel-overproduction-a-global-perspective/

164 https://www.reuters.com/legal/us-bankruptcy-court-approves-stalking-horse-bid-sunpower-assets-2024-08-29/

165 https://www.reuters.com/business/autos-transportation/trudeau-says-canada-impose-100-tariff-chinese-evs-2024-08-26/

Regulations to promote domestic production

The USA[166], Canada[167], Japan[168] and Europe[169] have passed laws to encourage domestic critical equipment production. This is very positive for the region's industrial development as these laws create a large market for investors (domestic or non-domestic). One drawback is that the higher labour costs and more stringent regulations than in China, lead to higher prices. To combat this, it is urgent that Western regions boost their R&D and innovation incentives to create new and cheaper solutions and processes. We have analysed above the benefits of the IRA.

The EU Net Zero Industrial Act (NZIA) stipulates that by 2030, 40% of clean tech products must be supplied in Europe. In this framework the European Commission has launched the Holosolis project. The factory located in Sarreguemines in France, is expected to produce 10 million solar panels annually—enough for around one million households—and generate over 2000 jobs by 2028 with an investment of €850 million. However, at least at the beginning, the silicon ingots will be imported from China.

Unlike in the USA, where the IRA offers generous subsidies, the EU's Green Deal Industrial Plan provides little new finance, and its implementation is much slower than IRA's. For example, the European Green Deal was launched in 2020, and in 2024, 60% of the money has still not been spent while the IRA planned spending envelope has been totally paid out two years after it was voted.

Rare earths, graphite and rare metals:

Western countries realized that to implement their energy transition they were not only dependent on Chinese clean tech equipment but also on certain raw materials: (as rare metals and rare earths) and graphite (for battery anodes)[170].

Driven by a desire for independence (or at least less dependence) on these strategic materials, manufacturers have evolved their technologies to use less of them. For example, by developing battery cells without cobalt and with less manganese and nickel.

Also, the regulations that have been adopted on the circular economy will oblige battery manufacturers to use recycled metals, thereby reducing the need to extract these metals (see chapter on the circular economy).

166 IRA: Inflation Reduction Act passed in 2022
167 https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/clean-electricity-regulation.html
168 https://www.enecho.meti.go.jp/en/category/special/article/detail_178.html
169 NZIA: Net Zero Industry Act voted in 2024

170 https://chinaobservers.eu/de-risking-rare-earths-the-greenland-stalemate-and-the-critical-raw-materials-act/

As for clean tech equipment, Western countries have adopted specific legislations on these raw materials:

- ✓ In 2021, the USA American Critical Mineral Independence Act[171] was adopted to provide support for a domestic supply of critical minerals.
- ✓ The EU has adopted in Q1 2024 its new Critical Raw Materials Act (CRMA)[172], and has been seeking to develop mining projects within EU borders. Various economically exploitable deposits have been found. For example, the mining company LKAB announced that it found a deposit of over 1 million tons of rare earths in Northern Sweden[173]. At the beginning of June 2024, Rare Earths Norway Group announced that their Fensfelter[174] deposit in south-east Norway should contains 8.8 million tonnes of rare earths[175] and that mining could begin in 2030. Investment in the project is estimated at €900 million. Other areas in Southern Europe, such as the Balkans, may also contain considerable resources, but remain largely underexplored at present.

Rare Earths Elements (REE176): Contrary to what their name suggests, they are abundant in the earth's crust, but they are found in low concentrations and are hard to separate from other elements, which is what makes them "rare."

They are used in various high-tech applications including, smartphones, wind turbines, electrical motors, hard disk drives, LEDs, and more. They are key for the energy transition as an electric car requires six times the mineral inputs of a conventional car, and a wind plant requires nine times more minerals than a gas-fired plant. REEs market is forecasted to grow from 2024 to 2031, with a projected CAGR between 10% and 13% and could increase six-fold by 2040.

