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EASA Expert Group - Environment, Climate, and Energy - Toward Clean Energy production

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1.1 RECOMMENDATIONS – BACKGROUND AND ACTION

1. The Conference of Parties (COP) 26 saw the participation of 90% of the world countries, including Brazil, which declared its commitment to reduce its emissions by 50%.
2. Looking at energy production, for the transition to be possible by the middle of the century, there is a need to develop technologies that are not yet fully available. It is time to work.
3. Firstly we have to go over our use of resources and energy with the aim to save those by better efficiency, reuse, repairing and modesty behavior.
4. Renewable energies will have to be implemented as far as possible without forgetting that each source, in order to be considered the main one, needs to present itself as safe, abundant, and reliable.
5. At the same time, hydroelectricity will find a great development in the coming years, especially thanks to the investments that China is dedicating to this form of energy production, defined by many as the only renewable energy capable of providing continuous and uninterrupted power.
6. The development of technologies in favor of Biofuels, Biomass or techniques such as Waste to Fuel will be equally important. Currently, it is mainly used to produce compost for agriculture and, to a lesser extent, biogas. An increasingly important sector, but with a rising cost for the community.
7. Hydrogen, especially green, will be a vector that could play an important role in the years to come, although it is still difficult to define its contours well due to the technological developments it needs to reduce costs.

8. The energy transition can be the right opportunity to overcome the ideological obstacles linked to the only energy with zero emissions that can act as a baseload for the electricity system: nuclear energy.
9. Nuclear power has a considerable advantage: it is able to supply large quantities of energy in a constant (24 hours a day) and controllable way. The same can also be done by hydroelectric and geothermal plants, which however require specific territorial characteristics that not all countries have.
10. Most of the technologies that today provide baseload are fossil fuel power plants that will have to be gradually replaced to achieve the emission reduction target. It would be natural to think that renewable sources such as wind and solar can be good substitutes.
11. Betting everything on fossil fuel power plants, however, would entail considerable technical difficulties: since they are variable and scarcely predictable sources (the wind does not always blow, the sun is not there at night and sometimes the sky is cloudy), they should be accompanied by numerous storage systems for the energy and / or complementary technologies capable of compensating for a possible drop in production, quickly and without producing CO2.
12. An energy system with a high amount of variable renewable energy would considerably increase energy costs for individual citizens and industries. Additionally, global development towards sustainability and resilient landscapes is needed to tackle the negative effect of the Anthropozene. For that we need financial margins. If the goal is to reduce emissions, where large amounts of hydroelectric and geothermal energy are not available, nuclear is therefore one of the most efficient solutions to replace fossil fuel power plants in the production of energy suitable for baseload.
13. Last not least also renewable energy causes additional costs – more intensive agriculture including water-use, intensive use of natural Rivers by hydro-power- plants, changes in the landscape – which may concern other high values and aims of holistic sustainable approach.
14. Nuclear energy can at least fill the time – gap of development of a mainly renewable - resource based energy concept. It guarantees the stability of the electricity grids that other renewable sources are unlikely to be able to offer, and also makes it possible to reduce the dependence of a given country on the energy imports necessary to meet its energy needs (e.g. imports of electricity from neighboring countries, fossil fuels from third countries, etc.).
15. Nuclear energy sources comprise fusion and fission technologies. In the frame of fission technologies, attention is paid at Small Modular Reactors good for energy production for local / private needs integrating Generation III+ and IV with passive shutdown mechanism up to subcritical reactors at Thorium coupling a Fission Subcritical Reactor with Cyclotron working also as waste transmuter.
16. Achieving climate goals would theoretically be possible even without further investment in nuclear energy. However, excluding this energy source from the energy mix would require a much larger mobilization of resources. If between now and 2040 it were decided to stop any investment in nuclear power, it would be necessary to compensate for the lack of electricity production with a quantity of wind and solar energy equal to five times the total installed capacity in the last 20 years globally. This is the main reason why European Union cannot miss the opportunity to introduce the Nuclear Energy into the Taxonomy.

1.2 BACKGROUND

"We must pursue the objectives of the energy transition. But we must also know that the technologies, necessary to achieve this, are not available yet"
Bill Gates, "How to avoid a climate disaster" (2021)

Combating climate change is a pressing issue. It urges the EU to scale up its efforts to demonstrate global leadership by making all sectors of the economy climate-neutral. As outlined in the 'A Clean Planet for All – A European strategic long-term vision for a prosperous, modern, competitive, and climate-neutral economy' Communication and confirmed by the 'European Green Deal' Communication, this necessitates compensating not only any remaining CO2 but also any other remaining greenhouse gas emissions. Several

European Green Deal initiatives have been implemented to supplement the existing policy framework, and others are in the works. The Regulation (EU) 2020/852 (the 'Taxonomy Regulation') on the establishment of a framework to facilitate sustainable investment, which provides appropriate definitions to companies and investors on which economic activities can be considered environmentally sustainable, is one of the initiatives that has been adopted.

This paper seeks to depict the predicted demand and supply of all energy sources, based on the expected rise in energy use in the coming decades. This paper will also present the spatial and technological limits of each of these sources. Highlighting the need for the European Union to develop an energy transition based on the concept of technological neutrality, which must consider all energy sources capable of reducing the environmental impact of energy production and consumption, taking into account future demand and supply and environmental impact in terms of CO2 emissions from each source. The STEP (Stated Policy) Scenario of the World Energy Outlook 2021 was chosen to achieve the highest level of realism in the forecasts provided by the paper, because it shows the trends by looking sector-by-sector at what measures governments have actually put in place, as well as specific policy initiatives that are under development. Just in terms of comparison, the graphs will also show the forecasts of the World Energy Outlook for the APS (Announced Pledges Scenario) scenarios that also take into account the policies announced by the countries but not yet in progress, and NZE (Net Zero Emissions), which are instead the scenarios that WEO considers necessary to achieve total de-carbonization by 2050.

Into the energy transition: trends - Total energy supply is expected to grow by 1.3 percent per year from 2020 to 2030, reaching 670 exajoules (EJ) by 2030, according to the Stated Policies Scenario (STEPS) scenario. In the 2020s, the globe is expected to consume more energy per year than it did in the preceding decade, with annual intensity gains averaging 2.2 percent. From 2020 to 2030, final energy consumption is predicted to rise by an average of 1.7 percent each year.

In the STEPS scenario, emerging market and developing nations account for nearly all of the 15% growth in global natural gas demand by 2030. China's demand will be 40% higher in 2030 than it was in 2020. A number of established markets, including Japan (down 25%) and Europe, are experiencing reductions, while demand in North America and Korea is expected to peak in the mid2020s. Increases in light manufacturing in China and India, as well as the chemical sub-sector in China, account for roughly 40% of global demand growth through 2030.

Supply: In the STEPS, there is a 430 bcm increase in natural gas demand between 2021 and 2030 while existing sources of conventional gas production decline by around 740 bcm. Projects that have already been approved add around 420 bcm of production in 2030, and the rest comes from new investment in around 460 bcm per year of new conventional gas projects and 230 bcm of new unconventional gas projects. Around half of the net increase in gas supply is for export. There is a 150 bcm ramp up in annual LNG export capacity, much of it in Qatar, United States, Russia and East Africa.

Environmental Impact: Coal-fired power stations are the largest source of CO2 emissions in electricity generation in Europe and around the world today; replacing them with gas plants of comparable output reduces emissions by more than two-thirds. This is exactly what happened in Italy (where gas now accounts for 40% of total energy consumption) and the United Kingdom. The degree of coal-to-gas conversion is a crucial driver of natural gas future prospects. Its potential varies by industry and region, and for a given country, it is determined by the rate and size of emission reductions desired. Because to coal-to-gas conversions that have occurred since 2010, notably in the power sector in the United States and Europe, as well as in buildings and industry in China, global emissions in 2020 were roughly 750 Mt CO2 fewer than they would have been otherwise. In 2030, an additional 100 billion cubic meters of gas will be utilized to replace coal, saving roughly 180 million tons of CO2. These increases in natural gas demand are somewhat countered by lower demand due to renewables, efficiency, and electrification on a worldwide scale. In the United States, Japan, and the European Union, there is also a small but significant transition away from natural gas and toward nuclear, modern bioenergy, and hydrogen-based fuels.

Considerations: The record highs in spot natural gas prices in 2021 have refocused attention on natural gas's role in the energy mix, raising new issues about how much, and for how long, it can keep its place as clean energy transitions accelerate. Even if there is not a singular narrative, natural gas's potential significance in the energy transition is undeniable. It will continue to play an important role in the transition to zero-emission energy for many years to come as a source of modular power generation capable of compensating for the shortfalls of variable renewable generation while also stabilizing the electricity grid. Furthermore, excluding gas from the list of "sustainable" investments that would facilitate financing through green bonds would have unintended consequences for the EU hydrogen strategy, leaving out the "blue" one, which is currently the only one that is both environmentally and economically sustainable. It would have an influence on gas-powered backup systems, which are becoming increasingly important as the usage of intermittent and non-programmable renewables grows, and will eventually contribute to compounding the gas supply shortage, which is the primary cause of current energy price hikes.

Demand: As electricity takes up a progressively larger share of household energy bills, governments have to ensure that electricity markets are resilient by incentivizing investments in flexibility, efficiency and demand-side response. This is why across all scenarios; according to Figure 1, World Energy Outlook (WEO)[1] predicts that the share of variable renewables in electricity generation expands to reach 40-70% by 2050, compared with an average of just under 10% today.

