Nuclear energy: a necessary evil to face the climate emergency?

GREENPEACE

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INTRODUCTION AND SUMMARY

Urgent action is needed for our climate

Urgent action to save the climate is needed now. The agreement signed in Paris at the end of 2015 commits governments to stabilize global warming well below 2°C, if not 1.5°C, according to scientific recommendations. Unfortunately, according to the United Nations Environment Programme (UNEP), the commitments made by states in 2018 will lead to a 3.2°C rise in temperatures by 2100.[1] Even these already-too-high trajectories are not respected; if CO_2 emissions continue at the current rate, the worst-case scenario predicts that temperatures will rise from 6.5°C to 7°C by 2100[2].

According to the UNEP report, to stabilize global warming below 1.5°C, we need to reduce our emissions by 7.6% each year between 2020 and 2030. The next 10 years are the most important in terms of efforts to avoid an excessive accumulation of CO_2 in the atmosphere and irreversible long-term consequences. These drastic efforts will have to continue well beyond 2030. So what should be done? What means do we have to address this emergency?

Nuclear energy in this context

Does the climate crisis require us to invest in nuclear power and build new plants in France and around the world? In France, the world's most nuclearised country per capita, there is growing talk of the essential role of nuclear power in the face of the French, European, and global climate crisis: for some, it is a solution born of scientific progress; for others, nuclear power would be a necessary evil or a done deal we cannot 'unsign'. Many also fail to take a position, mainly because it may seem difficult to take ownership of the issue.

The debate on nuclear power has dwindled to nothing: whether through social media or official declarations, any criticism of nuclear power is routinely dismissed on the grounds that it is a low-carbon energy source. For its supporters, low-carbon means green, virtuous, beneficial and essential for the climate. Opponents of nuclear power are therefore opponents of the fight against climate change.

This very offensive communication strategy of governments and the nuclear industry calls for a detailed response on our part. Fortunately, despite apparent complexities and urgent necessity, everyone has the right and the ability to form an educated opinion about nuclear power and the role it could or could not play in responding to the climate crisis.

This document attempts to re-situate the nuclear issue in a broader context to assess its current and potential contribution to the fight against the climate crisis. It looks at nuclear power from

[1] The United Nations Environment Programme, Emissions Gap Report 2019, 2019.

[2] CNRS, CEA, Météo France, Two French climate models consistently predict a pronounced global warming: press conference of 17 September 2019.

different angles: industrial and economic feasibility, climate resilience, ecological sustainability, and in comparison with other low-carbon solutions. We conclude that nuclear power is low-carbon, but not a realistic and effective solution to climate change. Worse, it is too slow to implement in the face of a climate emergency, too vulnerable to the impacts of global warming and natural hazards, too dangerous to be developed massively around the world, too expensive compared to other low-carbon options we have at hand to rapidly reduce global greenhouse gas emissions. France is highly nuclearised and no exception: the stubbornly continued use of nuclear power and the construction of new reactors are not the fastest, cheapest or most sustainable ways to achieve climate neutrality; instead, they divert us from real climate challenges and investments.

A review

Nuclear power and the climate issue around the world…

Nuclear power is far from a turnkey climate solution for the planet. It produces about 10% of the world's electricity: just 2-3% of the world's total energy consumption. Currently, it prevents the equivalent of 2.5% of greenhouse gas emissions (assuming it replaces an average non-nuclear mix). As it stands, nuclear power plays a very limited role in the fight against climate change. For nuclear power to prevent 10% of the world's emissions in 20 years, approximately one new reactor would need to be brought online per week between now and then.

Nuclear power is too slow, too complex, and too expensive to implement in a time of emergency. According to UNEP recommendations, to stabilise global warming at 1.5°C, greenhouse gas emissions must be reduced by 7.6% each year between 2020 and 2030. In other words, the next 10 years are crucial**.** However, on average, a nuclear project takes between 10 and 19 years (according to the IPCC), the number of projects is very low, and many construction sites are experiencing significant delays. Investments are in sharp decline and account for only 3.8% of energy investments in 2019, as new reactors now cost far more than renewables or energy savings. A global nuclear stimulus plan appears unrealistic and definitely compromised.

As a technology, nuclear power is vulnerable to a changing climate because it is highly water-intensive, making it very sensitive to water stress, temperature rises, and extreme events due to rising sea levels. Furthermore, nuclear power and natural risks – seismic, for example – do not mix well. These climatic and natural hazards are additional constraints and risk factors to consider that limit the potential use of the technology.

Nuclear power is also a weapon and a target. Nuclear sites are vulnerable to terrorist attacks, jet crashes, cyber attacks, and theft of dangerous materials. Given the environmental and health consequences in the event of an accident or proliferation, nuclear power requires close monitoring and very powerful supervisory authorities. There are many countries in geopolitically unstable areas where it would be clearly unthinkable and irresponsible to build nuclear power plants.

Fortunately, nuclear power is not an obligation. Other solutions will reduce our greenhouse gas emissions. In this race for "decarbonization" and "climate neutrality," we must transform our pollution-intensive agricultural model and our modes of transportation, insulate buildings, and invest in energy savings – all of which are faster, more agile solutions that do not produce hazardous waste. The IPCC report on the potential paths to stabilize global warming below 1.5°C focuses on these easier-to-deploy and more sustainable policies and measures. It considers that nuclear energy, as a low-carbon policy, is the least compatible with the United Nations Sustainable Development Goals. The report also points out that the role of nuclear power in efforts to stay below 1.5°C of warming varies enormously from scenario to scenario: From 1% to 39% of electricity generation in 2050. Over half of the scenarios studied by the IPCC estimate that the share of nuclear power will decline (to less than 9% of electricity generation in 2050).

Nuclear power and the climate issue in France…

France is the world's most 'nuclear' country per capita: nuclear power supplies 70% of our electricity. Historically, since the 1980s, French nuclear plants have helped abate France's carbon and greenhouse gas emissions. In recent years, renewable energy has taken over and enabled the closure of the last coal-fired power plants. That said, every French citizen still emits between 6 and 11 tons of CO_2 a year[3]; even decarbonized, electricity is not enough: nuclear energy accounts for less than 25% of the final energy consumed in France and its impact on CO_2 emissions concerns only electricity (about 10% of greenhouse gas emissions in France).

Today, nuclear resources are in decline: reactors are ageing, increasingly fragile, increasingly unavailable, and increasingly expensive to maintain. Their ecological footprint increases every year as they produce more and more hazardous and non-recyclable waste. Power plants are not eternal. The question is, what do we do next – build new reactors or invest in another low-carbon energy system?

The construction of new nuclear reactors is questionable given changes in temperatures and forecasts of water stress and heat waves that already affect existing nuclear reactors. Moreover, a rise in sea level will heighten the risk of flooding and extreme events in coastal areas, where policy-makers have volunteered to host new EPR reactors.

The construction of new reactors is also questionable given the delays and additional costs observed for all EPR construction projects (in Finland, the United Kingdom, China and France). The cost of the EPR site in Flamanville, France is now estimated at €19 billion, with delivery delayed over 10 years. By contrast, today's renewable energy projects can produce electricity two to three times cheaper and prevent greenhouse gases. The huge sums invested in EPR (born by consumers and taxpayers) could have helped to finance far more effective climate policies and measures: for

[3] Depending on whether or not 'imported' CO_2 emissions are included.

example, the thermal renovation of buildings would have reduced energy consumption, energy insecurity, housing problems, and (to a massive extent) household heating bills.

Several studies have shown that by 2050 or 2060, energy production in France could be 100% renewable and low carbon. They also calculated that even with the costs of storage and network adaptation, a 100% renewable electrical system in 2050 would not cost more than a system based on six EPR reactors or more.

Missing today is a clear policy direction and public investment strategy. The closure of old reactors is too little anticipated and too unclear; public R&D spending continues to favour nuclear energy (68%) at the expense of renewable energy (23%), and the government wants to invest “at the same time” in nuclear and renewable energy. This non-choice is costly to taxpayers and consumers alike, and impedes the transition to a less energy-intensive system.

CHAPTER 1.

NUCLEAR POWER: LOW CARBON, BUT TOO SLOW AND TOO LIMITED IN THE FACE OF THE CLIMATE EMERGENCY

Nuclear power is a low-carbon option... but this does not suffice to make it a realistic, effective, and acceptable solution

Let it be immediately clear: the problem with nuclear power does not lie with its carbon impact over its entire life cycle, which varies, by estimates and by countries, from a few grams to a hundred grams. Even with these variations, it is much less than a coal, fuel, or natural gas plant, and of the same order of magnitude as renewables. Globally, according to the IPCC, nuclear power emits between 3.7 and 110 g CO_2 eq/kWh, with a median of 12 g CO_2 eq/kWh[4]. This is very close to the carbon footprint of renewable energies (as they are produced at the present time): the median established by the IPCC is 11 to 12 g for wind power and 48 g for photovoltaic solar power. By comparison, the carbon footprint of fossil fuels is much higher: 820 GCO_2 eq/kWh for a coal plant and 490g for a natural gas plant (median established by the IPCC in 2014, see Figure 1 below).

Figure 1. CO_2 emissions (expressed as GCO 2 eq/kWh) over the life cycle of each power generation technology.

Table A.III.2 | Emissions of selected electricity supply technologies (gCO_2eq/kWh)[i]

Options	Direct emissions	Infrastructure & supply chain emissions	Biogenic CO_2 emissions and albedo effect	Methane emissions	Lifecycle emissions (incl. albedo effect)
	Min/Median/Max	Typical values			Min/Median/Max
Currently Commercially Available Technologies					
Coal—PC	670/760/870	9.6	0	47	**740/820/910**
Gas—Combined Cycle	350/370/490	1.6	0	91	**410/490/650**
Biomass—cofiring	n.a.[ii]	–	–	–	**620/740/890**[iii]
Biomass—dedicated	n.a.[ii]	210	27	0	**130/230/420**[iv]
Geothermal	0	45	0	0	**6.0/38/79**
Hydropower	0	19	0	88	**1.0/24/2200**
Nuclear	0	18	0	0	**3.7/12/110**
Concentrated Solar Power	0	29	0	0	**8.8/27/63**
Solar PV—rooftop	0	42	0	0	**26/41/60**
Solar PV—utility	0	66	0	0	**18/48/180**
Wind onshore	0	15	0	0	**7.0/11/56**
Wind offshore	0	17	0	0	**8.0/12/35**
Pre-commercial Technologies					
CCS—Coal—Oxyfuel	14/76/110	17	0	67	**100/160/200**
CCS—Coal—PC	95/120/140	28	0	68	**190/220/250**
CCS—Coal—IGCC	100/120/150	9.9	0	62	**170/200/230**
CCS—Gas—Combined Cycle	30/57/98	8.9	0	110	**94/170/340**
Ocean	0	17	0	0	**5.6/17/28**

Source: IPCC 2014

But the low-carbon nature of a technology or practice cannot suffice to declare that it is a necessary "solution". Its feasibility and the conditions of its implementation; its real capacity to reduce greenhouse gas (GHG) emissions in the short term, its cost and sustainability must also be examined.

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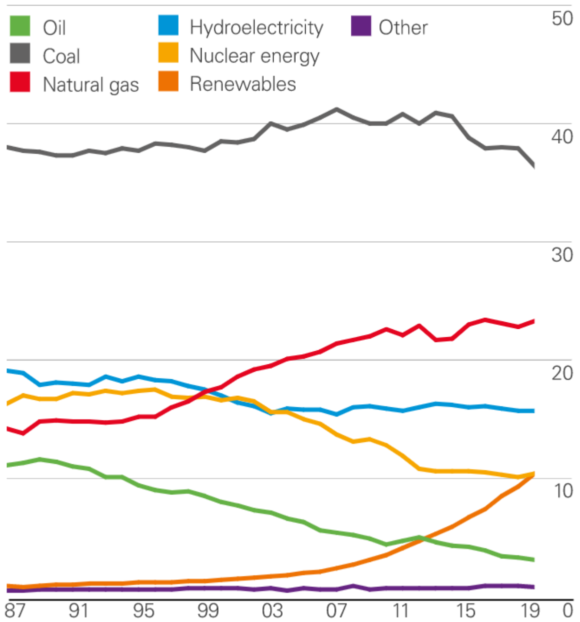
[4] Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report, Report of Working Group III, 2014.

So, before deciding whether nuclear power is one of the “solutions” to the climate emergency, we must first ask: what role does nuclear power play today in generating energy and reducing greenhouse gases? What role could it play in the future? What are its prospects for the future now, and are conditions met for its deployment (investments, construction, possible pace of development)? Is nuclear power sustainable from an environmental point of view, and more generally from a sustainable development point of view? How does it compare to the other low-carbon options at our disposal?

Nuclear power in 2020: a marginal role

To understand the role that nuclear power could play in addressing the climate emergency, we must begin by reviewing the role of nuclear power in the world today.

Figure 2. Share of each technology in global electricity production from 1987 to 2019 (expressed as a %)



Source: BP Statistical Review of World Energy 2020

Nuclear power in global electricity production The world’s nuclear power fleet currently consists of 409 active reactors in 32 countries. In 2019, according to the International Energy Agency (IEA), this nuclear fleet provided 10.3% of the world’s electricity (see Figure 2)[5]. Nuclear power is in decline: at its peak in 1996, it produced more than 17% of the world’s electricity. In 2019, new renewable energies (mainly solar and wind) surpassed nuclear power for the first time (generating

[5] International Energy Agency, Key World Energy Statistics, 2019 edition.

10.4% of the world's electricity).[6] When these new renewable energies and hydro power are combined, renewable energy accounts for 25% of the world's electricity generation and is playing a growing role in it.

Nuclear power in global electricity consumption Nuclear power produces mainly electricity, and electricity accounts for less than 20% of the world's end-use energy consumption. Of the total energy consumed worldwide, nuclear energy accounted for about 2.2% of final energy consumption[7] in 2018. In the same year, renewable energies (excluding agrofuels) already accounted for 10-11% of end-use energy consumed worldwide[8].

Nuclear energy in the reduction of greenhouse gas emissions According to the IEA, nuclear energy prevented up to 6% of annual GHG emissions related to energy production[9] in the 1990s (compared to an average non-nuclear mix for the reference year). In 2017, it prevented only about 4% (see Figure 3)[10]. In comparison, in the same year, renewable energy (including hydro power) prevented 12.7% of global energy-related emissions.

A broader examination of the impact of nuclear energy on global greenhouse gas emissions (beyond energy-related emissions alone) shows that nuclear plants would currently prevent, at best, 2.5% of annual global GHG emissions[11] compared to a virtual scenario in which all nuclear production is suddenly stopped overnight and replaced by the existing average electricity mix.

To maintain the role of nuclear power in decarbonizing the global electricity mix, a new reactor would need to be built every month between now and 2030. Given the age of nuclear resources and the pace of planned closures, nuclear power will continue to decline. To maintain it at its current level, 14 reactors would need to be built by the end of 2020, and 188 by 2030 to replace retired ones.[12] One reactor per month. This is completely hypothetical, of course: all construction would need to be completed within 10 years.