China entered the (REE) market in the 1980s and the Western countries were initially happy to let it takeover these material extraction and refining activities as they release toxic chemicals and radioactive wastes.

They paid little attention to China's increasingly significant lead. Yet, China's dominance over the sector gave it a significant political leverage. In September 2010, after a spike in tensions between China and Japan related to a territorial dispute, China appeared to place an unofficial embargo on rare earth exports to Japan.

In 2024, China's, accounts for one-third of known worldwide rare earth reserves, 60% percent of mined production and 85% percent of processing capacity.

Graphite is used for batterie's anodes. The need for graphite will increase by 25 times due to electric vehicle (EV) manufacturing growth alone.

In 2023, the USA imported 100% of its natural graphite of which 42% from China. The EU has a similar dependence. Western dependency was exploited in 2023 when China imposed graphite export restrictions in retaliation for USA limits on semiconductors sales.

171 https://www.congress.gov/bill/117th-congress/house-bill/2637
172 https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en
173 https://lkab.com/en/press-eu23/#:~:text=LKAB%20has%20identified%20significant%20deposits,electric%20vehicles%20and%20wind%20turbines.
174 https://www.ngu.no/nyheter/fensfeltet-satt-pa-europa-kartet-storste-forekomst-av-sjeldne-jordarter
175 Rare Earths are a family of 17 metals with special electromagnetic properties that make them indispensable to the energy transition).

176 REE describe the 15 lanthanides on the periodic table (La-Lu), plus Scandium (Sc) and Yttrium (Y).

IRA law prohibits manufacturers from sourcing battery components and critical minerals from Foreign Entities of Concern (FEOC) starting in 2024 and 2025, respectively. FEOCs include China, Russia, Iran and North Korea. However, the final rules, released May 2024, would delay the restrictions on graphite and some critical minerals until 2027.

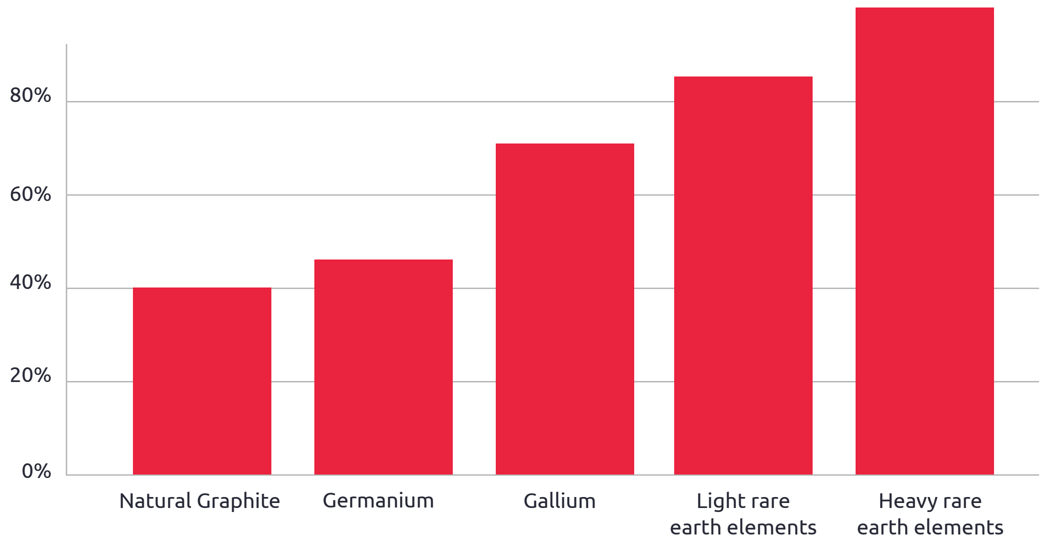
In this context, China, Europe and USA companies are eying *Greenland* which is thought to have the second-largest reserves of REE, surpassing Vietnam, Brazil, and Russia.[177] Greenland has also large graphite deposits: it's 6 Mt of known graphite resources could exceed the projected EV graphite demand for 2040 (3.5 Mt) and counter Chinese mineral supremacy. Greenland has also large Oil and Gas reserves. This is probably why, in 2019, USA President Donald Trump discussed the idea of purchasing Greenland!