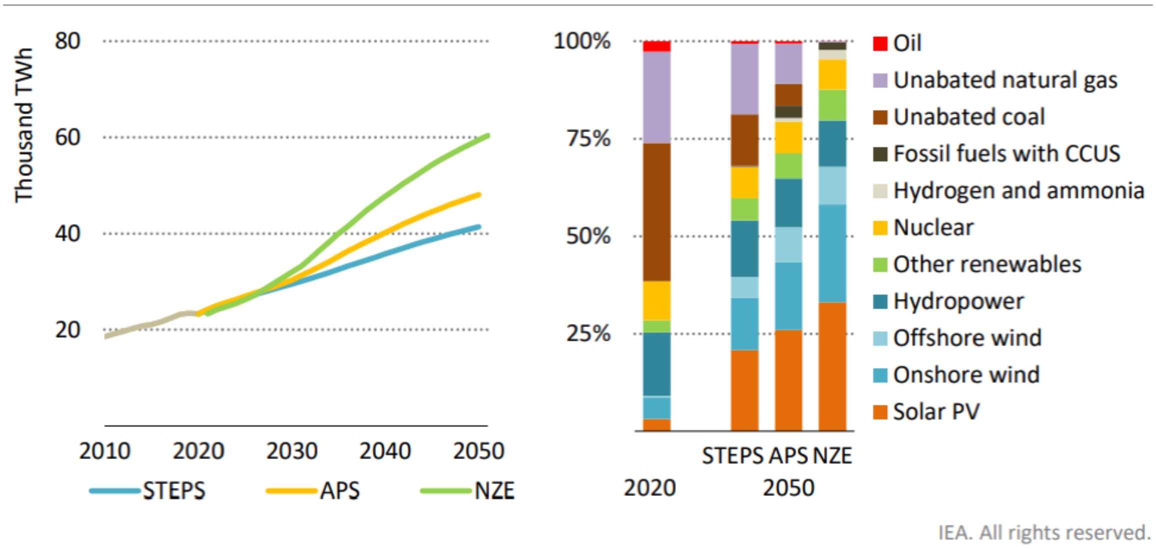

Figure 1. Supply: Change in electricity generation by source and scenario, 2020 to 2030 (WEO) Stated Policies Scenario (STEPS), Net Zero Emissions (NZE),

Over the next decade, the strong growth of renewables is set to continue in all scenarios. Solar PV and wind power lead the way with capacity increases that far outstrip those for other sources of electricity. This reflects policy support in over 130 countries and the success of solar PV and wind in becoming established as the cheapest and most competitive sources of new electricity in most markets. Current policies lead to an increase in combined capacity additions from a record 248 GW in 2020 to 310 GW in 2030 in the STEPS. Record amounts of solar photovoltaics (PV) and wind capacity were added to global electricity supply in 2020, while demand fell slightly related to the pandemic. As a result, the share of fossil fuels in electricity generation fell to a 20-year low, and coal-fired generation dropped to its lowest share in the past 50 years. Over the next decade, the strong growth of renewables is set to continue. Solar PV and wind power lead the way with capacity increases that far outstrip those for other sources of electricity. This reflects policy support in over 130 countries and the success of solar PV and wind in becoming established as the cheapest and most competitive sources of new electricity in most markets. Current policies lead to an increase in combined capacity additions from a record 248 GW in 2020 to 310 GW in 2030 in the STEPS. Solar PV and wind alone meet three-quarters of electricity demand growth to 2030.

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[1] https://www.iea.org/reports/world-energy-outlook-2022

Considerations: The amount of electricity demand and supply covered by renewables is not sufficient to understand why these will not be enough to achieve a complete and just energy transition. Other factors should be included in the discussion. First of all, the surface density of solar energy at ground level is low. In general, this means that the exploitation of renewable sources requires large areas for the collection plants with considerable territorial commitment, resulting in a high cost of the unit of secondary energy (thermal, electric, etc.) and making it difficult to achieve economic competitiveness. Another important defect of renewable energy is that its production in general is intermittent over time due to the daily, seasonal, climatic variability of the primary solar source. In order to understand the environmental and economic impact of the different sources of energy, a comparison can be made between two different countries: Germany and France.

Germany is a paradigmatic case, as per Figure 2 hereafter attached. It has made itself one of the leaders against climate change and leader in the production of energy from renewable sources, spending in the last 20 years 300 billion euros in subsidies for the installation of wind turbines, solar panels and biomass power plants.

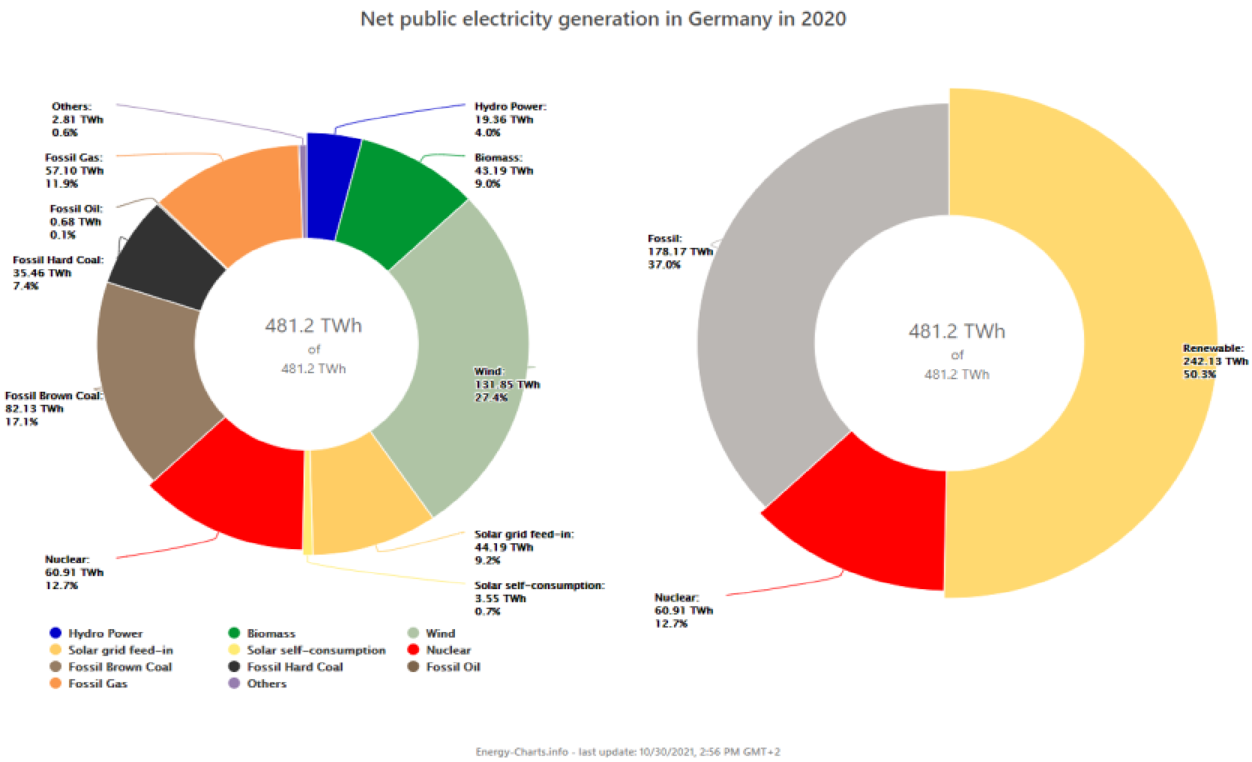


Figure 2. Energy Charts. (*Energy-Charts.info*; energy-charts.info/?l=en&c=DE)

On the other side, France in the 70s, after the two oil crises, decided to focus on nuclear power and to build 56 reactors by the end of the 90s (of which 32 by the beginning of the 80s) for a total cost of about 121 billion euros.

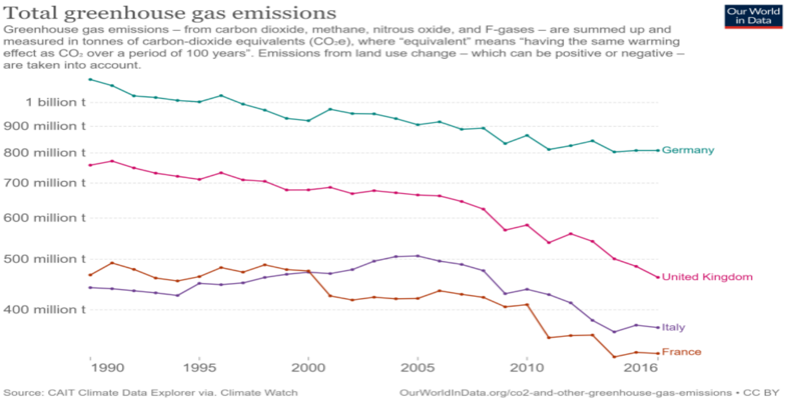


Figure 3. Total green House Emissions (CAIT Climate Data Explorer via Climate Watch)

The graph as per Figure 3 shows that France's pro-nuclear policy has paid off in terms of emissions, giving it back one of the least impactful energy systems (in CO2 terms) in the World. Germany, as we can see, appears to be one of the most impactful in the European area.