If nuclear power is expanded to prevent, in 20 years, 10% of the world's annual greenhouse gas emissions, one reactor per week would need to be built for the next 20 years. Bernard Laponche and Benjamin Dessus point out that, by order of magnitude, if nuclear power is to prevent 10% of global GHG emissions (instead of the current 2.5%) in 20 years, at least one new reactor would need to be started (and thus built) per week[13].

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6 BP , Statistical Review of World Energy , 2020.

7 Or 4.9% of primary energy consumption according to the International Energy Agency

8 REN21, Renewables 2020 - Global Status Report2020 edition (calculation based on IEA 2018 data).

9 International Energy Agency (IEA), Nuclear power in a clean energy system, 2019

10 Calculated by Négawatt based on the presentation: " Les limites du nucléaire" (in French)

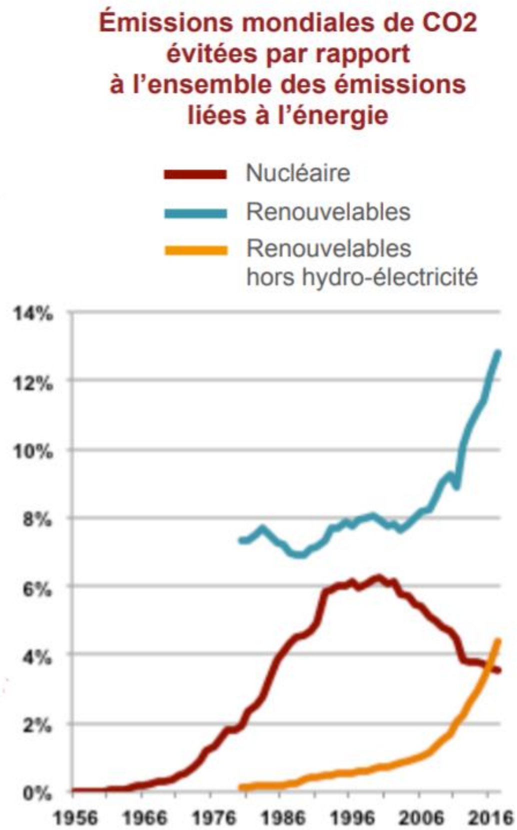
11 Calculations from Global Chance, re-published in an editorial by Bernard Laponche and Benjamin Dessus in 2018 (in French). Since this figure of 2.5% for annual global GHG emissions prevented by nuclear power was calculated based on 2013 data, it represents the high range of the current 2020 value: in seven years, the share of nuclear power in global electricity production has fallen by 4% (see Figure 2).

12 Mycle Schneider et al., World Nuclear Industry Status Report, 2019 edition.

13 Benjamin Dessus, Bernard Laponche et al., "Non le nucléaire ne sauvera pas le climat" an editorial published in the magazine Alternatives Economiques on 3 October 2018 (in French).

Whether the goal is to maintain the current contribution of nuclear power in reducing greenhouse gas emissions or to develop it, tens to hundreds of reactors would need to be built. This is far from the trend observed today, characterized by many closures, many delays, few new projects and few investments...

Figure 3. Global CO_2 emissions prevented compared to all energy-related emissions between 1956 and 2016 (expressed as a %)



Source: *Institut Négawatt, 2020*

To calculate the order of magnitude of a reactor per week: increasing the percentage of global emissions prevented from 2.5% to 10% in an otherwise identical system requires four times more reactors than there are currently in service. Even assuming that none of the 400 reactors currently in service close by then, it is therefore necessary to plan to build 1,200 reactors to reach a total of 1,600 in service (assuming that the new fleet generates average power equivalent to the current fleet). To put 1,200 reactors into service in 20 years, 60 must be put into service per year. That is more than one per week.

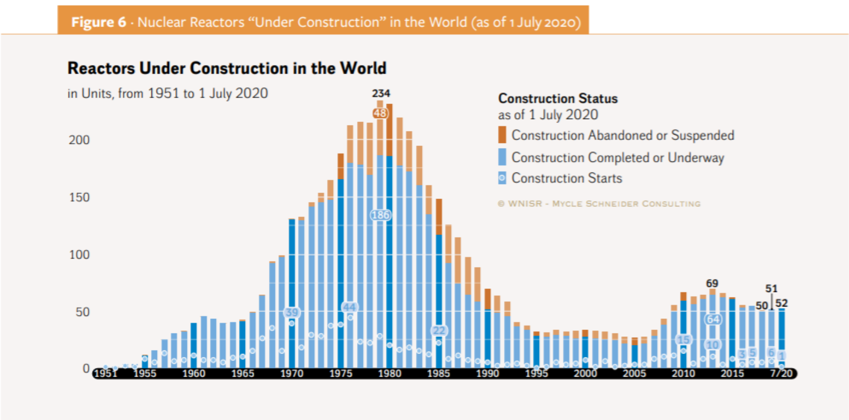
Very limited prospects for nuclear power

The world's nuclear park is ageing. Currently, the average reactor age is over 30 years; 81 nuclear reactors are over 41 years old. Several reactors will close in the coming years. As it stands, despite the willingness of many operators to extend the life of reactors to 60 years (especially in the United States), nuclear reactors around the world are closing well before 50 years (the median was 42.2 years between 2015 and 2019)[14]. This means it will be necessary to renew the nuclear park if we wish to maintain its role in the global energy system.

Few new reactors under construction. The number of reactor construction starts have dropped steeply, from 44 in 1976 to 15 in 2010, five in 2018 and six in 2019 (see Figure 4)[15]. In 2019, a dozen reactors were finally shut down in Japan, the United States, Switzerland, Germany, South Korea, Russia, Sweden and Taiwan.

A total of 50 reactors are currently classified as "under construction". This may seem like a lot, but it is very little compared to the 234 during the nuclear golden age of the 1970s, or the 69 nuclear reactors under construction in 2013. It is also very little compared to the number of construction sites needed if the role of nuclear power is to be maintained or expanded. It should be noted that certain reactor projects are decades old and postponed from year to year (one project in Iran dating from 1972 has just been restarted and two Slovak reactors have been "under development" for 35 years).

Figure 4. Nuclear reactors under construction worldwide from 1951 to July 2020



Sources: WNISR, with IAEA-PRIS, 2020

Notes:

This figure includes construction of two CAP1400 reactors at Rongcheng/Shidaowan, although their construction has not been officially announced (see China Focus). At Shidao Bay, the plant under construction since 2012 has actually two reactors on the site and is therefore counted as two units as of WNISR2020.

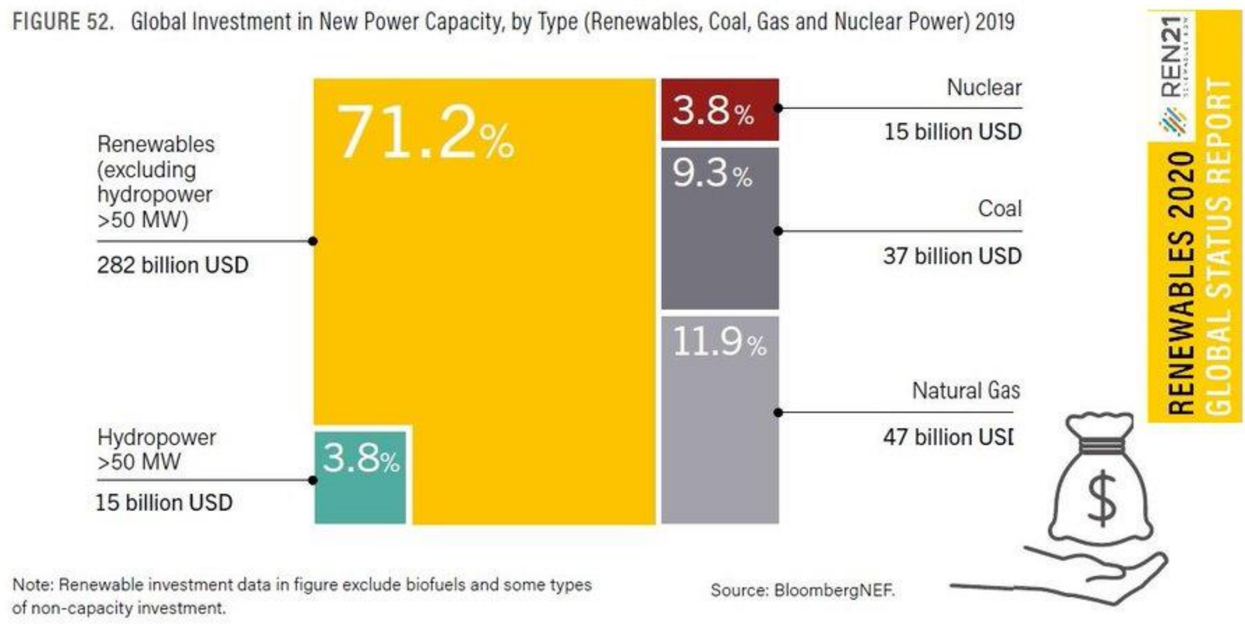
Source: World Nuclear Industry Status Report 2020

[14] Mycle Schneider et al., World Nuclear Industry Status Report, 2020 edition.

[15] In Russia, Bangladesh, Turkey, Iran, China, South Korea, and the United Kingdom.

Less investment In 2019, nuclear energy accounted for only 3.8 per cent of investments in new electricity generation worldwide, compared with 71–75% for the development of renewable energy (see Figure 5)[16]. The financial sector views nuclear projects as particularly risky, and does not venture to finance them without guarantees and government funding to reduce risk-taking.
But a political commitment to developing nuclear power for the sake of the climate seems far from shared: only 11 states mentioned nuclear power in their GHG mitigation plans submitted to the UN.[17]

Figure 5. Global investments in new electricity generation capabilities in 2019



Source: REN21 Renewables 2020 Global Status Report

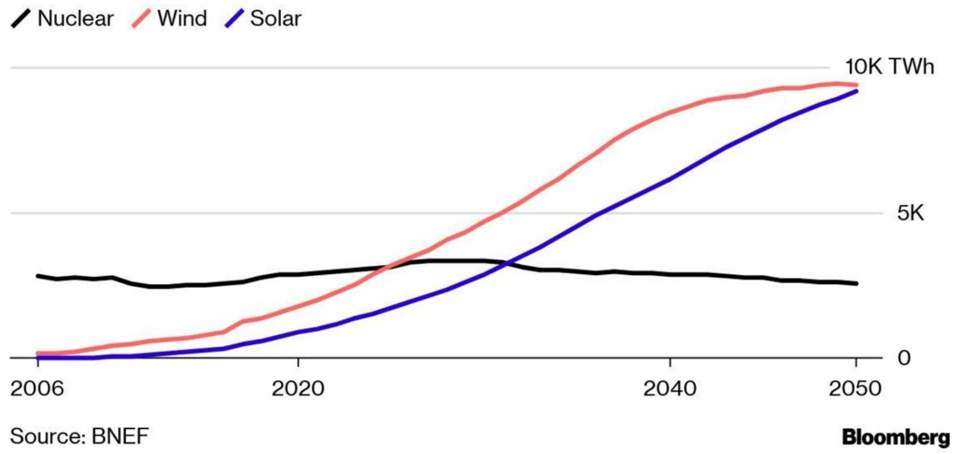
Data from the International Energy Agency[18] confirm this trend: while the IEA would like to see more investment in nuclear energy, it recognizes that the current rate of development is very low, and that investment forecasts do not currently allow for the revival of a global nuclear program. In these conditions, it is hard to imagine a rapid relaunch of nuclear power generation.

The heavy trend is quite clear: investors predict that nuclear power will continue to stagnate or decline. In contrast, renewables have taken off in a dramatic global surge for 10 years, far outpacing expectations. The cost of renewables continues to fall, and technologies are growing rapidly and becoming more efficient. According to Bloomberg New Energy Finance forecasts,[19]solar power (in 2030) and wind power (in 2025) will each produce as much electricity as nuclear power. In other

[16] REN21, Renewables 2020 - Global Status Report2020 edition (calculation based on 2019 Bloomberg New Energy Finance 2019 data).
[17] Mycle Schneider et al., World Nuclear Industry Status Report, 2019 edition.
[18] International Energy Agency (IEA), Nuclear Tracking report, June 2020.
[19] International Energy Agency (IEA), World Energy Outlook, 2019 edition.

words, by 2030, solar and wind will provide twice as much electricity as nuclear power in the world (see Figure 6). In 2040, according to the International Energy Agency, photovoltaic solar power will be the world's leading source of electricity, and renewable energy can be developed very quickly: the main adjustment variable is the regulatory framework in a given country.

Figure 6. Evolution and projection of nuclear, solar and wind power generation by 2050 (expressed in TWh)



Source: [Bloomberg Quint (BNEF)]

Until the "nuclear solution," is found, CO_2 emissions will accumulate in the atmosphere.

Construction times are very long. Currently, 64% of projects are affected by delays[20]. Chapter 4 of the IPCC report[21] notes that, on average, 10–19 years passes between the decision to build and the actual start-up of a nuclear power plant…Many hurdles must be jumped to obtain a green light from nuclear safety authorities, in addition to construction errors and delays that accumulate with each unexpected event. France is no exception: The Flamanville EPR is more than 10 years late – and well within this global average.

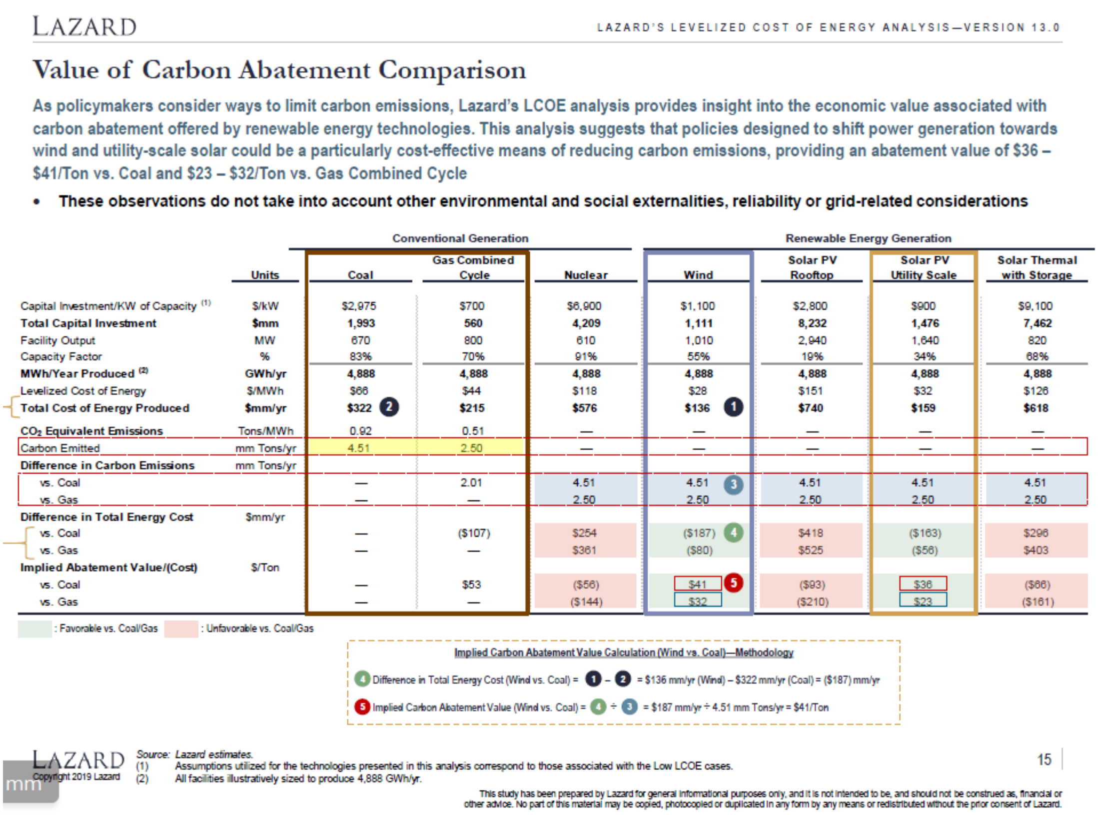
These implementation times are too long for the construction of new nuclear power plants to offer a rapid response to the climate emergency. In the midst of long decision-making and construction processes, which are chronically underestimated, dependence on fossil fuels will continue. While waiting for the start of the nuclear reactors that are supposed to take over from fossil fuels, coal, oil or gas-fired power plants will continue to generate emissions for long periods: at least a decade, if

[20] Mycle Schneider et al., World Nuclear Industry Status Report, 2019 edition.
[21] Intergovernmental Panel on Climate Change (IPCC), Special Report: Global Warming of 1.5°C, Chapter 4 , 2018. https://www.ipcc.ch/sr15/chapter/chapter-4/

not much longer. And it is therefore CO_2 emissions that will accumulate "pending" the possible start of nuclear reactors. In addition, part of the investment capacity of the company and the State will be concentrated on the construction of such reactor(s) and cannot be invested in other low-carbon policies and technologies that are quicker to deploy and can have immediate effects on the reduction of CO_2 emissions.