However, mining Greenland resources would be complex for various reasons such as remoteness, harsh climate, lack of infrastructure and limited workforce but also for political reasons. Indeed, in 2021, a ban on Uranium extraction[178] was decided which also challenges REE extraction, as uranium is commonly combined with REE in deposits.

Reducing the significant dependency on rare earths for Western countries would still require partnerships with third countries. Additionally, the USA and the EU are substantial importers of key components and finished products that use rare earths, especially green technologies that China dominates (see above).

FIGURE 9

EU reliance on select Chinese material imports



Source: European Council, May 2024

177 https://ip-quarterly.com/en/dont-buy-greenland-buy-its-minerals#:~:text=Mining%20Politics%20in%20Greenland&text=The%20ban%20was%20instated%20following,is%20commonly%20found%20alongside%20deposits.
178 https://ip-quarterly.com/en/dont-buy-greenland-buy-its-minerals#:~:text=Mining%20Politics%20in%20Greenland&text=The%20ban%20was%20instated%

Lithium and critical metals:
Critical metals notably, nickel, cobalt, lithium and copper are central to the production of EVs, batteries, wind turbines, photovoltaic panels and electrical grids.

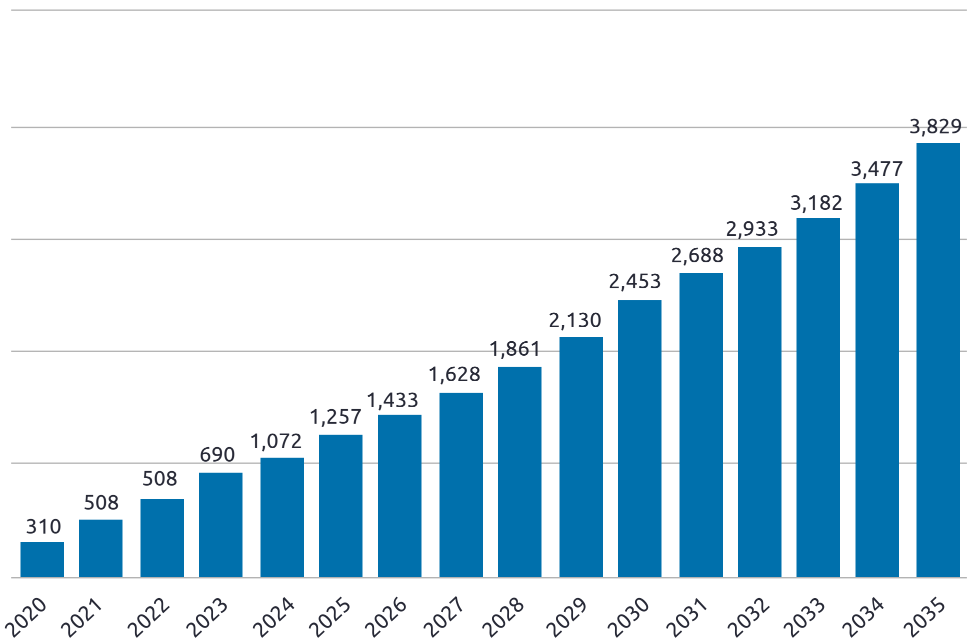
Increasing their control on these metals production is part of the USA and EU legislations analyzed above. In addition to legislation and public funding, private financing is mobilised. For example, in 2023, the French government launched the first European Union's private critical metals fund. InfraVia was selected to manage this €2 billion fund, which will be supported by French government and European manufacturers in the automobile, renewable energy and aeronautics sectors, as well as by financial investor.[179]

Lithium is used for batteries (see above). Its demand growth is forecasted to follow EVs growth, from around 1 070 million tons of lithium carbonate equivalent in 2024 to 3 800 million tons in 2035.