Hydropower

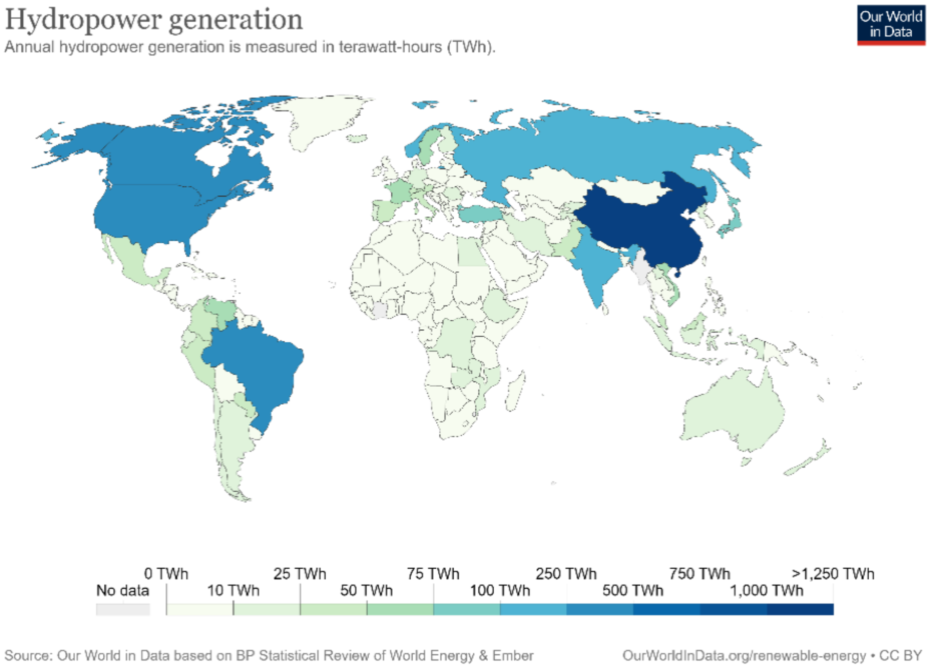


Figure 4. Hydropower generation (Source: Our World in Data Base on BP statistical Review of World Energy & Ember)

Providing one sixth of global electricity generation in 2020 (following coal and natural gas), at almost 4 500 TWh – 55% more than nuclear – hydropower technologies are the world's main source of low-carbon electricity (Figure 4), producing more than all other renewables-based generation combined. Hydropower plants range in size from less than 1 MW to 22 500 MW (the world's largest plant, the Republic of China's ["China"] Three Gorges Dam). Micro-hydro power applications are mostly located in developing regions of Africa and Asia to help meet basic electricity needs and are not usually connected to the grid. Although hydropower accounted for 17-19% of global electricity generation in the 1990s, this share has fallen slightly since the early 2000s to around 17% due to increasing amounts of wind and solar capacity and the growth of natural gas based power generation.

Demand: According to the International Energy Agency (IEA) *´Hydropower Special Market Report 2021´*, global hydropower capacity is set to increase by 17%, or 230 GW, between 2021 and 2030. However, net capacity additions over this period are forecast to decrease by 23% compared with the previous decade. The contraction results from slowdowns in the development of projects in China, Latin America and Europe. However, increasing growth in Asia Pacific, Africa and the Middle East partly offsets these declines. Between now and 2030, USD 127 billion – or almost one-quarter of global hydropower investment – will be spent on modernizing ageing plants, mostly in advanced economies. Work on existing infrastructure – such as the replacement, upgrade or addition of turbines – will account for almost 45% of all hydropower capacity installed globally over the period. In North America and Europe, modernization work on existing plants is forecast to account for almost 90% of total hydropower investment this decade. Overall, this spending on modernizing plants helps global hydropower investment to remain stable compared with last decade.

Global cumulative hydropower capacity is expected to expand from about 1 330 GW in 2020 to just over 1 555 GW by 2030 – a 17% (230-GW) increase. However, the increase in total capacity of new hydropower turbine installations will be greater (383 GW), split between Greenfield projects (new power plants) and brownfield activities (turbine replacements or uprates, or additions of new turbines to existing plants or to non-powered infrastructure). The amount of capacity to be retired over the forecast period (154 GW) accounts for the difference between net and gross capacity additions.

Low and Zero Carbon Hydrogen - Low-carbon hydrogen can reduce GHG emissions by replacing existing sources of hydrogen produced from unabated fossil fuels; by meeting new demand for low emissions fuels and industrial feedstocks; and by converting electricity to a storable fuel to assist with the system integration of renewables. Hydrogen can also be converted to other low-carbon hydrogen-based fuels, including synthetic methane, ammonia and synthetic liquids. To 2030 in the STEPS, there is limited demand for low-carbon hydrogen (although recent policy developments mean demand is higher than in previous World Energy Outlooks). Around 0.2 EJ of low-carbon, hydrogen is produced globally in 2030, equivalent to 0.05% of final energy consumption. The majority of low-carbon hydrogen in 2030 is produced via electrolysis to take advantage of renewable energy resources near demand centers in China, Europe, Japan and North America. Some cross-border trade also emerges, notably from Australia and the Middle East to demand centers in Asia. After 2030, in the STEPS, low-carbon hydrogen production continues to expand and demand in 2050 is equivalent to around 15% of today's total hydrogen use in industrial feed-stocks and oil refining. Around 80% of the low-carbon hydrogen produced in 2050 uses electrolysis, reflecting the significant policy support for electrolytic hydrogen in various regions.

Supply - Integrating low-carbon hydrogen in the energy system will require concerted efforts by governments during the 2020s to create market certainty and close the cost gap with incumbent technologies, for example by establishing targets and long-term policy goals, supporting demand creation in industry and other sectors, mitigating investment risks, promoting research and development projects, and harmonizing standards to remove barriers. Recent examples include a contracts-for-difference (CfD) system in the Netherlands that provides a guaranteed price for hydrogen production, a proposed auction mechanism in Germany and consultation on a support system based on the CfD model in the United Kingdom. Governments also need to ensure deployment of the new infrastructure required to support longer term increases in low-carbon hydrogen supply and demand, including hydrogen pipelines, port facilities and storage, as well as CO2 storage. The overall increases in hydrogen demand to 2030 in the APS and NZE may be small compared with increases in electricity and many other clean energy technologies, but they depend on early action by governments and industry.

Environmental Impact - Hydrogen can be made in a variety of ways, using a variety of energy sources including natural gas, coal, biomass, and electricity. Almost all hydrogen is now created from fossil fuels, either by natural gas steam methane reforming (75 percent of total) or by coal gasification (23 percent). Both processes emit CO2 (9 and 20 kg CO2/kg H2 for natural gas and coal, respectively), and carbon capture and storage (CCS) has only been used in a small number of cases. With an increase in production costs, carbon capture systems can cut direct emissions from steam methane reforming by up to 90%. However, the entire life cycle must be considered, particularly the significant residual methane emissions from upstream natural gas production and distribution activities. For a strict abatement strategy, the use of CCS in coal gasification processes looks to be more technologically hard and less likely to be economically viable. Electrolysis, which uses electricity and perhaps heat to divide water into its basic components of hydrogen and oxygen, can also be used to make hydrogen. Although this method currently contributes for barely 0.1 percent of overall hydrogen production, it has sparked considerable attention due to its potential to produce hydrogen with a very low carbon impact. Alkaline and proton exchange membrane (PEM) electro-lysers are technologically advanced and operated at low temperatures. Solid oxide electrolysis cells, for example, employ high-temperature steam and have substantially better electrical efficiency. While electrolysis does not produce direct carbon emissions, the indirect carbon intensity of the process is dependent on the electrical source used. As the carbon content of electricity is below 200 g CO2/kWh, which only a few nations in the world currently attain, hydrogen synthesis by electro-lysers delivers benefits in terms of carbon emissions when compared to unabated steam methane reforming. As a result, broad usage of electro-lysers can only be beneficial if they are directly coupled to a low-carbon source like wind, solar, or nuclear power, or if the power generation mix is nearly carbon-free.

Considerations - Hydrogen's potential is split between:

- Existing applications of hydrogen, where opportunities are available to use hydrogen produced using cleaner production methods and to make use of a more diverse set of energy sources.
- A wide range of potential new applications for hydrogen, as an alternative to current fuels and inputs, or as a complement to the greater use of electricity in these applications. In these cases – for example in transport, heat, iron and steel and electricity – hydrogen can be used in its pure form, or converted to hydrogen-based fuels.

The number of countries with polices that directly support investment in hydrogen technologies is increasing, with a rising focus on the first of these two types of contribution, but with support for new applications such as road transport as well. Governments have a critical role to play; they are working with an increasingly strong and diverse stakeholder community to address key challenges, including: high costs; policy and technology uncertainty; value chain complexity and infrastructure requirements; regulations and standards; and public acceptance. Tackling these challenges is not optional if hydrogen is to get more than a toehold in the broader energy system.

Biofuels - End-users may typically embrace biofuels with low retrofit costs, which is a major benefit. On the other hand, bio-fuels are expensive, and there is a finite supply of inexpensive and sustainable feedstocks. Conventional biofuels cost between 70 and 130 dollars per barrel of oil equivalent (boe), while advanced biofuels cost between 85 and 160 dollars per barrel of oil equivalent (boe). One key future issue will be to raise funds to build numerous new large-scale plants to reduce production costs; another will be to create new sustainable biomass supply networks. In the STEPS, biofuel demand climbs by roughly 1.5 million barrels of oil equivalent per day (mboe/d) between 2020 and 2030, with conventional ethanol accounting for more than half of biofuel consumption in 2030. As per Figure 5, advanced biofuels provide for the majority of the 2.2 mboe/d rise between 2030 and 2050 in the STEPS, but conventional ethanol remains the most common biofuel produced in 2050.