The World Nuclear Industry Status Report[22] and Lazard investment bank[23] calculate that the cost of reducing one ton of CO_2 is higher with nuclear power than with large photovoltaic or wind power plants (see Figure 7). Many nuclear power plants face severe economic difficulties, and sustaining them is costly in comparison to the dollar per ton cost of removing a ton of CO_2 emissions.

Figure 7. Comparative cost analysis of reducing CO_2 emissions, by technology (expressed in $/ton of CO 2)


LAZARD LAZARD'S LEVELIZED COST OF ENERGY ANALYSIS—VERSION 13.0

Value of Carbon Abatement Comparison

As policymakers consider ways to limit carbon emissions, Lazard's LCOE analysis provides insight into the economic value associated with carbon abatement offered by renewable energy technologies. This analysis suggests that policies designed to shift power generation towards wind and utility-scale solar could be a particularly cost-effective means of reducing carbon emissions, providing an abatement value of $36 – $41/Ton vs. Coal and $23 – $32/Ton vs. Gas Combined Cycle

- **These observations do not take into account other environmental and social externalities, reliability or grid-related considerations**

		Conventional Generation			Renewable Energy Generation			
	Units	Coal	Gas Combined Cycle	Nuclear	Wind	Solar PV Rooftop	Solar PV Utility Scale	Solar Thermal with Storage
Capital Investment/KW of Capacity (1)	$/kW	$2,975	$700	$6,900	$1,100	$2,800	$900	$9,100
Total Capital Investment	**$mm**	**1,993**	**560**	**4,209**	**1,111**	**8,232**	**1,476**	**7,462**
Facility Output	MW	670	800	610	1,010	2,940	1,640	820
Capacity Factor	%	83%	70%	91%	55%	19%	34%	68%
MWh/Year Produced (2)	**GWh/yr**	**4,888**	**4,888**	**4,888**	**4,888**	**4,888**	**4,888**	**4,888**
Levelized Cost of Energy	$/MWh	$66	$44	$118	$28	$151	$32	$126
Total Cost of Energy Produced	**$mm/yr**	**$322** 2	**$215**	**$576**	**$136** 1	**$740**	**$159**	**$618**
CO_2 Equivalent Emissions	Tons/MWh	0.92	0.51	—	—	—	—	—
Carbon Emitted	mm Tons/yr	4.51	2.50	—	—	—	—	—
Difference in Carbon Emissions	mm Tons/yr							
vs. Coal		—	2.01	4.51	4.51 3	4.51	4.51	4.51
vs. Gas		—	—	2.50	2.50	2.50	2.50	2.50
Difference in Total Energy Cost	$mm/yr							
vs. Coal		—	($107)	$254	($187) 4	$418	($163)	$296
vs. Gas		—	—	$361	($80)	$525	($56)	$403
Implied Abatement Value/(Cost)	$/Ton							
vs. Coal		—	$53	($56)	$41 5	($93)	$36	($66)
vs. Gas		—	—	($144)	$32	($210)	$23	($161)

: Favorable vs. Coal/Gas : Unfavorable vs. Coal/Gas

Implied Carbon Abatement Value Calculation (Wind vs. Coal)—Methodology

4 Difference in Total Energy Cost (Wind vs. Coal) = 1 – 2 = $136 mm/yr (Wind) – $322 mm/yr (Coal) = ($187) mm/yr

5 Implied Carbon Abatement Value (Wind vs. Coal) = 4 ÷ 3 = $187 mm/yr ÷ 4.51 mm Tons/yr = $41/Ton

LAZARD Copyright 2019 Lazard

Source: *Lazard estimates.*
(1) Assumptions utilized for the technologies presented in this analysis correspond to those associated with the Low LCOE cases.
(2) All facilities illustratively sized to produce 4,888 GWh/yr.

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mm

Source: Lazard's Levelized cost of Energy 13.0, 2019

22 Mycle Schneider et al., World Nuclear Industry Status Report, 2019 edition.
23 Lazard, Lazard's Levelized cost of Energy 13.0, 2019.

No, the IPCC neither prescribes nor promotes nuclear power

The IPCC (Intergovernmental Panel on Climate Change) is technologically neutral: its role is only to aggregate and describe what the scientific literature says. It is not mandated to prescribe, promote or rule out any technology or policy action. The 2018 IPCC report on ways to stabilize global warming below 1.5°C establishes several things:[24]

- It takes four "illustrative pathway archetypes" to emphasize that there are different ways and models of society to stabilize global warming below 1.5°C.
- It aggregates and compares 89 scientific scenarios to stabilize global warming below 1.5°C and draws averages and medians from them to provide insight into the assumptions made by scientific literature today.
- It also reflects on the feasibility and sustainability of the main options (technological choices, policies and measures) considered by the scientific literature.

It should be noted that nuclear power is included in the IPCC's analysis because it is also based on what currently exists: a little more than 400 nuclear reactors in operation.

In the four illustrative pathway archetypes given by the IPCC in the first section of the report, the share of nuclear energy increases (from 98% to 468%). The most nuclearised pathway is not the most decarbonized (P4): it is the one that temporarily exceeds 1.5 °C. Conversely, the pathways that rely the most on demand control (stabilization or even reduction of global energy consumption by one-third) and that do not exceed the 1.5°C threshold are also those in which the role of nuclear power is least important in terms of volume and share (P1 and P2). In all four pathways, even if its relative share increases, nuclear power continues to play a limited role in relation to other energy sources mobilized by the IPCC. In these same pathways, renewable energy accounts for the bulk of energy production (from 70 to 85%).

In any case, this is not enough to say that the IPCC advocates or predicts an increase in the share of nuclear power in the future. The IPCC does not say, "choose one of these pathways";instead it warns against over-interpreting them. It uses them as an illustration and entry point for reflection, which does not exclude other pathways. In a recent analysis, Négawatt[25] highlights the possibility of recombination, based on the same assumptions the IPCC regarding renewable-energy deposits and reduced consumption. This "P5 recombination" (see Figure 8) would stabilize global warming below 1.5°C, also by relying on a mix of renewable energy and reduced energy consumption (in comparison, the IPCC's so-called "P1" pathway proposes a reduction in consumption even greater

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[24] Intergovernmental Panel on Climate Change (IPCC), Special Report: Global Warming of 1.5°C, 2018.

[25] Négawatt, Quelle place pour le nucléaire et les énergies renouvelables dans les trajectoires mondiales de neutralité carbone ? September 2020 (in French)
To bring energy consumption under control, Négawatt espouses an intermediate hypothesis between P1 and P2, i.e. 7.5 GTOE of final energy in 2050. Concerning renewable energy, to build these four pathways, the IPCC estimates that the potential for renewable energy is between 4 GTOE and 10 GTOE. The P5 recombination predicts a need for 6.5 GTOE of end-use energy, and mobilizes different renewable energy sources beyond the base of 4 GTOE – without exhausting the maximum potential assigned to them by different pathways.

than that of Négawatt.) Unlike the P1, P2, P3, and P4 pathways, P5 recombination does not involve fossil fuels, carbon capture and storage, nuclear power, or geo-engineering.

Figure 8. Comparative global energy outcomes in 2050 between IPCC pathways (P1, P2, P3, and P4) and the Négawatt "P5" recombination (expressed as end-use energy)

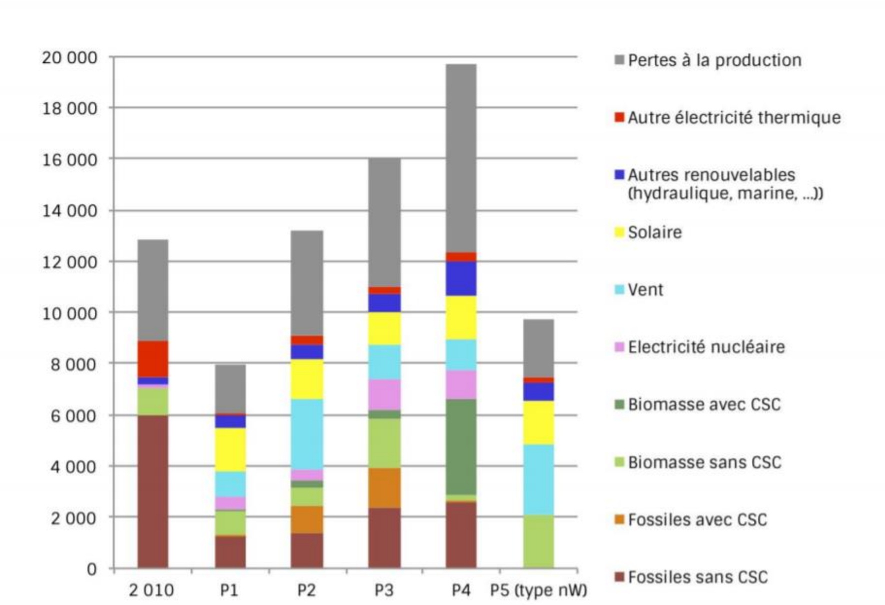

Figure 4 - Bilan énergétique mondial en 2050 dans les quatre trajectoires types proposées par le GIEC (P1 à P4) et recombinaison composée par négaWatt (P5)
Source : Association négaWatt (2020), d'après GIEC (2018)

Source: Négawatt 2020

With respect to the 89 IPCC scenarios: Nuclear power is a component of all scenarios, since they are based on the existing situation. But in the medium term, the role of nuclear power varies widely: depending on the scenario, it accounts for 1-39% of electricity generation in 2050![26] The share of nuclear power declines in half of the scenarios (in 2050, according to the IPCC median, nuclear power accounts for less than 9% of electricity generation, compared to 10.3% today), and disappears completely by 2100 in a dozen scenarios. Conversely, the potential for renewable energy development achieves a greater consensus: in half of the scenarios, renewable energy accounts for at least 67% of electricity generation (compared to less than 9% for nuclear power) in 2050 (see Figure 9).

[26] Intergovernmental Panel on Climate Change (IPCC), Special Report: global warming of 1.5 °C, Chapter 2 (page 134), 2018.

Figure 9. Share of nuclear and renewable energy in the 89 scenarios which stabilize global warming below 1.5°C and taken into account by the IPCC (in %)

Among the 89 scenarios	**The percentage provided by nuclear power in 2050**	**The percentage provided by renewable energy in 2050 (excluding biomass)**
Highest figures...	39 %	96.5 %
Lowest figures...	1 %	27.5 %
Electricity production (median)	8.7 %	67 %

Source: Chart based on data from the IPCC 1.5 °C 2018 Special Report

The IPCC report relativises the development potential of nuclear power

A feasibility challenge. Chapter 4[27] of the IPCC report reads: *"The energy system transition that would be required to limit global warming to 1.5°C is under way in many sectors and regions around the world (medium evidence, high agreement) The political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies has improved dramatically over the past few years, while that of nuclear energy [...] has not shown similar improvements."* Indeed, the report points to very long construction and deployment times (between 10 and 19 years on average for a reactor), high costs and the need for significant public support (or even monopolistic conditions), as well as the social acceptability of nuclear power and waste, among other things. These factors can limit its deployment. Chapter 5 also warns about the risks of nuclear proliferation and the challenge of ensuring the total independence of nuclear supervisory authorities in the face of economic and political pressures.

These obstacles raise questions about the feasibility of scenarios and pathway archetypes that give a growing role to nuclear power. They would involve the construction and start-up of hundreds or even thousands of reactors by 2050 (see Figure 10), and thus a far more intensive pace that has never been seen so far.[28]

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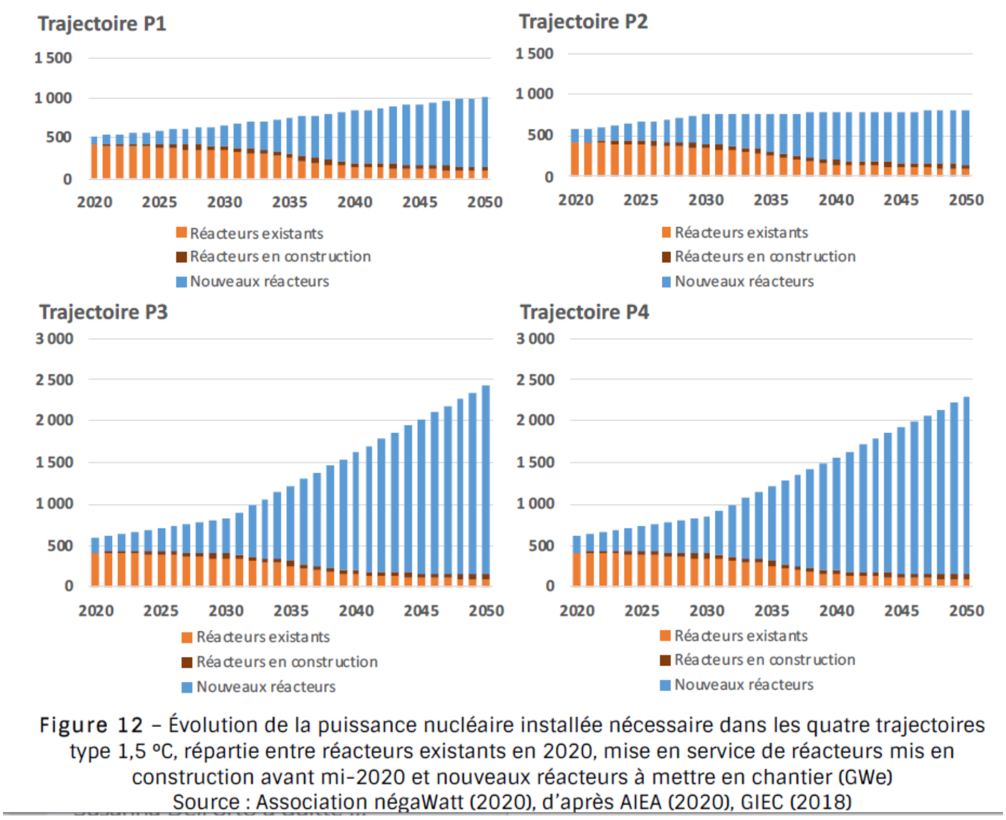
[27] IPCC, Special Report: 1.5°C Global warming, Chapter 4, page 5 (2018).
[28] Négawatt, Quelle place pour le nucléaire et les énergies renouvelables dans les trajectoires mondiales de neutralité carbone ? September 2020.