Despite holding less than 7% of the world's lithium reserves, China has managed to secure an 80% share of global refined lithium production.

FIGURE 10

Lithium worldwide demand



Source: Statista 2024

179 https://home.cib.natixis.com/articles/securing-critical-metal-supplies#:~:text=The%20critical%20metals%20fund%20%E2%80%93%20a,metal%20than%20we%20do%20currently.

Western companies are reacting on this dominance

- Mid-2024, the French Company, Eramet inaugurated its plant in Argentina where it invested $870 million[180]. The objective is to produce 24 000 tons of Lithium Carbonate Equivalent (LCE) in 2025 (around 2% of 2024 demand) increasing to 80 000 tons in the future.
- Chile has the world's largest lithium reserves and is the second largest producer after Australia. The Chilean government's plan, adopted in 2024, should increase lithium production by 70% by 2030. At the beginning of June 2024, Chile's Codelco and SQM[181] signed an agreement to join forces to exploit the lithium in the Atacama Desert in the North of the country. The aim is to achieve a total additional production of 300 000 tons of LCE in 2025-2030, This increase in lithium production will be achieved through improvements in process efficiency, the adoption of new technologies and the optimization of operations.
- Despite falling lithium prices[182] new players are entering this market: geothermal companies as Arvern Group[183] and large Companies as Exxon-Mobil. In 2023, the latter announced that it aims at becoming a leading producer of lithium, and work has begun for lithium production in southwest Arkansas. It should start producing lithium in 2027, and by 2030 it would be able to supply batteries for 1 million EVs per year.[184] The off taker would be "SK on" the South Korean battery manufacturer.

Conclusion

While increasing sovereignty on critical equipment and raw materials is important for the energy transition success, the interconnections between countries are strong and complex. It will thus be difficult to cut links with countries such as China.

Also, embargos are very often circumvented. For example, the "energy hub in Turkey" project is nothing more than an attempt to launder Russian gas supplies by mixing them with gas from other producers like Azerbaijan and Iran.

Moreover, these sovereignty policies will lead to cost and prices increases that must be accepted by taxpayers and citizens.

Finally let's not forget the saying "a bad agreement is better than a good economic war".

Given the current geopolitical tensions, it is probably not the right time to implement these cooperative solutions. Let's hope that cooperation will be possible in a more peaceful future world.

180 https://www.eramet.com/en/news/2024/07/eramet-inaugurates-its-direct-lithium-extraction-plant-in-argentina-becoming-the-first-european-company-to-produce-battery-grade-lithium-carbonate-at-industrial-scale/
181 https://www.codelco.com/prontus_codelco/site/docs/20160401/20160401130745/310531_comunicado_acuerdo_codelco_sqm_en.pdf
182 From a peak of $81000/ton in November 2022 to $14000/ton in June 2024
183 Lithium is found in deep geothermal brines.
184 https://www.reuters.com/markets/commodities/exxon-aims-make-key-lithium-technology-decision-by-year-end-2024-02-15/

General conclusion

In 2023 and 2024, geopolitical tensions increased with the continuation of the war between Russia and Ukraine following the unjustified invasion of Ukraine and tensions in the Middle East following the Hamas massacre of Israeli civilians on October 7, 2023. These tensions have led many countries to increase their military budgets They have also resulted in a global economic slowdown.

Despite these tensions, commodity and **energy prices have not generally risen.** On the contrary, spot electricity and gas prices fell significantly in early 2024 in Europe, while demand remained stagnant. The price of certain strategic metals such as lithium has dropped by a factor of 2.5.

2023 was a record year for the installation of new renewable production capacity.

Year on year, these new capacities increased by 14% with a larger capacity expansion of solar (32%) than wind (13%). Solar PV alone accounted for three-quarters of renewable capacity additions worldwide. China commissioned as much solar PV as the entire world did in 2022, while its wind additions also grew by 66% year-on-year.