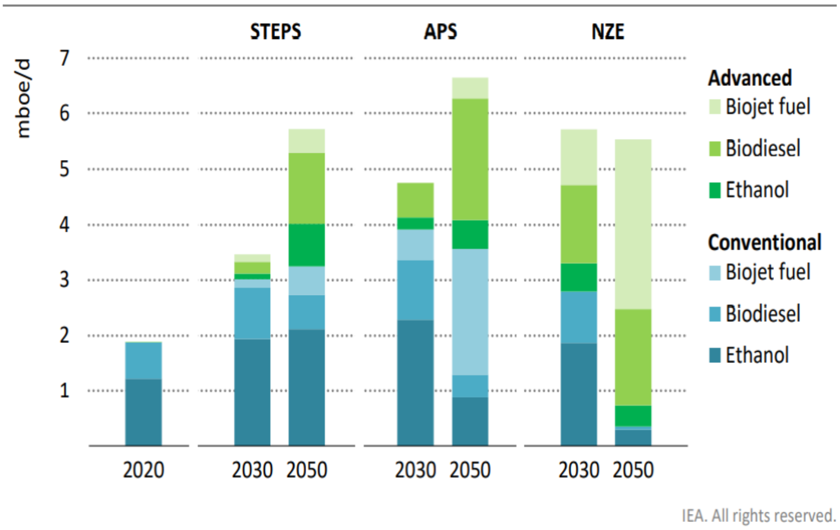


Figure 5. Biofuels cost. ("World Energy Outlook 2021 – Analysis." *IEA*, prod.iea.org/reports/world-energy-outlook-2021).

Nuclear Fission

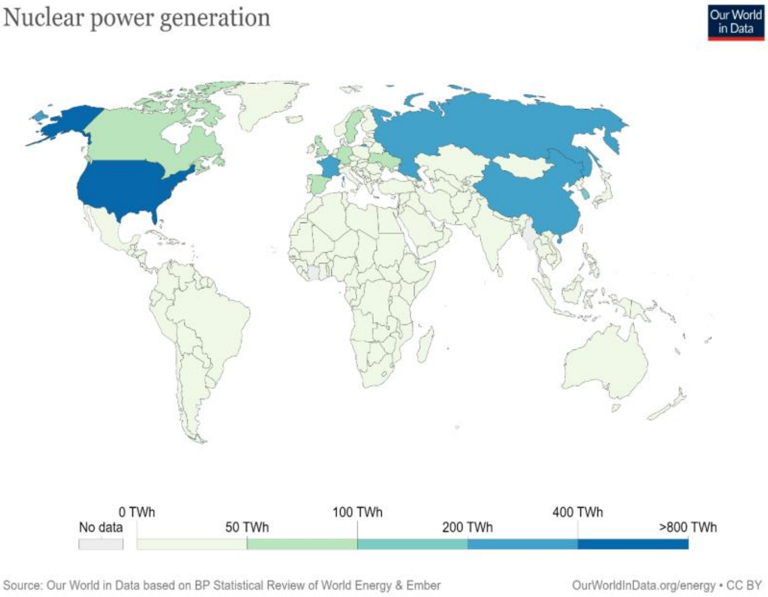
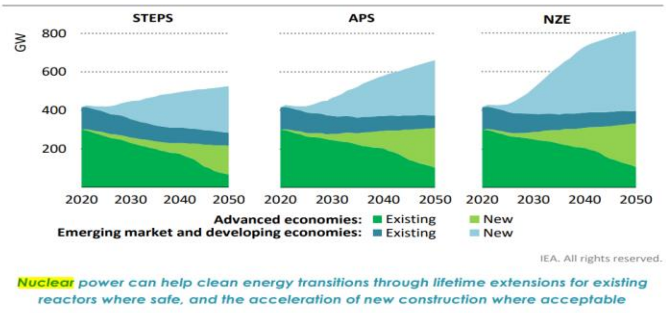


Figure 6. Nuclear Power Generation Distribution (Source: Our World in Data based on BP Statistical review of World Energy & Ember)

The future of nuclear power is dependent on decisions about existing reactors as well as new ones. Global nuclear energy generation capacity increased modestly between 2011 and 2020, with a total of 59 gigawatts (GW) installed, as per Figure 6. While programs in various nations allowed for the continuing operation of existing nuclear power facilities for up to 80 years in some circumstances, 48 GW was nevertheless retired owing to reactor shutdowns within the same time period. As countries throughout the world raise their climate aspirations, expedite their decarbonization plans, the next decade, and beyond may see greater nuclear power deployment, reflecting the plans of a number of countries. According to the IEA's Net Zero by 2050 Roadmap, nuclear electricity generation will have to treble between 2020 and 2050 if the world is to achieve its net zero goals. The roughly 60 GW of capacity under development in 19 nations at the start of 2021 will have a significant impact on nuclear power expansion during the following decade. Many recent projects in China, Russia, and Korea have been finished in five to seven years, both at home and abroad, so some new reactors that begin construction before 2025 may be completed by 2030. Beyond 2030, there are approximately 100 GW of planned projects that have yet to break ground, with many more suggested individually or through policy targets. Existing reactor retirements are more unpredictable, with many aging reactors in the United States, Europe, and Japan in need of extra investment (and, in some cases, new regulatory approvals) to extend their operational lifespan. Market conditions, stringent safety checks, and social acceptance difficulties all play a role in determining whether or not to extend one's life. As per Figure 7, by 2030, the STEPS plan calls for about 65 GW (23%) of the existing nuclear fleet in advanced economies to be decommissioned.



Nuclear power can help clean energy transitions through lifetime extensions for existing reactors where safe, and the acceleration of new construction where acceptable

Figure 7. Nuclear power contribution to clean energy (Source: Data & Statistics IEA)

Even if lifetime extensions offer a cost-effective way to produce more low-emission electricity over the next decade, there is a risk that reactors in industrialized economies may be retired even faster, undermining nuclear power's low-carbon base for electricity production (IEA, 2019b). By 2040, over three-quarters of the current nuclear fleet in advanced economies will have served for more than 50 years, and this appears to be extremely likely to result in a wave of retirements in any scenario. Innovative nuclear power technologies, such as small modular reactors, could reduce the time it takes to build and approve new capacity, as well as expand nuclear power's applications beyond electricity, such as heat and hydrogen production. However, innovation efforts must be accelerated to improve the technology's prospects.

Environmental Impact

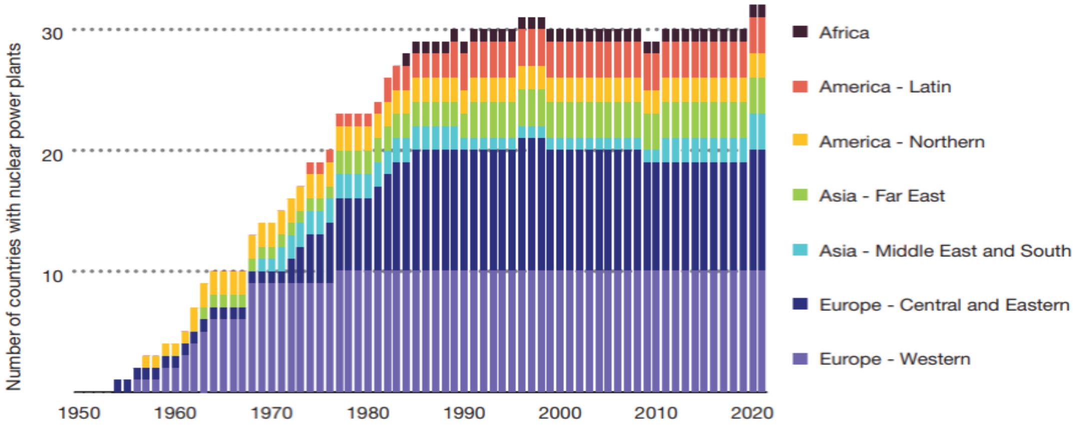
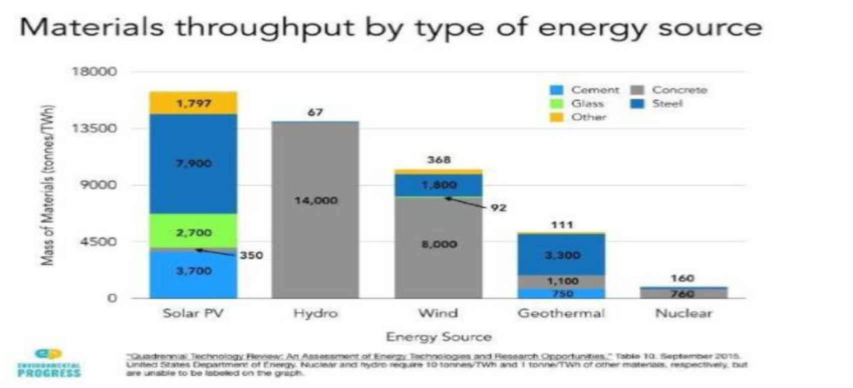


Figure 8. NPPs all over then world (Source: World Energy Outlook 2021)

The Figure 8 shows the progression of the number of countries with nuclear power plants in the last sixty years. As the graph explains, even if the quote of Central and Eastern Europe decreases, the global quote stays the same, thanks to the power plants that has been built in new countries. Nuclear power plants in more than 30 nations are already cutting CO2 emissions in the global power sector by roughly 10%, and 19 countries are actively building around 50 additional reactors with a total capacity of 54 GW. Many of these newcomer countries recognize nuclear power's role in both climate change and long-term economic development, and around 30 countries are working with the IAEA (International Atomic Energy Agency) to explore the introduction of nuclear power for the first time. Bangladesh and Turkey are building their first reactors, while Belarus and the United Arab Emirates began generating nuclear electricity in 2020.