Figure 10. Predicted trends in installed nuclear power required in the four IPCC 1.5°C report pathways (expressed in number of reactors)



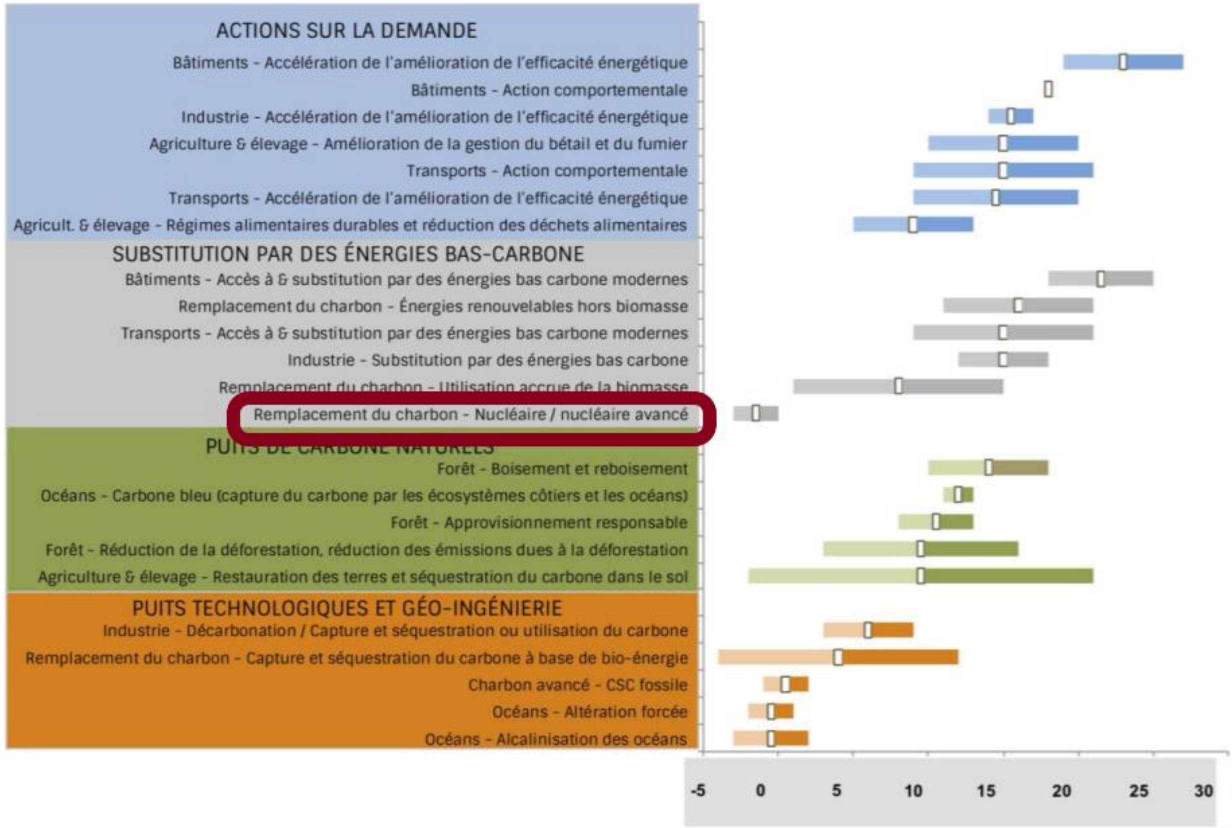
Source: Négawatt 2020

The issue of sustainability. The IPCC also looks at the sustainability of the key mitigation technologies and policies being considered. Based on scientific literature, it assesses their contribution to achieving the 17 United Nations Sustainable Development Goals (SDGs)[29], which must be achieved by 2030. These are the "17 priorities for socially equitable, environmentally sound, economically prosperous, inclusive and predictable development by 2030".

Nuclear power is the lowest-scoring option (see Figure 11). By contrast, not surprisingly, the most sustainable option and the one most likely to contribute to the SDGs according to this assessment is energy renovation in buildings. Below is a report published by Négawatt summarizing the IPCC assessment.

[29] The 17 Sustainable Development Goals are presented here: https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Figure 11. Comparative impact of major options for reducing greenhouse gas emissions on the Sustainable Development Goals



Source: [*Négawatt 2020*]()

In conclusion, nuclear power's contribution to stabilizing global warming below 1.5°C is far from achieving consensus in the scientific literature, unlike energy conservation and renewable energy. Developing nuclear power is not a mandatory measure to stabilize global warming below 1.5°C; as an option it must be weighed based on its actual feasibility and social and environmental sustainability.

CHAPTER 2.

NUCLEAR ENERGY: INCOMPATIBLE WITH CLIMATE, NATURAL AND GEOPOLITICAL RISKS

Nuclear power plants: high-risk facilities

If we stick to the exaggerated reading of the IPCC report by certain stakeholders, 700 to 2,000 new nuclear reactors around the world should be built and brought online, in order of magnitude, by 2050. This means installing a large number in certain specific countries, or a few everywhere. But is this even feasible?

Nuclear power plants are high-risk facilities. In an interview with French daily Le Monde in 2016[30], Pierre Franck Chevet, former president of the Autorité de surêté nucléaire (ASN), France's nuclear watchdog, did not rule out the possibility of a major nuclear accident in Europe or France:

> ***"In France, there can be earthquakes and floods greater than expected, along with acts of malice against a power plant… […] A major accident, such as Chernobyl or Fukushima, cannot be ruled out anywhere in the world, including in Europe. We need to keep this in mind. Fukushima had a radiological impact across a 100-km radius. If you draw a 100 km circle around Europe's nuclear power plants, you can see that, for many of them, several countries are implicated."***

This is particularly the case in France, where several power stations are located close to the Belgian, Swiss and Luxembourg borders. In France, according to a study by the Institut de Radioprotection et de Sûreté Nucléaire (IRSN)[31], the cost of a "major" accident could reach €430 billion and create hundreds of thousands of "radiological refugees".

In the event of a nuclear accident, the economy would be severely and sustainably affected, the soil and water polluted, and the risks of contamination of the population very difficult to control, even decades later. Power stations cannot be installed just anywhere, and there are risks that will increase in the coming decades: from seismic faults, political instability and terrorist risks, to the need to secure a cold-water source at all times in a context of water stress and rising sea levels. Nuclear power is not installed everywhere – far from it.

Nuclear power in the face of water stress, the warming of rivers, and rising temperatures

Nuclear power: a water-hungry technology Nuclear power consumes a lot of water for cooling. Consider France: In 2016, nuclear power was by far the largest water-harvesting activity in France; far superior to agriculture or drinking water, with 15.7 billion cubic meters used to cool plants (see Figure 12)[32].

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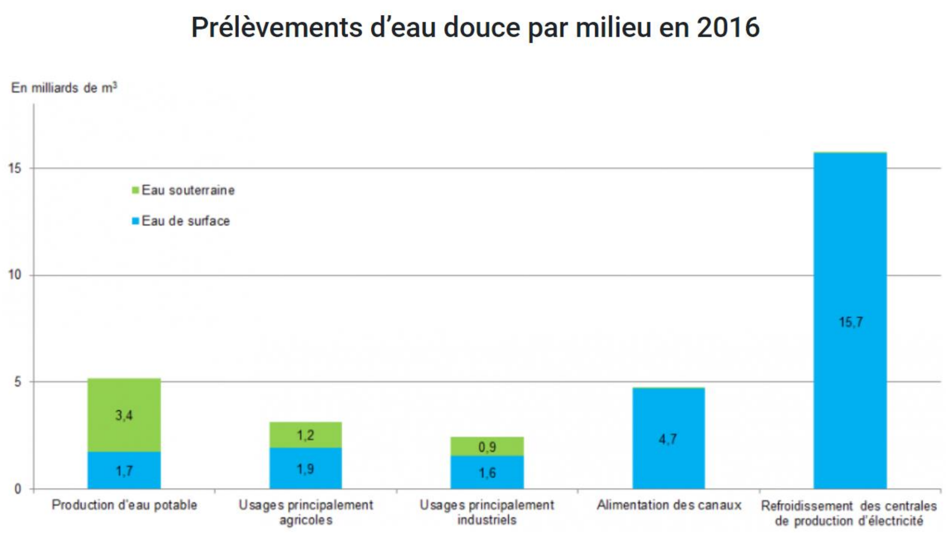
[30] *Le Monde*, interview with Pierre Franck Chevet, "30 ans après Tchernobyl: un accident nucléaire majeur ne peut être exclu nulle part dans le monde", 22 April 2016 (article consulted on 8 October 2020) (in French).
[31] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), "Le coût économique d'un accident nucléaire: le coût économique pour deux scénarios accidents" (Special issue, consulted on 8 October 2020) (in French).
[32] Ministry of Ecological Transition, Rapport sur l'état de l'Environnement en France, 2019 edition.

Approximately 10% of the water taken is not returned to the aquatic environment and is classified as "consumed". In total, nuclear power accounts for 30% of water consumed each year, second only to agriculture according to INSEE[33].

Water taken from the environment is not returned in the same conditions: the discharged water is warmer and contributes to warming the stream, which has a significant effect on ecosystems. Moreover, several plants installed along a river mean more cumulative warming (12 and 14 reactors are located along the Rhône and the Loire, respectively). For each plant, maximum temperature thresholds are set (for example, at the Golfech plant, the limit is set at 28 °C). If the temperature of the watercourse is higher than usual, due to a heat wave or a decrease in flow, this may lead to a discharge authorization being suspended and thus to the shutdown of the reactor.

Figure 12. Fresh water withdrawals in France in 2016 (expressed in billions of cubic metres)



Source: Le Rapport de l'Environnement, Ministère de l'Ecologie, 2019 (in French)

Already, in the United States and France, nuclear reactors are shut down or activity is drastically slowed during heatwaves. In July 2020, the driest month since 1959, the two powerful 1450-MW reactors at the Chooz power station (located in the Ardennes, France) were shut down because of the pressure imposed on the Meuse river, the flow of which had been divided by ten. The Golfech plant (located in southwest France suffered from the lowest rainfall recorded in the Haute-Garonne region in the last 60 years.

More generally, rising temperatures can weaken power plants and equipment. According to a note published in July 2020 by the IRSN[34], "*high temperatures can affect the operation of ventilation and safety equipment and the cooling capacity of safety systems that evacuate reactor power. [...] In particular, emergency generators (or "diesels") are essential equipment for reactor safety in the event of accidents. High outside temperatures can interfere with their operation."*

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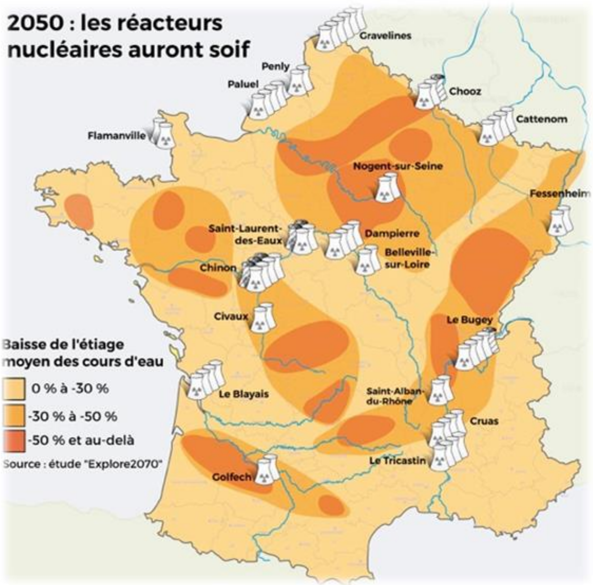
[33] INSEE, Les acteurs économiques et l'environnement, 2017 (p. 144).

[34] Institut de Radioprotection et Sûreté Nucléaire (IRSN), L'effet de la canicule sur la production et la sûreté des centrales nucléaires, briefing note, 31 July 2020 (in French).

In the longer term, low-water flows in rivers are likely to decrease significantly, according to Explore 2070 modelling work.[35] Many of the reactors in operation across the country are located in an area affected by significant decreases in low-water levels (see Figure 13).

Figure 13. Illustration of the decline in average low water levels of rivers by 2050 in France



Source: [Réseau Sortir du Nucléaire](#) based on the Explore 2070 Study (in French)

This water shortage is global: by 2050, at least one in four people could live in a country affected by chronic or frequent water shortages, according to the World Resource Institute.[36] India, the country currently building the most nuclear capacity (and where France hopes to build nuclear power plants), is among the 17 countries most affected by the water crisis. Reactors in operation may be regularly shut down due to water shortages and compete with other uses (e.g. agriculture). In countries that rely heavily on nuclear power, there is also the risk of pressure on supply security and of exemptions granted to operate reactors at all costs, which could increase environmental consequences or reduce safety margins.

Nuclear power in the face of floods and rising oceans

Other phenomena will intensify as a result of global warming and further weaken nuclear power plants.

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[35] Ministry of Ecological Transition, "Bilan du projet Explore 2070, résultats du projet et premiers enseignements sur eau et changements climatiques" (in French). Consulted here: http://www.gesteau.fr/sites/default/files/gesteau/content_files/document/explore2070.pdf

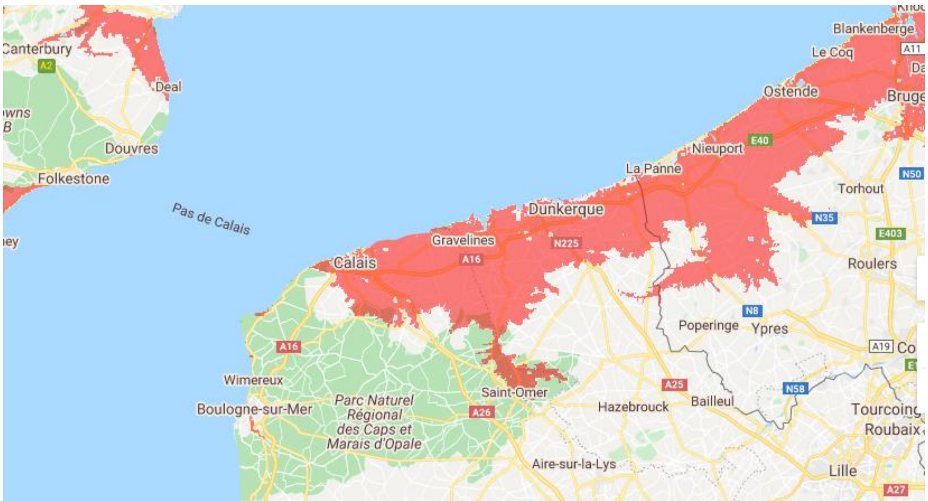
[36] World Resource Institute, Aqueduct Project, 2019.