There has been a revival in nuclear power, with a burgeoning number of large and small reactors potential projects, finally recognising the fact that nuclear power does not emit greenhouse gases.

However, at the same time, fossil fuels consumption rose by 1.5% in 2023, driven by growth in developing countries and China.

Consequently, when compared with the previous year, energy-related **greenhouse gas emissions rose by 1% in 2023.**

Renewables intermittent sources of energy increase poses a problem on grid balancing. Thus, there is a need to increase sensors deployment on the grid and in customer premises, storage capacity, low emission dispatchable generation as nuclear or pumped Hydro Storage, and cover heating demands with more storable green heat produced with biomass or geothermal energy.

Intermittent renewables penetration rate in electricity generation lead to more frequent episodes of negative prices, which in turn is hampering the future profitability of new renewable or nuclear power generation capacity, which have a high CAPEX component.

If there is too much renewables generation, grid operators curtail the surplus. Using this free electricity to produce green hydrogen (by water electrolysis) would help to bring down its cost. However, these electricity input variations are causing problems to electrolysers functioning and are accelerating their ageing.

The massive production of green hydrogen is encountering problems as its cost is much higher than grey hydrogen's, the availability of additional quantities of renewable energy and nuclear power is limited, and the long-distance transport of hydrogen remains complex. In this situation a large enough green hydrogen market is not foreseen. One can therefore assume that the **European political promises of a very rapid increase in volumes of green hydrogen will not materialise within the timeframes announced.**

The world is not on track to meet the Paris Agreement's target of a 1.5% increase in global temperature by the end of the century, with the current trajectories leading to an increase of more than 3°C.
To get closer to these targets, **existing technologies** (intermittent renewables, hydroelectricity, green heat, nuclear including SMRs.) **would have to be deployed at scale by 2030**. This deployment requires favourable legislation, public and private funding, which is currently lacking (especially in developing countries).

Public acceptance is increasingly difficult to get because of the energy transition related price rises caused by the cohabitation of two subsidized energy systems: fossil fuels and renewables. By 2040, some technologies may be promising, such as Advanced Modular Reactors, White Hydrogen or Space-Based Solar Power, but they have yet to prove their industrial and economic viability. Despite progress in laser fusion, it is very likely that nuclear fusion will not produce significant amounts of electricity before 2050.

While **Generative Artificial Intelligence** is not specific to the energy sector, it will have a major impact on it: it helps to combat climate change, but the associated data centres will consume a huge amount of energy and water. Besides construction of massive renewable or nuclear production plants, measures should be taken to limit this consumption increase.
In conclusion, **in addition to mitigation measures to limit GHG emissions, adaptation measures fast implementation is needed** to increase energy infrastructures (and other

infrastructures) robustness to exceptional events and rethink their operating conditions.

China has continued to increase its dominance in clean technologies and strategic raw materials. Western countries have responded by imposing **sovereignty measures** and passing laws to create domestic markets for local production of the needed equipments and favourable conditions for local extraction of strategic minerals.

It is good that sovereignty is finally being considered in public policy. But let's not have illusions about the effectiveness of customs barriers and embargoes.

Peaceful agreements between countries are the best way of achieving the objectives of the energy transition, especially as pollution is global. However, the present geopolitical tensions should ease to make this possible.

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Colette Lewiner

Paris, September 16th, 2024

About Capgemini

Capgemini is a global business and technology transformation partner, helping organizations to accelerate their dual transition to a digital and sustainable world, while creating tangible impact for enterprises and society. It is a responsible and diverse group of 340,000 team members in more than 50 countries. With its strong over 55-year heritage, Capgemini is trusted by its clients to unlock the value of technology to address the entire breadth of their business needs. It delivers end-to-end services and solutions leveraging strengths from strategy and design to engineering, all fueled by its market leading capabilities in AI, cloud and data, combined with its deep industry expertise and partner ecosystem. The Group reported 2023 global revenues of €22.5 billion.

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