In addition to pollution, an important parameter for measuring the environmental sustainability of a source is the **amount of material needed to build and operate a power plant, per unit of energy produced (Figure 9)**.



"Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities." Table 10. September 2015. United States Department of Energy. Nuclear and hydro require 10 tonnes/TWh and 1 tonne/TWh of other materials, respectively, but are unable to be labeled on the graph.

Figure 9. Required Materials and Energy source (Source: US DOE - Quadrennial Technology Review)

A nuclear power plant is very compact, in relations with the TWh produced, but must be located near a source of water for cooling (rivers, lakes, seas). Gas power plants can be located anywhere but need infrastructure for transporting gas (typically thousands of km, the main fields are in the Middle East, Russia, Southeast Asia), while coal-fired power plants are located near large underground or surface fields, or this must be transported by ship. Renewable sources instead use energy distributed over the entire surface of the globe, in particular solar thermal and photovoltaic will have better performance the closer you are to the equator, while wind will be more efficient in the open sea where the wind blows with more continuity than on land. Every solar park and wind turbine are power plants, so each one must be connected to the electricity grid. This therefore requires new transmission lines, which can also cross entire states to reach places where there is demand for energy (most of the German industries are located in the south, but the large wind farms in the north, even 800 km away), which however are often opposed by residents.

New Technologies - III and III+ Generation - The nuclear power industry has been developing and improving reactor technology for more than five decades and is starting to build the next generation of nuclear power reactors to fill new orders. Several generations of reactors are commonly distinguished. Generation I reactors were developed in 1950-60s, and the last one shut down in the UK in 2015. Generation II reactors are typified by the present US and French fleets and most in operation elsewhere. So-called Generation III (and III+) are the advanced reactors discussed in this section. The first ones are in operation in Japan and others are under construction in several countries. Generation IV designs are still on the drawing board and will not be operational before the 2020s. Reactors derived from designs originally developed for naval use generate over 85% of the world's nuclear electricity. These and other nuclear power units now operating have been found to be safe and reliable, but they are being superseded by better designs. Reactor suppliers in North America, Japan, Europe, Russia, China and elsewhere have a dozen new nuclear reactor designs at advanced stages of planning or under construction, while others are at a research and development stage. Fourth-generation reactors are at the R&D or concept stage.

So-called third-generation reactors have:

- A more standardised design for each type to expedite licensing, reduce capital cost and reduce construction time.
- A simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets.
- Higher availability and longer operating life – typically 60 years.
- Further reduced possibility of core melt accidents.
- Substantial grace period, so that following shutdown the plant requires no active intervention for (typically) 72 hours.

- Stronger reinforcement against aircraft impact than earlier designs, to resist radiological release.
- Higher burn-up to use fuel more fully and efficiently, and reduce the amount of waste.
- Greater use of burnable absorbers ('poisons') to extend fuel life.

The greatest departure from most designs now in operation is that many incorporate passive or inherent safety featuresi, which require no active controls or operational intervention to avoid accidents in the event of malfunction, and may rely on gravity, natural convection or resistance to high temperatures. Another departure is that most will be designed for load following. European Utility Requirements (EUR) since 2001 specify that new reactor designs must be capable of load following between 50 and 100% of capacity. While most French reactors are operated in that mode to some extent, the EPR design has better capabilities. It will be able to maintain its output at 25% and then ramp up to full output at a rate of 2.5% of rated power per minute up to 60% output and at 5% of rated output per minute up to full rated power. This means that potentially the unit can change its output from 25% to 100% in less than 30 minutes, though this may be at some expense of wear and tear.

A feature of some new designs is modular construction. The means that many small components are assembled in a factory environment (offsite or onsite) into structural modules weighing up to 1000 tonnes, and these can be hoisted into place. Construction is speeded up.

Among the most successful Generation III reactors from a sales point of view is the VVER.

The VVER nuclear reactor is a series of pressurized water nuclear reactors designed and built by the Russia. The macroscopic and external differences with respect to Western reactors are the presence of a large number of steam generators, generally from 6 to 8, against 4 or less in Western models, and that these are positioned horizontally and not vertically. The aims of the project are to produce a series of low-cost but at the same time safe reactors, using safety systems that make the construction of a large containment building, which encloses the entire power plant, unnecessary. In fact, the construction of this external shield, normally adopted in all modern western supply chains, is a significant cost for a nuclear power plant. Recently, Belarus opened the Central Ostrovets. The start-up of the power plant marks the entry of small Belarus into the club of nuclear energy producers. The VVER-1200 is a generation III + type of pressurized water reactor, an evolution of the VVER-1000, which can count on a solid operational experience of 1400 reactor years. The VVER-1200 boasts the most scrupulous active and passive safety features, the result of recent technological evolution and the lessons learned following the Fukushima accident. As proof of this, in addition to having successfully passed the checks of the International Atomic Energy Agency (IAEA), which has conducted seven missions in Belarus from 2012 to today, Belarus has voluntarily subjected the plant to stress- tests foreseen by the European regulator for nuclear energy (ENSREG), obtaining a positive peer-review.

A second unit will be connected to the grid by 2021, bringing Belarus' nuclear capacity to 2.4 GW overall. Considering that, to date, 97% of the country's electricity (39 TWh in 2018) comes from natural gas, when fully operational the Ostrovets plant will cover approximately 50% of production, reducing annual CO2 emissions by over 9 million tons.

Ap1000 - The AP1000 nuclear reactor is a type of III + generation reactor manufactured by the Toshiba-Westinghouse Electric Company, and it will be the first type of Generation III reactor to receive approval from the American nuclear regulator (NRC). This type of reactor is essentially the enhanced version of the AP600 model, which is able to generate up to 1154 MW with the same use of land. The AP1000s were counted among the hypothetical reactors that Italy would have been willing to build for its new nuclear plan. Being Ansaldo Nucleare the licensee of Westinghouse for Europe, and one of the major suppliers for the Chinese AP1000 reactors, and having signed Italy a plan of understanding with the USA for the exchange of knowledge in the nuclear field. In China, the AP1000 supply chain is highly quoted, in fact in the intentions of Westinghouse and China there is the intention to have 100 or more AP1000 reactors in operation or under construction for 2020. Technically speaking, the AP1000 Plant is a two-loop pressurized water reactor (PWR) that uses a simplified, innovative and effective approach to safety. With a gross power rating of 3,415 megawatt thermal (MWt) and a nominal net electrical output of 1,110 megawatt electric (MWe); with a 157-fuel-assembly core, is ideal for new baseload generation.

Simplification was a major design objective of the Ap1000 Plant. Simplifications in overall safety systems, normal operating systems, the control room, construction techniques, and instrumentation and control systems provide a plant that is easier and less expensive to build, operate and maintain. Plant simplifications yield fewer components, cable and seismic building volume, all of which contribute to considerable savings in capital investment, and lower operation and maintenance costs. At the same time, the safety margins for the Ap1000 Plant have been increased dramatically over currently operating plants. The AP1000 PWR is comprised of components that incorporate many design improvements distilled from 50 years of successful operating nuclear power plant experience. The reactor vessel and internals, steam generator, fuel and pressurizer designs are improved versions of those found in currently operating Westinghouse-designed PWRs. The reactor coolant pumps are canned-motor pumps, the type used in many other industrial applications where reliability and long life are paramount requirements (see Gaio 2009)[2].

This also allows more work to be done in parallel. The use of heavy lift cranes enables an "open top" construction approach, which is effective in reducing construction time. The **AP1000** plant has a smaller footprint than an existing nuclear power plant with the same generating capacity. The plant arrangement provides separation between safety-related and non-safety related systems to preclude adverse interaction between safety-related and non-safety related equipment. Separation between redundant, safety-related equipment trains and systems provides confidence that the safety design functions of the **AP1000** PWR can be performed. In general, this separation is achieved by partitioning an area with concrete walls.

OVERNIGHT CONSTRUCTION COST OF AP1000 - The **AP1000** plant reduces the amount of safety-grade equipment required by using passive safety systems. Consequently, less Seismic Category I building volume is required to house the safety equipment (approximately 45 percent less than a typical reactor). The AP1000 plant's modular construction design (Figure 10 – Outline) further reduces the construction schedule and the construction risks, with work shifted to factories with their better quality and cost control as well as labor costs that are less than those at the construction site.