Floods will become more intense and frequent and could threaten the safety of nuclear facilities. In these conditions, is it a good idea to build nuclear reactors in areas regularly hit by floods? This is happening in Bangladesh, for example: Russia launched a construction site there in 2017 on the edge of the Padma River. At the end of August 2020, two months of torrential rain caused the river to overflow. This is the region in Bangladesh most affected by floods this year. The site was chosen in 1963; at that time, climate risk was not taken into account. Despite the alarming projections of scientists, Russia continues to build.

Rising sea levels mean that many of the world's coastal areas will be below sea level by 2100 and subject to the risk of flooding, raising questions about whether nuclear power plants can be built in a given area. The risk of drought has led to the conclusion that nuclear power plants should be built next to the sea rather than rivers to ensure their operation, but coastal areas will be vulnerable to other types of extreme events: floods, storms, tidal waves, and in seismic, tsunami-prone zones. France will not be spared. According to projections by the European Environment Agency[37], sea levels on the French coastline could rise between 20 cm and one metre. An extract from a global model developed by Climate Central[38] shows that the location of the Gravelines generating station – which was built on a polder – is susceptible to flooding (see Figure 14). And yet it is one of the sites being considered for the construction of two new EPR reactors.

As a reminder, the Blayais power station near Bordeaux, France narrowly escaped disaster during the storm of 1999. Between the high tide that swelled the Gironde estuary and 140 km/hour winds, the dike that was supposed to protect the power plant did not withstand the waves that drowned part of the safety installations.

Figure 14. Projection of known flood risks areas in 2050 in the region where the Gravelines power station is located (areas in red)



Source: Climate Central

[37] European Environment Agency, Climate change impacts in Europe (ArcGIS).. Consulted: July 2020.
[38] Climate Central, Coastal risk screening tool, consulted: July 2020.

Nuclear power and seismic risk

Climate change-related risks are of course additional to the already known ones posed by natural hazards: seismic risk, for example. This is a deployment challenge and a constraint to consider when planning to build nuclear power plants around the globe.

The planet is widely exposed to seismic risks. The nuclear industry points out that already many nuclear reactors are located in seismic zones: according to the World Nuclear Association[39], in 2012, nearly 20% of existing plants were installed in high-risk seismic zones. But in no way should this existing situation minimize the additional risks of building new reactors. They are difficult to master, and expensive to anticipate. They require intensive monitoring, and there is no guarantee that the risk is properly assessed and taken into account. The Fukushima disaster in 2011, for example, led nuclear safety authorities around the world, including in France, to raise seismic standards in nuclear power plants.

This is not to be taken lightly: some power plants are located below the level of the nearest river and protected by dykes that must be able to withstand an earthquake. If the dyke were to break, the power plant would be flooded. This is the case at the Tricastin and Fessenheim plants, for example. It is important to note that the prescribed standard is not always the one applied: in France, not all nuclear power plants are compliant, eight years after standards were made more stringent. Seismic risk requires compliance with the very strict specifications of the French Nuclear Safety Authority (ASN), but calculations are theoretical and, in practice, EDF is often behind schedule on required work. In 2018, for example, the ASN demanded that EDF repair the “resistance defects” found on the dyke which is supposed to protect the Tricastin power plant[40]. EDF has still not completed this work.

Moreover, seismic standards could be updated further in the future.

A continually evolving risk Seismic risk and how it is assessed changes over time. In France, plants were designed on the basis of a given seismic risk assessment. However this risk has evolved since: the risk map adopted in 1991 was modified in 2011[41] (see Figure 15) and rated seismic risk in France higher than before. Since 2011, 12 out of France’s 19 power plants are located in seismic zones. Some have been included in the zone since, and others have been classified as higher risk (see Figure 16).

Following the Teil earthquake in 2019 near the Cruas and Tricastin nuclear power plants, the IRSN is investigating the need to revise seismic benchmarks upward, and CNRS seismologists[42] are even considering updating their assessment of seismic risksin France, because the Teil earthquake occurred on a fault that was classified as “inactive.” A reassessment of seismic risk would involve additional studies, possible resizing work, as well as additional costs and risks. In early 2020, all of

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39 World Nuclear Association, page consulted on 8 October, 2020.

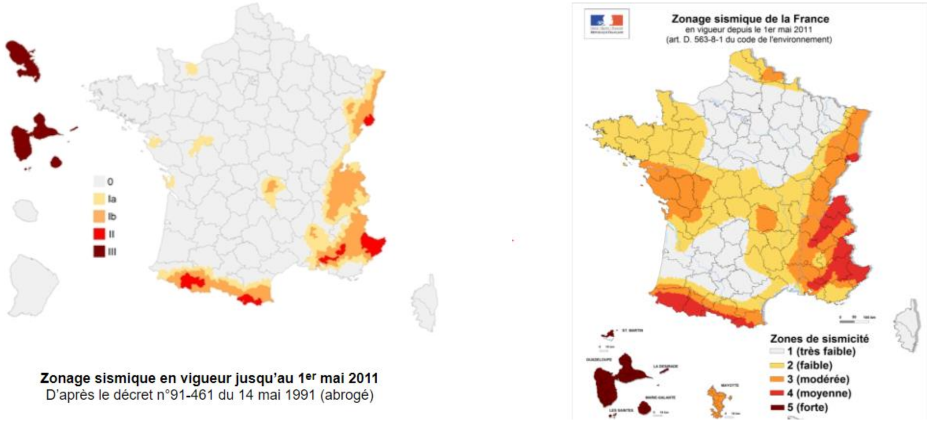
40 Letter from the ASN dated 25 June, 2018 (in French).

41 Plan Séisme, Seismic zoning in France, maps valid before and after 2011 (in French).

42 CNRS, The Le Teil earthquake provides new insights on seismic risk in France and Western Europe, 2020

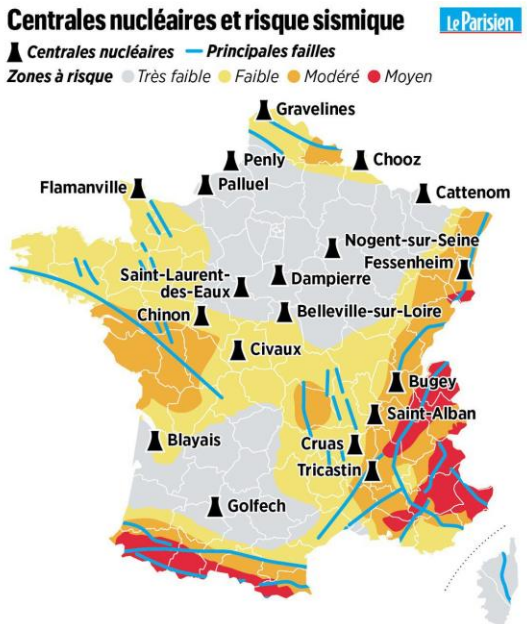
this did not prevent several elected representatives from the Tricastin region from promoting the construction of two EPR reactors at the existing plant site.[43]

Figure 15. Seismic zoning in France before and after 2011



Source: [Plan Séisme France](#) (in French)

Figure 16. Construction of nuclear power plants in identified seismic zones since 2011



Source: Chart published in the Le Parisian daily paper [Le Parisien (2019)](#)(in French)

[43] *Le Dauphiné*, article dated 11 February 2020 (in French)

A risk impossible to control 100% If, to avoid 10% of GHG emissions in 20 years, we had to start one reactor per week by then, how many would end up in seismic zones? Turkey and India are among the countries most exposed to seismic risks: they are also two countries with reactor construction sites. Unfortunately, even with stringent standards, it is well known that this is not necessarily enough to avoid catastrophe, especially when factors accumulate (seismic risk + tsunami-prone coastal zone, for example). This is what happened in Fukushima, Japan, in 2011: to this day, entire areas around the plant remain condemned. Others have been more or less properly decontaminated, at great expense. There are still “hot spots,” i.e. areas where radioactivity is too high (even in the Olympic village according to recent measurements taken by Greenpeace in 2019).[44] Decommissioning of the site will take at least 40 years, and has not begun. The Japan Center of Economic Research[45] estimates that the total cost of the disaster could reach €400 billion to €570 billion.

Nuclear power is also a weapon, a target, and a risk

Nuclear power is also vulnerable to malicious acts. Nuclear factories and plants are easy targets for malevolent acts: terrorist threats, the risk of unintentional or voluntary airliner crashes, and cyberattacks. The enclosures of plants and certain ancillary buildings containing radioactive materials are not designed to withstand this type of attack or shock. French nuclear power plants are ageing: they were designed in another era, with the information available at the time, and in a context that has changed enormously since then. At the time, engineers did not factor in the risk of a serious accident, did not foresee the risk of an airplane crash, or the risk of malevolence or terrorism that would have required bunkering certain buildings, reinforcing the thickness of containment enclosures, etc. These vulnerabilities were the subject of a Parliamentary Inquiry Committee and a series of recommendations by the French National Assembly in 2018[46].

Nuclear materials are dangerous and can be diverted. Under certain conditions, civil nuclear power can make it possible to manufacture materials that are themselves used to make bombs (with highly enriched uranium or plutonium). Plutonium is an extremely dangerous material and must not be allowed to proliferate. In France, plutonium is produced in power plants. Following “reprocessing” operations at the La Hague plant in north-western France, plutonium is then transported on French roads to the South-east region of the country. Greenpeace has already repeatedly denounced and demonstrated the vulnerabilities of this type of transport to malicious acts.

Nuclear power plants in geopolitically unstable zones? The presence of hazardous materials and the vulnerability of facilities to malicious acts make their construction all the more dangerous in politically unstable parts of the world.

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[44] Greenpeace International, Letter to the Japanese Minister of the Environment, November 18, 2019.
[45] Japan Research Center, Accident Cleanup Costs Rising to 35-80 Trillion Yen in 40 Years, 2019.
[46] Rapport de la Commission d’Enquête sur la sûreté et la sécurité des installations nucléaires, July 2018 (in French).

And what about countries that find it difficult to build an independent and sufficiently powerful nuclear watchdog? This problem is discussed in the IPCC special report on 1.5°C[47]: *"The safety of nuclear plants depends on the public authorities of each country. However, because accidents affect worldwide public acceptance of this industry, questions have been raised about the risk of economic and political pressures weakening the safety of the plants (Finon, 2013; Budnitz, 2016)".*

This did not stop Nicolas Sarkozy, then President of France, from seeking to sell nuclear power plants to Libya in 2008. In 2020, the construction of nuclear power plants was mentioned during Emmanuel Macron's visit to Iraq[48].

[47] IPCC, Special Report: 1.5°C Global warming, Chapter 4, page 19 (2018).

[48] Reuters, "Macron parle de coopération militaire et énergétique avec le chef du gouvernement irakien", September 2020 (in French).

CHAPTER 3.

NUCLEAR POWER, AN ECOLOGICAL DISASTER

Nuclear power is not green

Increasingly, a semantic shift occurs: because nuclear power is low-carbon, it is necessarily virtuous, "green," and "sustainable." France is pushing Europe to integrate nuclear power into the "taxonomy of green investments." The government's stimulus package has chosen to include nuclear power in its "ecology" and "green" hydrogen chapters.

But this ignores a major nuclear-specific problem: radioactive waste that is dangerous to both the environment and people for hundreds or even hundreds of thousands of years. When making a technological choice, however, it is essential to consider all of its environmental and social externalities.

The environmental factor is enormous in the case of nuclear power. At each stage of the manufacturing and combustion process, upstream and downstream, there is waste and pollution and the contamination of water, soil and populations.

Nuclear energy produces unrecoverable waste at each stage

Waste as soon as the uranium is extracted. It starts from the moment of extraction: nuclear energy, like coal, is an extractive industry for which raw material is sought in the soil, in Niger, in Canada, in Kazakhstan, in Australia and elsewhere. A large amount of mine waste and tailings – low in radioactivity, of course, but still a source of pollution and dangerous in the event of prolonged exposure or ingestion – remain on site[49]. Uranium is no longer mined in France, but there are over 200 former mining sites in the country[50], with more or less effective monitoring of soil pollution at these sites. Also problematic on all extraction sites is the razing of forests and ecosystems sacrificed to allow access to the site. This is notably the case in Kazakhstan, where Orano has obtained authorization to raze a protected forest to create a mining site.

Non-recyclable nuclear waste every time you turn on the light. Nuclear power generates significant amounts of nuclear waste during the production of electricity. Let's not forget: every time we turn on the light, unless we buy electricity from a supplier who does not buy nuclear electricity, we contribute to the production of a little more nuclear waste. Worldwide, the International Atomic Energy Agency has identified more than six million cubic metres of radioactive waste. In France, the official inventory lists almost one million cubic metres of nuclear waste in the country linked to nuclear power plant activity.[51] This figure excludes other waste that is qualified as "valuable

[49] *Le Monde*, "À Arlit, les gens boivent de l'eau contaminée par la radioactivité", interview with Amina Weira, 2018 (in French).
[50] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), "Exploitation des mines d'uranium en France: impact environnemental et risque pour les populations", special edition, updated in 2017 (in French).
[51] Agence nationale pour la gestion des déchets radioactifs (ANDRA), Inventaire national des matières et déchets radioactifs, édition 2020 (in French).

materials." But in reality, these materials are not revalued and are, for the most part cannot be – unless we find technical solutions that still do not exist after more than 60 years of research. Furthermore, these proposed "solutions" would make it necessary to continue the nuclear programme – and thus the production of new radioactive waste – in order to reuse these materials.

In the meantime, less than 1% of spent fuel and less than 2% of other so-called valuable materials are actually used.[52] The rest piles up, without a storage solution, on the grounds that one day it may be possible to reuse these materials (see figure 17). But the prospects for recycling this waste are too low or distant to reduce the stocks already accumulated in France (see figure 18).

Figure 17. Stocks of non-recycled "valuable materials" accumulated in France by end 2017 (in tonnes of heavy metal).

Tableau 1. Stocks de matières à requalifier en déchets[48]

Matière	Production par an[50] (en tonnes de métal lourd)	Taux de réutilisation actuelle par an	Perspective de « valorisation » future ?	Stock accumulé fin 2017[51]	Quantité de « matière » à requalifier en déchet fin 2017
Uranium appauvri	6720 tML	1,6 %	Très faible	315 000 tML	315 000 tML à requalifier en déchets FA-VL
Combustible Usé UNE	1080 tML	Moins de 1 %	Très faible	11 522 tML	11 522 tML à requalifier en déchets HA-VL
Combustible Usé URE	0 tML	0 %	Non démontrée	631 tML	631 tML à requalifier en déchets HA-VL
Uranium de Retraitement	1026 tML	0 %	Très faible	30 500 tML	30 500 tML à requalifier en déchets FA-VL
Combustible MOX usé et en cours d'utilisation	110 tML	0 %	Non démontrée	2381 tML	2381 tML à requalifier en déchets HA-VL
Total	**Fin 2017, déjà 360 000 tonnes de « matières » qui sont en réalité des déchets HA-VL et FA-VL**				

Source: Tableau Greenpeace 2019 (based on ANDRA inventory) (in French)

[52] Greenpeace, A quel prix? Les coûts cachés des déchets nucléaires, 2019 (calculated using the ANDRA database) (in French).

Figure 18. Review of possible uses of this stockpiled "material"

Tableau 2. Synthèse des pistes de valorisation identifiées par la filière nucléaire

Pistes de valorisation	Maîtrise/faisabilité technique	Conditions socio-économiques	Capacité à réduire les stocks	Horizon de temps
Piste n°1. Maintenir le retraitement	· Installations vétustes · Rejets radioactifs et effluents	Coût-bénéfice non démontré	· Très faible · Le stock de combustible non-retraité augmente chaque année	Jusqu'en 2040 officiellement mais en cas de saturation et aléas, cela ne sera pas possible
Piste n°2. Moxer des réacteurs 1 300	Modifications techniques importantes non abouties	Coût-bénéfice non démontré	· Augmente les stocks, au lieu de les réduire · En concurrence avec l'urtage	Envisagée à partir de 2032
Piste n°3. Enrichir l'uranium de retraitement (l'urtage)	Pas de capacité industrielle en France	Pratique cessée car non-rentable selon Areva à l'époque	Très faible et pas avant 2040, en concurrence avec le moxage	Reprise annoncée pour 2023
Piste n°4. Enrichir l'uranium appauvri par centrifugation	Techniquement faisable mais pas à une échelle industrielle	· Coût-bénéfice inconnu · Pas rentable actuellement selon Orano	Très faible	n/a
Piste n°5. Recycler combustible MOX	· Au stade de la R&D seulement · Nécessiterait nouvelles installations	Rentabilité non démontrée, débouchés non garantis	À condition d'avoir 38 EPR en France selon EDF	n/a
Piste n°6. Réutiliser les matières dans des réacteurs à neutrons rapides (RNR)	Au stade de la R&D depuis 1960	n/a	n/a	Pas de prototype avant 2040 au mieux

Source: Tableau Greenpeace 2019

This toxic waste is not at all biodegradable

The radioactivity of nuclear materials and waste decreases over time. "Short-lived nuclear waste must be monitored and contained for up to 300 years. In the case of "long-life" waste, however, radioactivity only decreases enough after thousands, tens, or hundreds of thousands of years. It will therefore be necessary to monitor them and ensure that they do not contaminate the environment and populations – for lengths of time that exceed human understanding. Some waste, referred to as "high-activity", is particularly dangerous. This is particularly the case for spent fuel discharged from nuclear reactors, which remains radioactive for hundreds of thousands of years. A person standing one meter from a spent fuel assembly that was discharged from a reactor a year earlier would receive a lethal dose in about one minute.[53]

[53] Allan Hedin "Spent nuclear fuel - how dangerous is it? A report from the project 'Description of risk', SKB Report - Technical Report TR-97-13 (March 1997)

Figure 19. Timeline of the average lifetime of plutonium 239

Source: Greenpeace, 2019

It is precisely this waste for which no viable long-term management solution exists. So far, waste disposal projects for the most radioactive waste have not yielded conclusive results anywhere in the world.[54] In France, the Cigéo project in the region of Meuse does not solve these problems either. France Nature Environnement recently published a study[55] questioning the solidity of the geological layer chosen by the authorities to store our highly radioactive waste in the Meuse. Many questions, notably concerning the project's capacity to properly contain this waste for thousands of years (there is a risk of fire or leakage into the ground or groundwater) or its reversibility (in reality very limited, hypothetical and complex, which would prevent any subsequent solution), remain unanswered. For existing high activity and long-lived waste, secure "subsurface" dry storage is an alternative, put forward in particular by Greenpeace. But the current lack of a solution should, if anything, be an incentive to stop producing more radioactive waste.

Daily pollution

Also important to remember is radioactive discharge into water and the atmosphere, which happens on a daily basis (see Figure 20)[56]. Nuclear safety authorities establish thresholds to not exceed, but this still represents pollution. Operators are granted a right to pollute. This pollution is not always monitored: leakage into the environment occurs regularly.

Cases of chronic tritium pollution of rivers and streams are regularly reported[57] [58]. For example, on November 6, 2019, in the middle of the fourth 10-year visit, EDF alerted the ASN to abnormally high

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[54] See the 2019 Greenpeace report, The global crisis of nuclear waste for a review of waste storage projects around the world.

[55] France Nature Environnement, Enfouissement des déchets radioactifs: un schéma qui remet en cause le projet Cigéo, August 2020 (in French).

[56] Autorité de sûreté nucléaire (ASN), Etat de la sûreté et de la radioprotection en France en 2019 (2020)

[57] CRIIRAD, "Contamination en tritium dans l'environnement: une pollution qui ne doit pas être banalisée", June 2019 (in French).

[58] Tritium is a radioactive isotope of hydrogen. It is produced in very large quantities in the heart of nuclear reactors and found in liquid and gas forms of waste. Sometimes it is found in drinking water. Beyond a certain threshold, and for certain populations, tritium is not harmless.

levels of tritium in the water underneath the Tricastin plant – 1,150 becquerels per litre, which exceeded the authorized threshold of 1000 becquerels/litre. Since then, the piping of the leaking effluent tank has been repaired, but according to EDF, *"a few peaks in tritium activity, up to 5,300 Bq/l*[59]*, were recorded in November and December 2019. [...] we could observe, in connection with this event, new fluctuations or peaks in tritium activity at the level of the internal groundwater table in the weeks or even months to come"*[60]. Already in 2013, a leak in an underground building and the lack of sealing joints between buildings caused tritium to migrate to the table and pollute the groundwater – despite discharging into water tables being strictly prohibited.

Figure 20. Liquid and gas radioactive discharge reported by EDF in 2019

Source: rapport annuel de l'ASN 2019

At the La Hague power station, large volumes of contaminated water are discharged a few kilometres from the coast every day into the English Channel via a large pipe from the plant. And this is legal, whereas, paradoxically, it is no longer permitted to dump nuclear waste drums into the sea. At the Malvési site, a few kilometres from the centre of Narbonne, there are basins filled with effluents – open-air "radioactive sludge".[61]

[59] 5,300 becquerels corresponds to a level 2,000 times higher than the level of detectable tritium in an uncontaminated water table.
[60] EDF, Note sur le marquage en tritium de la nappe contenue dans l'enceinte géotechnique de la centrale du Tricastin, 2020 (in French).
[61] Agence nationale pour la gestion des déchets radioactifs (ANDRA), Inventaire 2019, focus sur les bassins de Malvési

An immense environmental disaster in the event of a nuclear accident

After the Fukushima disaster, Japan must also manage the mountains of waste: those related to site decontamination and plant decommissioning, and those directly related to the accident. One example are the contaminated waters of Fukushima, which the Japanese government does not know what to do with and which it proposes to dump into the sea. In total, more than 1 million cubic metres of radioactive water is stored in 977 tanks at the Fukushima[62]site. Volumes continue to rise every day, even if in more moderate quantities than the first few years after the disaster. Since 2019, the government has proposed to release this contaminated water as vapour into the atmosphere or directly into the ocean, gradually, for years. If the pollution were visible, in the form of fluorescent yellow plastic straws or beads, would the Japanese government and nuclear industry have suggested such a measure?

Nuclear waste adds to the bill

Managing mountains of nuclear waste already costs a fortune in all nuclear countries[63], and the bill is increasing. For example:

- **In Belgium**, total costs, including a margin for unforeseen events, were estimated at €3 billion in 2011, but are now estimated at €8 billion or even €10 billion.
- **In Sweden**, in 2017, the SKB (Swedish Nuclear Fuel and Waste Management Co) estimated at €9.5 billion the total future cost, until their closure, of all management facilities which process all the waste from nuclear reactors.
- **In Japan**, the cost of waste storage was estimated at €29 billion in 2011 by the Ministry of Economy, Trade and Industry (METI). But delays of several decades will result in much higher costs.
- **In the United States**, in 2008, the Department of Energy (DOE) published a revised life-cycle cost estimate of €100 billion for the indefinite storage of 70,000 tonnes of spent fuel from commercial reactors at the Yucca Mountain site. But, with the estimated production over 112,000 tons of spent fuel if the reactors continue to operate, these costs will also rise significantly.
- **For the United Kingdom**, cost models for the planned storage facility reached €12.6 billion in 2008, but excluded spent fuel from new nuclear reactors. Everywhere in the world, the uncertainties are enormous.

In France, concerning officially inventoried waste, the total invoice at the end of 2018 came to €73 billion for the CEA, Orano and EDF. Every year, operators must finance the management of the additional tonnes of waste produced. For example, costs for EDF increased €3 billion per year

[62] *Le Monde*, Eau contaminée: poison durable de Fukushima, 12 September 2019 (in French).
[63] Greenpeace, The global crisis of nuclear waste, 2019.

between 2010 and 2018,[64] and this excludes the costs of managing “valuable materials.” These materials are not considered waste today, which alleviates the burden on operators; but some or all will one day be reclassified as waste, given the absence of feasible options for recovery. In a report published in 2019[65] during a national debate in France on nuclear waste, Greenpeace estimated that the cost of the additional waste already stands at around €18 billion. This does not include the cost of materials and waste to come in the future. Also necessary is a reassessment of the cost of the geological deep disposal project, which, as it stands, is not sized to store these additional volumes, and the cost of which has been underestimated. In 2019, the French Court of Audit[66] warned of the costs of this non-standard project and recommended a more "realistic" costing exercise.

[64] Greenpeace calculation based on EDF annual reports between 2010 and 2018.
[65] Greenpeace, A quel prix? Les coûts cachés des déchets nucléaires, 2019 (in French)
[66] French Court of Audit, L’aval du cycle du combustible, July 2019 (in French).

CHAPTER 4.

NUCLEAR ENERGY:
TOO EXPENSIVE

The cost of producing nuclear electricity is rising. And that of renewable energy is declining

The era of "cheap nuclear power" is over. According to the French Court of Audit[67], the cost of producing nuclear electricity in France is increasing (see Figure 21). According to the national comptroller, the current economic cost has increased from €49.6/MWh in 2010 to €59.8/MWh in 2013 and then to €62.6/MWh in the second half of 2014: an increase of more than 20%.

Figure 21. Trends in production costs for EDF between 2010 and 2013

Tableau A : comparaison des coûts de production d'EDF 2010-2013

En M€ courants	2010	2013	2013/2010
Dépenses d'exploitation	9 017	10 003	+ 10,9 %
Investissements sur le parc existant	1 747	3 804	+ 117,7 %
Provision pour gestion des déchets et du combustible usé	1 133	1 301	+ 14,8 %
Provision pour démantèlement	461	520	+ 12,8 %
Loyer économique	7 880	8 501	+ 7,9 %
Total	**20 238**	**24 129**	**+ 19,2 %**
Production en TWh	407,9	403,7	- 1 %
Coût en €/MWh	**49,6**	**59,8**	**+ 20,6 %**

Source : Cour des comptes et EDF

This per-MWh cost is probably even higher today, in particular due to the decrease in the fleet's production (from a traditional 410 TWh to 379 TWh in 2019 and 325 TWh in 2020, according to EDF estimates). Fixed costs, however, have not decreased.

This is partly linked to a major refit investment programme (to upgrade to post-Fukushima standards and "renovate" the reactors to extend their lifespan, the cost of which is currently estimated by the Court of Audit at €100 billion by 2030[68]), but also linked to the costs of waste and dismantling, which EDF regularly reviews upwards.

This cost is now comparable to the production costs of the most recent renewable energy plants. The costs of these continue to fall, to between €50 and €65/MWh on average for wind and solar power – approximately the same amount it costs to generate nuclear power.

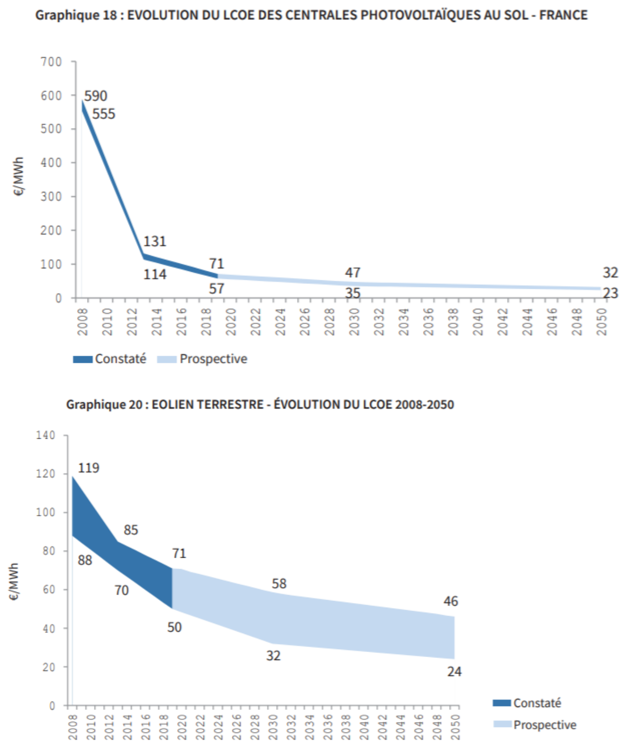
[67] French Court of Audit, Le coût de production de l'électricité nucléaire (published in 2013 and updated in 2014) (in French).

[68] This is only an estimate: the nuclear watchdog has not yet determined the requirements for projects to expand reactor lifespans, and will publish standards to be met on a case-by-case basis, after a very detailed visit of each nuclear reactor. For more information on the timetable, click here. Click herefor more about the issues and challenges related to the continued operation of reactors for more than 40 years, according to Greenpeace.

Photovoltaic solar energy: according to the CRE (French Energy Regulatory Commission)[69], costs are falling at a rapid pace; over the last three years alone, investment costs have fallen by an average of 32%. CRE judges the sector competitive. In 2019, "*over the last tendering period, average production costs ranged from €62 to €99/MWh depending on the size and type of facility. For large ground-based facilities, the costs of the most competitive facilities are around €48/MWh, including the IFER tax of €6/MWh*", according to the CRE. For the ADEME[70], the LCOE (Levelized cost of energy) for large ground facilities now stands at between €45 and €72 per MWh and will be further halved by 2050 (see Figure 22).

For onshore wind, the ADEME gave a range of €57 to €91/MWh at the end of 2016 and €50 to €71/MWh at the beginning of 2020. As with solar energy, the LCOE of onshore wind will be almost halved by 2050 (see Figure 22).