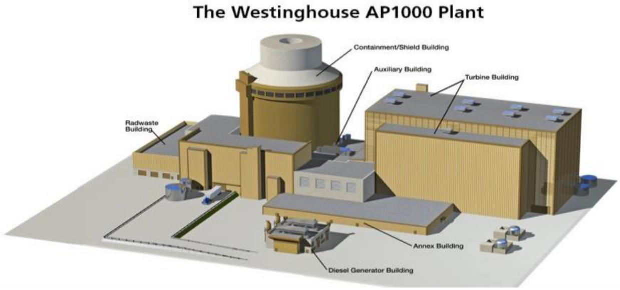


Figure 10. AP 1000 Overview (credit: **https://inis.iaea.org/collection/NCLCollectionStore/_Public/42/026/42026956.pdf)**

This also allows more work to be done in parallel. The use of heavy lift cranes enables an "open top" construction approach (Figure 11), which is effective in reducing construction time. The AP1000 plant has a smaller footprint than an existing nuclear power plant with the same generating capacity. The plant arrangement provides separation between safety-related and non-safety related systems to preclude adverse interaction between safety-related and non-safety related equipment. Separation between redundant, safety-related equipment trains and systems provides confidence that the safety design functions of the AP1000 PWR) can be performed (see: https://www.westinghousenuclear.com/energy-systems/ap1000-pwr). In general, this separation is achieved by partitioning an area with concrete walls.

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[2] https://www-pub.iaea.org/MTCD/publications/PDF/P1500_CD_Web/htm/pdf/topic3/3S05_P.%20Gaio_PM.pdf, accessed 15/3/2023

Figure 11. AP1000 in Construction – Containment Bottom

European Pressurized Water Reactor (Evolutionary Power Reactor) The EPR is a third generation pressurized water reactor design. It has been designed and developed mainly by Framatome (part of Areva between 2001 and 2017) and EDF (Electricité de France) in France, and Siemens in Germany. In Europe, this reactor design was called European Pressurized Reactor, and the internationalized name was Evolutionary Power Reactor, but it is now simply named EPR.

The first operational EPR unit was China´s Taishan 1, which started commercial operation in December 2018. Taishan 2 started commercial operation in September 2019. (https://world-nuclear-news.org/Articles/Fourth-Chinese-AP1000-enters-commercial-operation).

The main aims of the EPR project are to increase safety and, at the same time, provide better economic competitiveness through gradual improvements to the previous and widely tested PWR, pushed up to the power size of 1600 MW. The EPR reactor can use as fuels: enriched uranium oxide up to 4.9% in input (~ 3.5% average considering the other partially burned cycles), or MOX (mixture of uranium and plutonium oxides) up to 100% of the core.

Small Modular Reactors - SMRs are advanced nuclear reactors with a power capacity of up to 300 MW(e) per unit, which is roughly one-third of the producing capacity of typical nuclear power reactors. SMRs, which can generate a huge amount of low-carbon electricity, include the following:

- **Small** - physically a fraction of the size of a conventional nuclear power reactor.
- **Modular** – allowing systems and components to be factory-assembled and transported as a unit to a location for installation. • Small – physically a fraction of the size of a traditional nuclear power reactor.
- **Reactors** — using nuclear fission to generate heat for energy production.

Many of the advantages of SMRs are inextricably related to their compact and modular design. SMRs can be built in regions that are not appropriate for larger nuclear power facilities due to their smaller footprint. SMRs can be built in prefabricated components and then shipped and installed on site, making them less expensive to build than huge power reactors, which are generally specially constructed for a specific area, causing building delays. SMRs offer cost and construction time reductions, and they can be deployed in stages to meet rising energy demand. Infrastructure - low grid coverage in rural regions – and the expenses of grid connection for rural electrification are two of the barriers to speeding energy access. A single power plant should not account for more than 10% of total grid capacity deployed. Because of their reduced electrical output, SMRs can be deployed into an existing grid or remotely off-grid in places where transmission lines and grid capacity are limited, delivering low-carbon power to industry and the general public. This is especially true for micro-reactors, which are a type of SMR designed to generate electrical power of up to 10 megawatts (e). Micro-reactors have a smaller footprint than other SMRs, making them more suitable for areas where clean, reliable, and inexpensive energy is unavailable. Micro-reactors could also be used as a backup power source in emergency scenarios or to replace diesel-fuelled power generators, such as in rural towns or remote enterprises. Proposed SMR designs are often simpler than existing reactors, and the safety concept for SMRs often depends more on passive technologies and intrinsic reactor safety characteristics, such as low power and operating pressure. Because passive systems rely on physical processes such as natural circulation, convection, gravity, and self-pressurization, no human intervention or external power or force is necessary to shut down systems. In some circumstances, the expanded safety margins remove or greatly reduce the risk of dangerous radioactive releases to the environment and the population in the event of an accident. Fuel consumption is lower with SMRs. SMR-based power plants may require less frequent refuelling, such as every 3 to 7 years, as opposed to every 1 to 2 years for traditional plants. Some SMRs can run for up to 30 years without needing to be refuelled. Efforts to bring SMR technology to fruition within this decade are being led by both public and private organisations.

Thorium Reactors - Thorium is a radioactive element that exists in nature in a single isotopic form: thorium 232. It decays very slowly: its half-life is equal to 14.5 billion years, about three times the age of the earth. Thorium research was born to investigate its potential use as a fuel in nuclear reactors.

Currently, the fuel traditionally used in reactors is uranium 235. Thorium and uranium, despite having similar properties, differ in their behavior. Uranium 235 is a fissile material: when hit by a neutron, it gives rise to a fission reaction, releasing other neutrons that trigger new fission reactions. On the contrary, thorium is a fertile material: when it absorbs a neutron, it decays until it transforms into a fissile element, uranium 233. For this reason, thorium can be used in breeder reactors, that is, those reactors in which the fuel is composed both from uranium 235 (fissile) and from thorium 232 (fertile). In this way, it is possible to have a continuous availability of fissile: as it is consumed, uranium 235 is replaced by uranium 233, produced by the transformation of thorium. Research on thorium is conducted in parallel with that on safer and more innovative fourth generation reactors, which envisage its use as a component of nuclear fuel. The fourth generation reactors are, like their antecedents, reactors that produce energy by means of fission reactions but which differ from the former because they represent an evolution in terms of safety and sustainability. Compared to uranium, the use of thorium has several advantages, like:

- Thorium is 3 to 4 times more abundant than uranium, widely distributed in nature as an easily exploitable resource in many countries and has not been exploited commercially so far. Thorium fuels, therefore, complement uranium fuels and ensure long term sustainability of nuclear power.
- Th-232 is used in molten salt reactors; it has the potential to decrease the volume and radiotoxicity of the waste. Conceptually, this happens because Thorium is a lighter element than Uranium. Hence, longer transmutation chains are needed to produce transuranic materials, i.e., elements with more than 92 protons, which make up most of the highly radioactive waste. Longer transmutation chains result in less likelihood of producing transuranic elements by neutron capture.

A few months ago, China announced that it was ready to test, on the edge of the Gobi desert, a molten salt reactor capable of producing 2 MW of thermal energy using thorium as a fuel. If the experiment is successful, China aims to build a new 373 MW reactor by 2030.

Subcritical Reactors

A so-called critical reactor is that type of reactor that has a geometry of the uranium fission mechanism based on the chain reaction internal to the core of the reactor. The fission of the nucleus, which produces energy, also releases a neutron, which in turn breaks up another nucleus. Critical reaction, in this case, simply means that it proceeds on its own. Subcritical reactors therefore need an external neutron source to maintain the necessary level of flux. This source is supplied by means of a beam of protons which, having reached high speeds inside an accelerator, collide with a heavy metal target in liquid or solid form. The neutrons that are emitted by the reactions of the protons with the target are a few tens per incident proton and are then introduced into the subcritical core. The great advantage of this system, called ADS (Accelerator Driven System) which owes its birth to the intuitions of Carlo Rubbia when he was director of CERN, lies in the fact that it can be coupled with the use of Thorium as a fuel, thus adding all the advantages this presents over uranium.

To date, several projects, including numerous private companies, are developing this new type of nuclear power.

Another system in this new type of reactors is the Lead Fast Reactor (**LFR**), which use lead as a coolant instead of water or sodium, and the use of natural thorium fuel. All this leads to several results:

- Drastically reduce the volume of radioactive waste produced, eliminating the need for a geological repository for transuranic elements.

- Much more effective use of the existing uranium fuel, while moving towards the use of natural thorium.
- Avoidance of nuclear accidents since the reactor core always remains subcritical and the nuclear cascade can be stopped instantly by turning off the accelerator.

Radioactive Waste Management - Radioactive waste are by-products or materials that are no longer usable as they still contain radionuclides that emit various types of radiation (α, β) whose intensity decreases over time and halves over a period ranging from a few seconds to many years depending on the type of radioisotope contained. This diversity justifies the difference in treatment and storage of nuclear waste. Indicatively, the nuclear industry produces about 1 kg / year of nuclear waste per inhabitant. For a substance to be considered a radioactive waste, in addition to being a waste material of a process that involves or produces radioactive isotopes, it must originate more than one disintegration per second (Bequerel, in abbreviation Bq) per gram of material. Everything present on Earth (plants, animals, rocks, our own organism, the objects we use daily, the water we drink, the foods we eat, etc.) is radioactive, with an average radioactivity of the order of 0.1-1 Bq / g.

This and other sources of natural radiation, such as cosmic rays, entail for all humanity a natural dose of radiation (on average 2 milliSieverts per year), to which the human organism has certainly adapted in the thousands of generations that there they preceded on Earth.

The slag/energy ratio of the nuclear energy source is 1/1 000 000 compared to conventional sources (fossil fuels) even with a non-optimised cycle.

Future fuel cycles are:

Closed cycle: fuel cycle in which all the U extracted from the mine is submitted to fission (directly or "indirectly") and whose final slag consists solely of fission products.

Transmutation: transformation of one nuclide into another by neutron absorption.

Reprocessing and Separation: recycling of actinides (and possible separation) from fission products and their reintegration into reactors as "fresh" fuels.