Figure 22. (Observed and prospective) trends in LCOE in France of ground-based photovoltaic power plants and onshore wind farms between 2008 and 2050 (Expressed in euros/MWh)



Source: ADEME, Coût de production des énergies renouvelables, 2020 (in French)

Critics of renewable energy like to invoke the "astronomical costs" of public support for the sector. In fact, much of the costs paid by consumers today (several billion euros per year) are for the first

69 CRE, Le photovoltaïque français, une filière compétitive, 2019 (in French).
70 ADEME, Coût de production des énergies renouvelables, 2020 (in French).

generations of solar and wind farms, when industry and government support were not mature and production costs were much higher. Renewable energy projects now require much less support, so the amount paid by consumers will decrease. It will reach its peak in 2025 and then decrease very rapidly before and after 2030[71]. Eventually, it will be almost nil.

Beyond investment costs, socio-economic benefits and spin-offs must also be assessed. According to an Ernst and Young study for the Syndicat des énergies renouvelables[72] published in January 2020, every euro of public support invested in renewable energies generates on average two euros of added value in 2019, and 80% of this value remains in France. In 2028, the renewable energy sector will generate €21 billion in gross added value in France. In particular in the regions that largely benefit from the development of renewable energy, the tax benefits of renewable energy for local authorities are estimated at €1 billion in 2019 and €1.6 billion in 2028. Nearly a third of these spin-offs are of direct benefit to city authorities.

Renewable energy also play an important role in cutting energy costs in France: thanks to them, €4.6 billion less was spent on fossil fuels in 2019 in the heating and transportation sectors.[73] In 2028, renewable energy will be the source of 236,000 jobs. This is more than the nuclear sector, which says it creates 220,000 (a very generous estimate made in 2008).

According to the ADEME[74], a 100 % renewable scenario would be the source of nearly 900,000 jobs by 2050. How? Energy transition sectors generate more employment that the fossil and fissile energy sectors do – a €1 million investment, for example, creates 16 building jobs and 14 in the renewable energy sector, compared to six in the nuclear and coal industries.[75]

“New” nuclear is even less competitive than renewable energy in France and worldwide

In France

The Flamanville EPR fiasco. According to the report published by the Court of Audit in 2020[76], the cost of the Flamanville EPR currently stands at €19 billion: in addition to the €12.4 billion in construction estimated by EDF, €6.7 billion in additional costs (notably financial costs) must be added. Again according to the Court of Audit, the cost of the electricity produced by the Flamanville EPR could be between €110 and €120/MWh, i.e. a cost three to four times higher than that initially forecast by EDF and twice the average cost of the most recent large renewable facilities[77]. These

[71] IDDRI et Agora Energiewende, Financing renewable energy by 2040, October 2019.
[72] Ernst and Young, La contribution des énergies renouvelables à l’économie, January 2020 (in French).
[73] Ibid
[74] ADEME, Vers un mix électrique 100% renouvelable: évaluation macro-économique, 2016 (in French).
[75] Quirion, Perrier, 2016
[76] Court of Audit, Rapport sur la filière EPR, July 2020 (in French).
[77] ADEME, Coût de production des énergies renouvelables, January 2020 (in French).

EPR-related costs will be paid by taxpayers and consumers. According to a non-public CRE note, EPR could increase the cost of generating nuclear electricity by 7%.[78]

> Les conséquences de ces dérives pèsent évidemment sur les coûts et la rentabilité de l'EPR de Flamanville. Son coût de construction est estimé par EDF à 12,4 Md€$_{2015}$, auxquels s'ajouteront des coûts complémentaires qui pourraient atteindre près de 6,7 Md€$_{2015}$ à la mise en service du réacteur, toujours prévue mi 2023, dont environ 4,2 Md€ de frais de financiers. Dans ces conditions, il est regrettable que ni EDF ni les autorités publiques concernées n'aient calculé la rentabilité prévisionnelle de l'EPR de Flamanville 3, considérant apparemment comme normal qu'elle soit diluée dans la moyenne de celle de l'ensemble des réacteurs du parc électronucléaire. En l'absence de données produites par l'entreprise, la Cour a estimé, sur la base d'hypothèses exposées dans le rapport, que le coût de l'électricité produite par l'EPR de Flamanville pourrait se situer entre 110 et 120 €/MWh.

Source: Court of Audit, Rapport sur la filière EPR, 2020 (in French).

The very high cost of future EPR reactors. In the long term, investing in the construction of new nuclear reactors would not be the most economically optimal way to reduce our CO_2 emissions.
In a study published in early 2020 that models the costs of a CO_2-free system with or without nuclear power[79], the CIRED concludes *that "these results dispel the notion that building new nuclear power plants is economically justified in France, especially given that in our estimates we have not taken into account the cost of a possible nuclear accident or the cost of waste management, and that the hypothesis (borrowed from the JRC) we have chosen for investment costs in power plants (€4500/kW) is well below the estimated costs for the EPR being built in Finland, France and the United Kingdom, or those estimated for the new nuclear power plants by Lazard Bank."*
To date, the cost reduction estimated at 30% by EDF and the nuclear industry if several EPR pairs are built has yet to be demonstrated.

A growing number of studies show that a 100% renewable electricity system does not present any additional costs. Nuclear and non-nuclear scenarios cost around the same amount: nuclear costs more in investment, waste management and dismantling, while renewable energy costs a little more in network/pilot management costs. According to a joint analysis by Alain Grandjean, Philippe Quirion and Behrang Shirizadeh[80], the total cost of nuclear and nuclear-free scenarios by 2050 would be around €35 billion each (see Figure 23).

In 2016, an ADEME study also concluded that the costs of a 100% renewable electrical mix would be in the same order of magnitude as a nuclear mix.[81]

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78 Contexte, le vrai coût du nucléaire est de 48 euros, 10 September 2020 (in French)

79 Philippe Quirion, Behrang Shirizadeh, Coût d'un système électrique optimal sans émissions de CO2 pour la France, avec et sans nucléaire(in French). Centre international de recherche sur l'environnement et le développement. 2020. ffhal-02434990f

80 Grandjean, Quirion and Shirizadeh, La montée en puissance des énergies électriques, (published in Enerpresse), January 2020 (in French).

81 ADEME, Un mix électrique 100% renouvelable? Analyses et optimisations, 2016 (in French).

Figure 23. Cost comparison for an energy mix with and without nuclear in 2050

Coût d'investissement (€/kW)	Nos hypothèses	Coûts observés par Lazard pour 2019[b]
Éolien offshore	2 500[c]	2 661
Éolien onshore	1 190[a]	1 001-1 365
Solaire PV	525/590/700[a]	819-1 001 (grandes centrales)
Nucléaire	4 500[a, d, e]	6 279-11 102
Turbines à gaz	550[f]	637-864

Résultats de l'optimisation avec un taux d'actualisation de 8 %

	avec nucléaire		sans nucléaire	
Coût annualisé (mds€)	35,3		35,8	
Production annuelle	**TWh**	**%**	**TWh**	**%**
Éolien maritime	0	0 %	49	8 %
Éolien terrestre	330	60 %	341	57 %
Solaire PV	98	18 %	141	23 %
Hydraulique au fil de l'eau	40	7 %	40	7 %
Hydraulique de lac	15	3 %	15	3 %
Biogaz	15	3 %	15	2 %
Nucléaire	52	9 %	0	0 %
Total	**550**	**100 %**	**601**	**100 %**

Source: Grandjean, Quirion, Shirizadeh (2020)

Around the world

EPR: An international fiasco. Currently, all EPR projects have been subject to significant cost overruns and delays.[82] The EPR in Taishan, China, started five years late and with a 60% cost overrun. The Hinkley Point EPR in the United Kingdom is already 18 months behind and has incurred €2 to €3 billion in additional costs. The EPR project in Olkiluoto, Finland, is 12 years behind schedule and triple its projected cost. The EPR in Flamanville, France, is now at least 11 years behind schedule and the cost is estimated at €19 billion (Court of Audit, 2020). It would appear that nuclear power is the only low-carbon technology is seeing its costs rise rather than fall.

New reactors are increasingly expensive. This trend is palpable around the world. According to Lazard, an investment banking firm[83], in North America, in 10 years, the cost of nuclear energy has increased by 23% on average, while the cost of wind has fallen by 69% on average and solar by 88% on average (see Figure 24). Several nuclear reactors will be shut down for reasons of profitability. This is also the case in Sweden, for example, where nuclear reactors 1 and 2 at the Ringhals site operated by Vattenfall will close five years ahead of schedule due to a lack of sufficient profitability.

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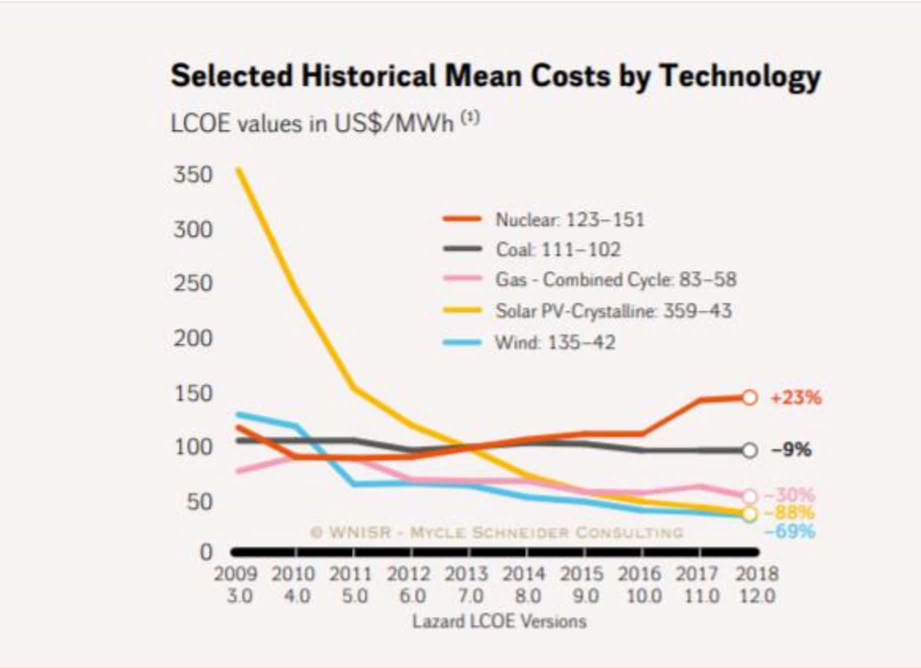
[82] Jean Martin Folz, Rapport au PDG d'EDF: la construction de l'EPR de Flamanville, September 2019.
[83] Lazard, Lazard's Levelized cost of Energy 13.0, November 2019.

Figure 24. Trends in levelised costs of energy (LCOE) by technology In North America (expressed in $US/MWh)



Source: World Nuclear Industry Status Report 2019(Lazard data)

Is renewable energy: also more competitive than coal and gas?

As we have seen, whether in France or in the United States, new renewable installations are seeing their costs fall and are becoming more competitive than nuclear power. But what about their competitiveness compared to coal and gas?

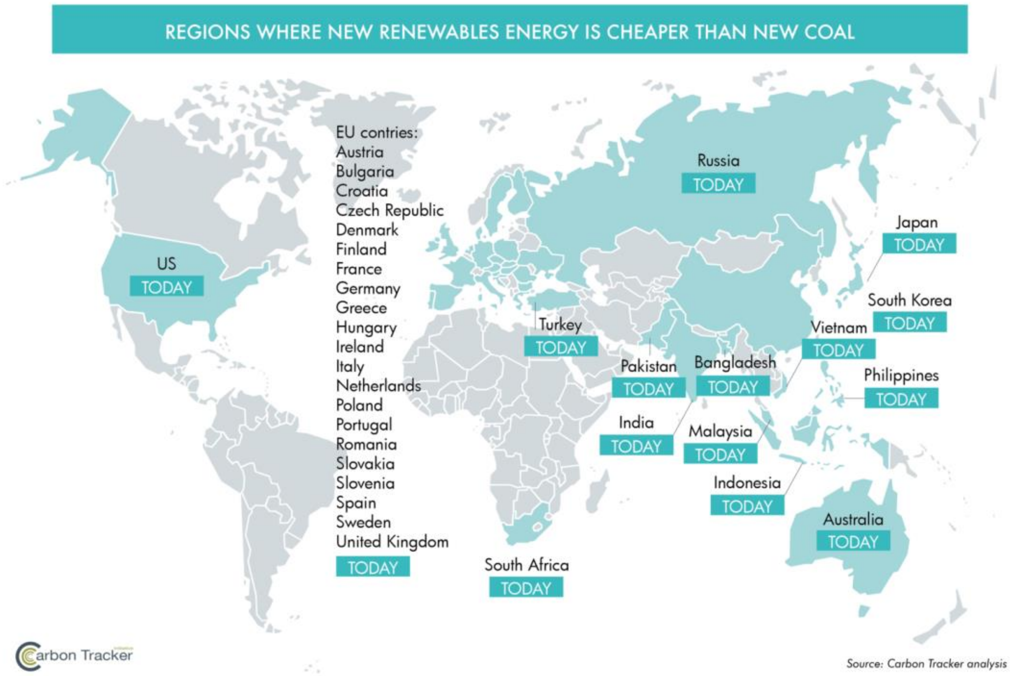
Data from Lazard shows that in North America, despite lower costs, coal and gas are now less competitive than certain renewable energy technologies (see Figure 24).

The increasing competitiveness of renewables compared to coal is confirmed by a recent report (2020) by Carbon Tracker[84]: in most countries, new renewable energy installations produce cheaper electricity than coal-fired plants (see Figure 25). For more than half of the coal-fired power plants in operation, continuing their operation would be more expensive than building new renewable capacity. This is even more true in Europe, where, according to CarbonTracker[85], 96% of coal-fired power plants produce more expensive electricity than newly installed solar and photovoltaic plants.

[84] Carbon Tracker, How to waste half a trillion dollars: the economic implications of deflationary renewable energy for coal power investments, March 2020.
[85] Ibid.

According to the report, investing in new coal-fired power plants will generate huge losses for investors (both governments and companies), that will amount to hundreds of billions of euros worldwide.

Figure 25. Regions of the world (in blue) where new renewable installations cost less than new coal-fired power plants



*Source: Carbon Tracker*report*, 2020*

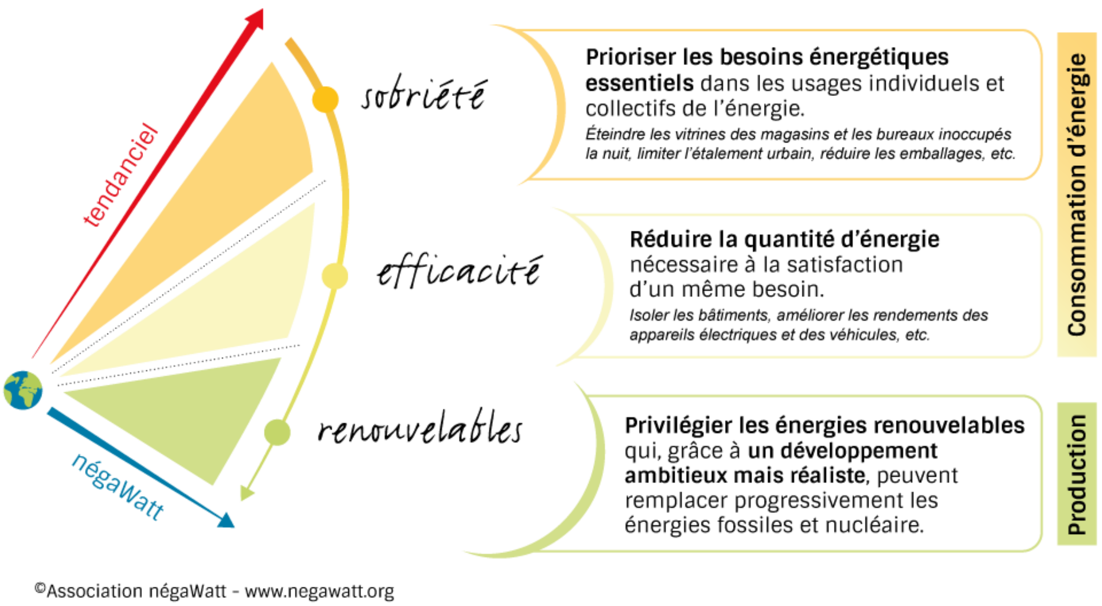
CHAPTER 5.