Closed cycle presents some advantages, like:

- Full exploitation of U's resources
- Minimization of the mass and toxicity (especially long-term) of nuclear waste destined for geological repositories
- Maximization of the resistance to proliferation of the materials involved thanks to appropriate reprocessing techniques combined with high burn-up

Transmutation advantages instead are:

- Reduction of the source of potential radiotoxicity in a geological repository
- Reduction of waste heat: increase in the capacity of the geological repository
- If transuranics are not separated from each other, decrease the risk of proliferation

Some countries operates also a recycling of plutonium, to be implemented in the LWR Reactors as MOX Fuel. The safe use of plutonium in fast sodium reactors in U-Pu mixed oxide fuel (expressing in this sense since the 60s and 70s, e.g. SEFOR reactor) is proven. The use of Pu in HTR reactors (neutron studies – irradiation experiments with excellent results: 750 GWD/tHM without the fuel deteriorating) looks very promising.

The advantages of it are:

- Reduction of the risk of proliferation (the total amount decreases and the isotopic composition becomes poorer in Pu239 and richer in high mass number isotopes)
- This results in a reduction in long-term slag toxicity (PF+MA) by an order of magnitude
- Energy is produced from "waste material"

The "closure" of the fuel cycle is the purpose of innovative fuel cycles (which Generation IV Initative also deals with) and involves a full exploitation of uranium resources and a reduction of radiotoxicity of HLW slag to be stored permanently as it is reduced to fission products only. 3000 anni"*

Decommissioning - Decommissioning a nuclear facility is an activity to be performed in the post operational phase of a nuclear facility lifecycle. Thanks to new technologies, the decommissioning of a fission power plant with a return to 'green field´ in 15/20 years, from the end of the life cycle of the plant, is possible.

It is agreed that planning for decommissioning begins during the design of the facility and continues during its construction and throughout its operational life. Along with other objectives, this earlier planning would provide a sound basis for decommissioning cost estimation and funding provisions.

The OECD estimates for decommissioning costs (OECD, NEI, IEA, 2010) indicate a cost equal to 15% of the overnight cost of the nuclear technology plant and a cost equal to 5% of the plant for conventional technologies (CCGT and PC).

These costs occur only at the end of the plant's life (after as minimum 60 years of operation or longer like for new NPPs having a design life equal to 100 years) and are assumed to result in a financial outlay in the 10 years following the start of the decommissioning activities.

The financial peculiarities of these costs mean that assuming any realistic interest rate, the current value of the decommissioning costs is extremely low.

But natural radioactivity, and consequently the natural dose of radiation, are very variable from point to point of the earth's surface. With values in some areas double, triple and in some cases even 10 times higher than the average values indicated above. Without these entailing differences in the state of health or life expectancy of the populations living in these areas compared to those living in neighboring areas with similar characteristics in terms of climate, diet, economic and social contexts, etc.

Considerations - Combining nuclear and renewable energy sources can speed up the transition: nuclear power's low material intensity means it is unlikely to run into supply shortages for essential minerals, which could stymie the deployment of other low-carbon alternatives. This emphasizes how critical it is to have nuclear energy in the portfolio of alternatives for a successful transition to a net-zero future. Time is running out to reduce global emissions and avert serious climate change consequences. This urgency necessitates the use of all low-carbon solutions to transition away from fossil fuels, especially those that are proven, cost-effective, and supportive of broader development and environmental goals. To understand why reports like JRC (2021) has given a positive opinion on nuclear power, we must first take the view that there is no "totally clean" method of producing energy. Human action always has an impact on the environment. Renewable energies also require minerals that must be extracted and processed; solar panels and wind turbines do not last forever and require large tracts of land dedicated only to energy production; dams modify the river environment where they are built, etc. If we enter into this perspective, then the problem of nuclear power no longer becomes that of establishing whether it has an environmental impact, but that of analyzing how large its environmental impact is compared to that of other energy sources. If you look at the numbers, the environmental impact of nuclear power is comparable to that of renewable energy, with the further advantage that the atom does not have the problem of intermittence, which is instead the primary reason why today it is not you can think of doing everything with solar and wind.

Nuclear Fusion

Energy System Transition. The technology of Nuclear Fusion The use of nuclear fusion as a source of energy production has numerous advantages:

- Almost all of the waste produced has low radioactivity values, eliminating the problem of storage.
- Does not produce greenhouse gases, radioactive gases or plutonium.
- The fuel, which is extracted from the water, can be said to be inexhaustible.
- The risk of major accidents is lowered: if control of the reactor were to be lost, it would cool down spontaneously.

ITER (Figure 12 – ITER Site outline) will be a tokamak reactor – thought to be the best hope for fusion power. Inside a tokamak, a gas, often a hydrogen isotope called deuterium is subjected to intense heat and pressure, forcing electrons out of the atoms. This creates a plasma – a superheated, ionised gas – that has to be contained by intense magnetic fields. The containment is vital, as no material on Earth could withstand the intense heat (100,000,000°C and above) that the plasma has to reach so that fusion can begin. It is close to 10 times the heat at the Sun's core, and temperatures like that are needed in a tokamak because the gravitational pressure within the Sun cannot be recreated. When atomic nuclei do start to fuse, vast amounts of energy are released. While the experimental reactors currently in operation release that energy as heat, in a fusion reactor power plant, the heat would be used to produce steam that would drive turbines to generate electricity. Tokamaks are not the only fusion reactors being tried. Another type of reactor uses lasers to heat and compress a hydrogen fuel to initiate fusion. In August 2021, one such device at the National Ignition Facility, at the Lawrence Livermore National Laboratory in California, generated 1,35 Megajoules of energy.

Figure 12. ITER Site – Construction in progress (Source: ITER Organization)

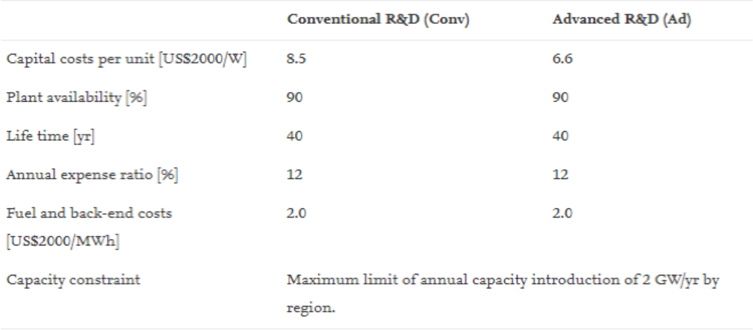
This record-breaking figure brings fusion power a step closer to net energy gain, but most hopes are still pinned on tokamak reactors rather than lasers. In June 2021, China's Experimental Advanced Superconducting Tokamak (EAST) reactor maintained a plasma for 101 seconds at 120,000,000 °C. Before that, the record was 20 seconds. Ultimately, a fusion reactor would need to sustain the plasma indefinitely – or at least for eight-hour 'pulses' during periods of peak electricity demand. A real game-changer for tokamaks has been the magnets used to produce the magnetic field. "We know how to make magnets that generate a very high magnetic field from copper or other kinds of metal, but you would pay a fortune for the electricity. It would not be a net energy gain from the plant," says Dr. Tim Luce, head of science and operation at the International Thermonuclear Experimental Reactor (ITER). The solution is to use high-temperature, superconducting magnets made from superconducting wire, or 'tape', that has no electrical resistance. These magnets can create intense magnetic fields and do not lose energy as heat. High temperature superconductivity has been known about for 35 years. But the manufacturing capability to make tape in the lengths that would be required to make a reasonable fusion coil has just recently been developed. One of ITER's magnets, the central solenoid, will produce a field of 13 tesla – 280,000 times Earth's magnetic field. Superconducting cables are becoming a preferred solution in nuclear fusion with respect to conventional busbar systems when very large electrical currents are transported over relatively long distances, thanks to:

- The much larger current densities: 200 A/mm2 instead of 2 A/mm2for conventional busbars leading to a drastic reduction of footprint and weight.
- The mechanical flexibility of superconducting cables when compared to rigid busbars, simplifying installation & upgrade operations.
- The drastic reduction/ elimination of intermediate electrical joints (depending on length of the circuit) present in large numbers in conventional busbars.
- The elimination of energy losses in the powering system, making the nuclear plant overall efficiency higher.
- The displacement of the transition from room to cryogenic temperature from the 'hot' tokamak area to a 'cold' region of the power converters, where it can be more easily controlled and eventually maintained.
- The integration of the superconducting cable cooling system within the cryogenic plant of ITER, which would result in a further optimized solution, leading to a virtually' maintenance-free' operation of the powering system.

The inner walls of ITER's vacuum vessel, where the fusion will occur, will be lined with beryllium, a metal that will not contaminate the plasma much if they touch. At the bottom is the divertor that will keep the temperature inside the reactor under control. "The heat load on the divertor can be as large as in a rocket nozzle," says Luce. "Rocket nozzles work because you can get into orbit within minutes and in space it's really cold." In a fusion reactor, a divertor would need to withstand this heat indefinitely and at ITER; they will be testing one made out of tungsten. Meanwhile, in the US, the National Spherical Torus Experiment – Upgrade (NSTX-U) fusion reactor will be fired up in the autumn of 2022. One of its priorities will be to see whether lining the reactor with lithium helps to keep the plasma stable. "If ITER is successful, it'll eliminate most, if not all, doubts about the science and liberate money for technology development," says Luce. That technology development will be demonstration fusion power plants that actually produce electricity. "ITER is opening the door and saying, yeah, this works – the science is there."

Possible Capital Costs- The possible costs of fusion power generation has been assessed by the Paper *´Potential contribution of fusion power generation to low-carbon development under the Paris Agreement and associated uncertainties´*. The Paper builds a scenario that considers all the uncertainties of future socioeconomic development, CO2 emission pathways corresponding to the long-term target of the Paris Agreement, and fusion energy development scenarios.

The Paper assumed two types of commercial fusion power plants, which have different capital costs as shown in the table below. According to Hiwatari et al. the parameters were set based on the 10th kind of proposed conceptual designs of a tokamak fusion power plant, CREST, and Slim-CS. The Table 1 shows two different hypothetical situations of Conv (Conventional R&D), where the research and development investments on nuclear fusion remains the actuals and Ad (Advanced R&D) which states an improvement to the R&D of nuclear fusion by the current projects and experiments.



	Conventional R&D (Conv)	Advanced R&D (Ad)
Capital costs per unit [US$2000/W]	8.5	6.6
Plant availability [%]	90	90
Life time [yr]	40	40
Annual expense ratio [%]	12	12
Fuel and back-end costs [US$2000/MWh]	2.0	2.0
Capacity constraint	Maximum limit of annual capacity introduction of 2 GW/yr by region.	

Table 1: Conventional and Advanced R&D Cost

Assumptions on available regions of fusion energy are shown in attached Figure 13. The paper assumed maximum capacity expansion constraint based on historical experience of nuclear fission capacity expansion. There could be two major factors, which affect capacity expansion rate of fusion: initial loading of tritium and location of fusion power plants. This is the reason why countries like Canada, known for the large investments that they are operating on nuclear fusion, is showed in blue. Since the more fusion power plants exist, the more excess tritium can be produced for new power plants.

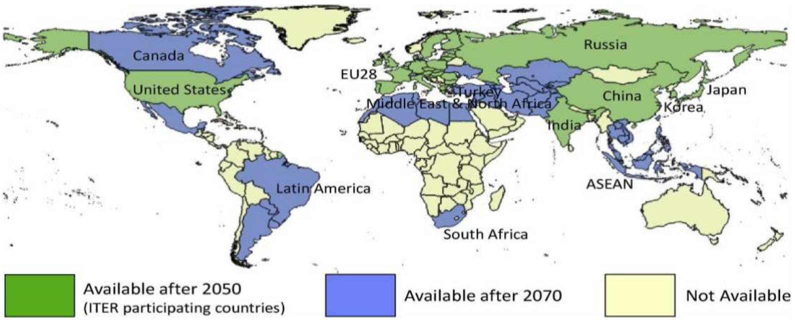


Figure 13. Fusion technologies in the World (ITER Organization)

Considerations - Taking into consideration the assumptions extracted from the recent G20, which, although no longer referring to precise dates, declares the need for a decarbonization of the energy production system by the middle of the century. Adding the incontrovertible fact that denotes an increase in energy needs and of energy consumption, we must find a system that is able to reconcile these two things, now apparently in contrast. Beyond the contribution to reducing current emissions, the real problem is to build an energy system in the middle of the century that presents a baseload-type source, free of carbon, which gives a contribution in terms of safe, applicable energy. Today we are at the stage in which nuclear fusion can pass within the middle of the century from the experimentation phase to the demonstration phase.

This awareness is pushing several private companies to invest in nuclear fusion, sometimes presented as the only alternative that meets all the requirements in terms of emissions and production. Today these realities owe their awareness to the choice that developed countries made decades ago, with the founding of ITER. In a time when there was still no talk of decarbonization, the choice to build a reality like that of ITER proved prescient, and still works today as a source from which to draw on to speed up the investment processes and construction of new experiments for fusion nuclear.

For this reason, the need to continue investing in research and development is emphasized, in order to guarantee the realization within the middle of the century.

Conclusions - The Conference of Parties (COP) 26 saw the participation of 90% of the countries, including Brazil, which declared its commitment to reduce its emissions by 50%. Brazil's participation, also praised by the United States Special Representative for Climate, John Kerry, sends an important message on the direction that world governments have decided to take with regard to the energy transition. From the point of view of energy production, for the transition to be possible by the middle of the century there is a need to develop technologies that, as Bill Gates explains, are not yet present. Precisely for this reason, developed nations should aim for an energy transition based on technological neutrality. Starting from the assumption of Confucius, according to which 'it does not matter what color the cat is, as long as it catches the mice', developed nations will have to concentrate on favoring an energy mix that includes all sources of energy, especially natural gas and nuclear. The first, thanks to its lower density of CO2 emissions compared to oil and the growing market that is developing around this source, can represent an important source of transition to the development of valid alternatives. Renewable energies, on the other hand, will have to be implemented as far as possible but without forgetting that every source, in order to be considered the main one, needs to present itself as ´safe, abundant and reliable´. At the same time, hydroelectricity will find a great development in the coming years, especially thanks to the investments that China is dedicating to this energy, defined by many as the only renewable energy capable of providing continuous and uninterrupted energy. The development of technologies in favor of Biofuels, Biomass or techniques such as Waste to Fuel will be equally important. Countries like Italy collects about 30 million tonnes of waste every year, of which 14 million tonnes is correctly separated. Of this, about 7 million tonnes is OFMSW. By promoting the increased and more accurate separation of kitchen waste, this figure could reach 10 million tonnes of OFMSW. Currently, it is mainly used to produce compost for agriculture and, to a lesser extent, biogas. An increasingly important sector, but with a rising cost for the community. By combining a well-managed separated waste collection and more Waste to Fuel plants across Italy, we could obtain about a billion liters of bio-oil annually, equivalent to about 6 million barrels of crude oil per year. Hydrogen, especially green, will be a vector that could play an important role in the years to come, although it is still difficult to define its contours well due to the technological developments it needs to reduce costs.

The energy transition can be the right opportunity to overcome the ideological obstacles linked to the only energy with zero emissions that can act as a baseload for the electricity system: nuclear energy. Nuclear power has a considerable advantage: it is able to supply large quantities of energy in a constant (24 hours a day) and controllable way. The same can also be done by hydroelectric and geothermal plants, which however require specific territorial characteristics that not all countries have. In the case of hydroelectricity, it is also useful to underline that to date, in the most developed countries; the sites with the highest production and economic potential have for the most part already been used.

To better understand the importance of nuclear power, it is necessary to illustrate how the demand for electricity is structured, and consequently its production, which follows it moment by moment to ensure grid stability. Demand varies considerably throughout the day: it reaches its minimum at night, increases during the day and usually peaks before dinner. It is therefore possible to divide the electricity consumption into two parts: a constant consumption present at every hour of the day (**baseload**) and only one during peak hours (**Peakload**). Most of the technologies that today provide baseload are fossil fuel power plants that will have to be gradually replaced to achieve the emission reduction target. It would be natural to think that renewable sources such as wind and solar can be good substitutes. Betting everything on them, however, would entail considerable technical difficulties: since they are variable and scarcely predictable sources (the wind does not always blow, the sun is not there at night and sometimes the sky is cloudy), they should be accompanied by numerous storage systems for the energy and / or complementary technologies capable of compensating for a possible drop in production, quickly and without producing CO2. Technologies that exist today, but not on a large scale, and which, if available, would be expensive to install and use, at least as long as technological advances and economies of scale help make them more competitive. An energy system with a high amount of variable renewable energy would considerably increase energy costs for individual citizens and industries. If the goal is to reduce emissions, where large amounts of hydroelectric and geothermal energy are not available, nuclear is therefore one of the most efficient solutions to replace fossil fuel power plants in the production of energy suitable for baseload.

Nuclear is efficient for achieving climate goals, but also in terms of reliability of national energy systems. Nuclear energy guarantees the stability of the electricity grids that other renewable sources are unlikely to be able to offer, and also makes it possible to reduce the dependence of a given country on the energy imports necessary to meet its energy needs (e.g. imports of electricity from neighboring countries, fossil fuels from third countries, etc.). An often-debated topic when it comes to nuclear energy is waste disposal. The technology available today, however, allows the storage of waste safely, without posing any risk to the environment.

Europe has to look at this challenging sustainable energy production with common glasses and differentiated visions. It is true that at National Country level there are divergent opinions and visions in Fission Nuclear sources applications (largely supporting the effort in Fission Countries like France / Russia, East European Countries, UK and largely against Countries like Italy and Germany). It is time to go above the obstacles of political visions and enter the technical / sustainable energy sources evaluation also because for the first-time private capital investment is entering the development if fission technologies all over European Countries, comprehensive of Italy and Germany. There is full acceptance in all Europe on Fusion technology. It is time to demonstrate that the technology of sub-critical reactors at Thorium working as transmuter or as energy supplier do not deviate by the requirements affecting also fusion technologies in nuclear energy production.

It is time to be realistic paying attention to the COP26 target and implementing all required effort to generate sustainable energy as also supported openly by European Commission strategy.

Achieving climate goals would theoretically be possible even without further investment in nuclear energy. However, excluding this energy source from the equation would require a much larger mobilization of resources. **If between now and 2040 it was decided to stop any investment in nuclear power, it would be necessary to compensate for the lack of electricity production with a quantity of wind and solar energy equal to five times the total installed capacity in the last 20 years globally.** This is the main reason why European Union cannot miss the opportunity to introduce the Nuclear Energy into the Taxonomy.

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