THE REAL SOLUTIONS ARE ELSEWHERE

What is the alternative to nuclear power?

Often, the question at this stage of reflection is whether there are reliable alternatives to nuclear development that can decarbonize electricity generation. This section provides an update on what options exist to both reduce greenhouse gas emissions from the electricity system and meet our needs. The first observation is that the low-carbon means of replacing fossil fuels – coal in particular – are renewable energies and energy savings.

Figure 26. The Négawatt approach



Source: Scénario Négawatt 2017-2050 (in French)

The second observation is that electricity, even 100% decarbonized, will not solve the climate equation, because most of our greenhouse gas emissions are elsewhere: in transportation, industrial agriculture, deforestation, and so on. Addressing the climate emergency requires priority action on these sectors.

Replace nuclear and fossil fuels with a complementary mix of renewable energies

Eventually, it will be possible to produce 100% low-carbon, renewable electricity

When the debate is exaggerated, it tends to oppose a scenario of nuclear power generation to a scenario of 100% wind power, for example. Yet this is not what is suggested in scenarios to generate 100% renewable electricity. They are almost all based on a mix of technologies. This is because leveraging the complementarity of renewable energy sources is the best way to optimize their intrinsic variability.

Most renewable energy sources (not all!) produce in a variable way, depending on the seasons, weather or the time of day. But, as a general rule, they do not produce at the same time, which makes it possible to spread production across a region and over time. Solar and wind potentials vary by region, season and schedule, so production can be spread at the national level and supply/demand managed at the country level (e.g. France) or regional level (e.g. Europe).

Moreover, their production is variable but predictable. Weather forecasting has greatly improved; it is possible to predict the production of renewable facilities several days in advance, and thus to control the electricity grid accordingly. In 2015, the ADEME scenario[86] on the feasibility of a 100% renewable electrical mix tested the hypothesis of a very cold but windless week and modelled it hour by hour. It concluded that 100% of electricity could still be produced using renewable energy sources.

To ensure a balance between supply and demand, the controllability of production and consumption will be key. Some renewable energies can already be directly controlled, such as hydraulic or wood energy for heating, for example. One can choose when to produce them and when to consume them. More generally, oversight is an important notion: Historically, production is controlled (which plant works when and to what degree); but now consumption must be controlled as well. Many uses are in fact painlessly controllable. For example, water heaters can be configured not to operate continuously and therefore unnecessarily, but to heat water at times when power generation is high and in surplus. The water remains hot even if it is consumed at another time of the day. There is also a series of resources that can be leveraged by RTE, France's electricity transmission system operator, to improve the piloting and flexibility of the network in case of production shortages (shutting down all advertising screens, for example).

Beyond oversight, we must do more, and reduce the amount of energy consumed – and thus to be produced. This will make it easier to achieve a 100% renewable mix but will also reduce the CO_2 footprint of electricity. To achieve this, it is essential to reduce so-called "power demand": in France today, demand for electricity is so high at times that the equivalent of 100 GW of electrical power is needed at certain times of the year. This is the case, for example, when all electric heaters are switched on at the same time, in addition to lights, screens, ovens, refrigerators, factories, etc. This

[86] ADEME, Vers un mix électrique 100% renouvelable en 2050 ?, 2015 (in French).

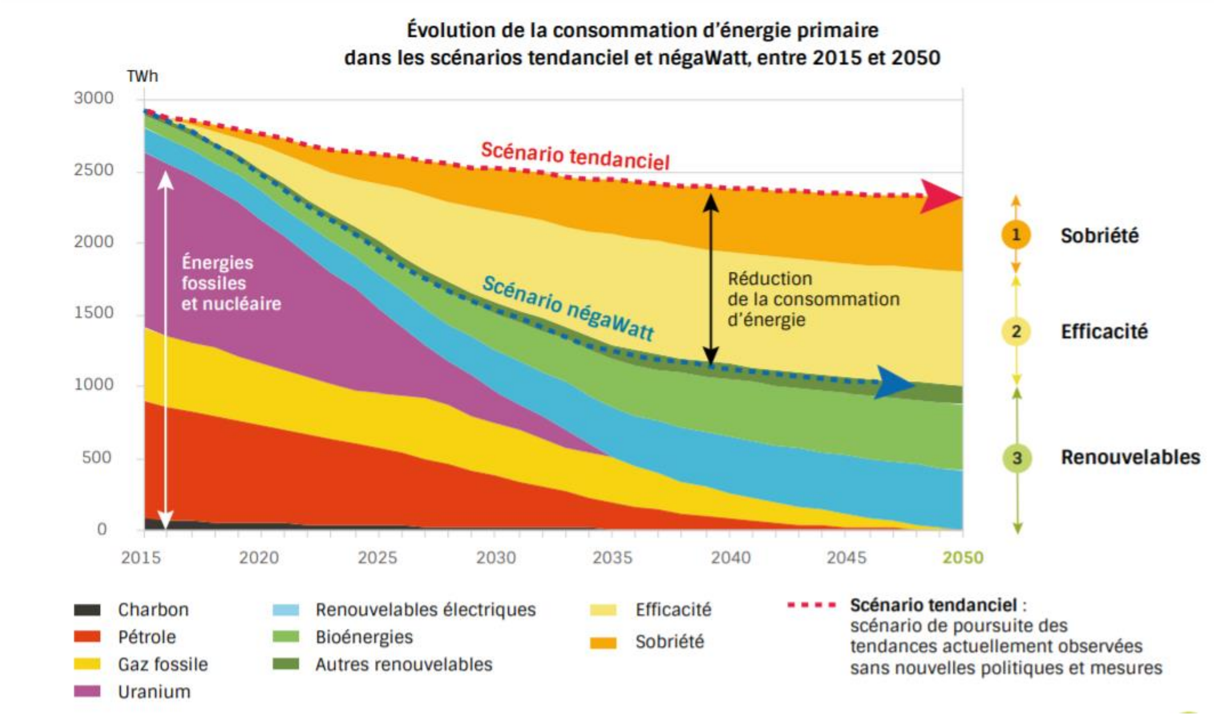
situation is unsustainable as it forces France to resort to emergency coal or gas-fired production because its low-carbon production units (including nuclear) are insufficient to meet demand. The solution is not to increase the means of production, but to try to rein in today's electricity consumption – an 'under-explored' idea today. In the Négawatt scenario[87], for example, in 2050, the maximum power demand would no longer be 100 GW, but only 60 GW, owing to efforts to pilot and reduce consumption (including eliminating energy-intensive heaters and renovating all buildings). In short, the lower the peak in electricity consumption, the less fossil and nuclear energy is needed.

Lastly, storage technologies are developing at a fast rate. The main problem is the still high cost of storage (according to Bloomberg New Energy Finance, however, it has already fallen by 85%). Because renewable energy accounts for only 20% of the electricity produced in France at the moment, the question of storage does not arise in the immediate future. The use of increasingly high-performing storage technologies, which are maturing and will continue to cut costs, is accompanied by the development of complementary renewable energy. In addition, storage can take many forms that do not require great innovation: Demand control allows, in part, the storage of energy (in water heaters, in batteries of electric vehicles, by favouring certain hours to recharge them, in hydraulic steps as proposed by EDF, or in power-to-gas). In the Négawatt scenario, for example, produced electricity that is not consumed is stored as gas, and either used as gas or converted to electricity later.

Today, there is no obstacle to the feasibility of a 100% renewable mix: It is a policy choice to be made, and a proactive policy to be put in place. What is very important, however, is to not do it indiscriminately: it must be done for and by citizens, with the lowest possible ecological impact. This will not happen overnight; that's why it is described as a transition. But it must be prepared now.

[87] Négawatt, Scénario de transition énergétique 2017-2050 pour la France, 2017.

Figure 27. A Négawatt scenario that transitions to a 100% renewable energy mix in 2050



Source: Scénario Négawatt 2017-2050 (in French)

Renewable energy is gaining momentum around the world and is helping to displace fossil fuels

Around the world

Renewable energy is playing a growing role in global energy production. Non-hydro renewable energy production surpassed nuclear production for the first time in 2019.[88] Nearly 75% of global energy investments are made toward the development of renewable energy (see Part 1 of the study) and in 2019, a record number of renewable installed capacity was connected worldwide (+184 GW excluding hydro power, compared to +2.4 GW of nuclear power)[89].

In 2018, renewable energy prevented 215 million tonnes of greenhouse gas emissions according to the International Energy Agency[90]. This is less than energy efficiency but much more than nuclear power (see Figure 28).

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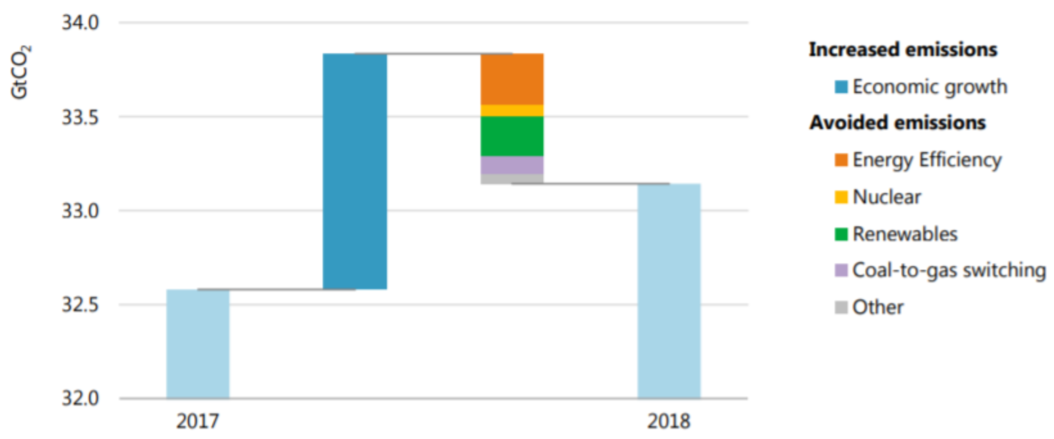
88 BP Statistical Review of World Energy 2020

89 Mycle Schneider et al. World Nuclear Industry Status Report, 2020 edition.

90 International Energy Agency, Global Energy and CO2 status report, 2019.

Figure 28. CO_2 emissions in the energy sector prevented thanks to renewable energy between 2017 and 2018

Figure 5. Change in global energy related CO2 emissions and avoided emissions, 2017-18



Increased use of renewables in 2018 had an even greater impact on CO2 emissions, avoiding 215 Mt of emissions, the vast majority of which is due to the transition to renewables in the power sector.

Source: *AIE 2019*

In China, despite the start-up of new nuclear power plants, the sum of wind and photovoltaic electricity production (455 TWh) was already significantly higher than that of nuclear power (366 TWh) in 2018. Unfortunately, at the same time, electricity and energy consumption continues to rise massively in China.

In the United States, in 2019, renewable energy produced more electricity than coal-fired power plants for the first time.[91] In Europe, too, the rise in renewable energy has been confirmed, at the expense of nuclear and coal.

In Europe

The decline of coal. Coal has entered a decline in Europe (see Figure 29). Since 2018, coal consumption has decreased by ¼ and emissions from the electricity sector have decreased by 12%. In Germany, the share of coal in electricity generation fell from 39% to 30%, in Denmark from 20% to 13%, in Spain from 13% to 5%, in Greece from 28% to 20%, in Portugal from 21% to 11% and in the United Kingdom from 5% to 2%.[92] Six countries now have no coal-fired power plants in

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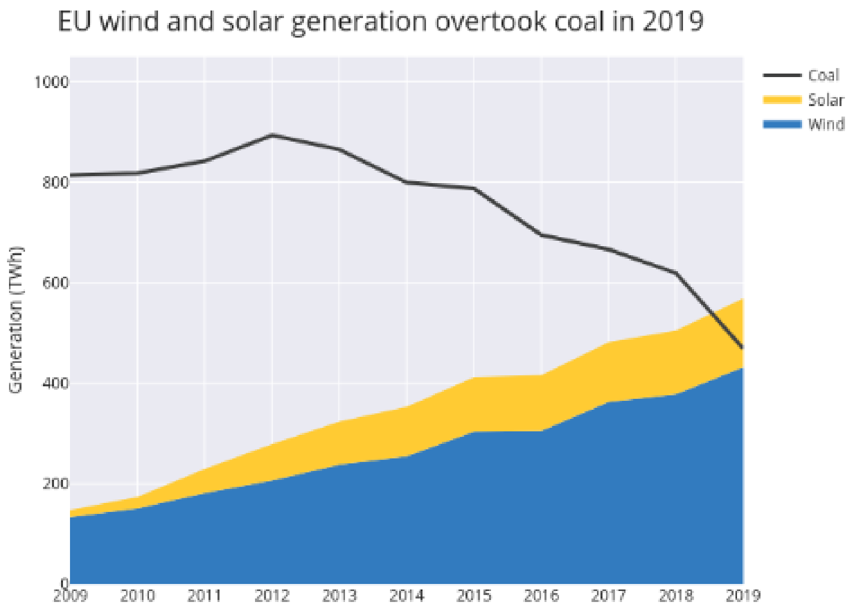
[91] Ibid.

[92] Agora Energiewende and Sandbag, The European power sector in 2019: Up-to-Date Analysis on the Electricity Transition, 2020.

operation, and another 14 have pledged to abandon coal by 2030[93]. The decline would be much faster if states stopped subsidizing coal. Unfortunately, €14 billion is at stake to build new coal-fired power plants (+ 7.6 GW) despite their lack of competitiveness. The problem is not economic, but political.

Figure 29. Trends in solar, wind and coal electricity generation in Europe (expressed in TWh of electricity generation)



Source: [Agora Energiewende and Sandbag 2020][94]

The rise of renewable energy. Solar and wind power generation has tripled in 10 years. Almost all new capacity installed in 2018 is renewable. In total, across the EU, renewable electricity production totalled as much as 32% of gross electricity consumption in 2018 (see Figure 30), and 34.6% in 2019[95]. In comparison, nuclear power accounts for only 26% of electricity production in the EU[96].

Since 2019 (before the Covid-19 pandemic), solar and wind power generation has outstripped the output of coal-fired power plants in Europe. Even better, in the first quarter of 2020, renewable energy produced 40% of Europe's electricity, and fossil fuels produced only 34%[97]. This has been made possible by a drop in energy consumption due to Covid, but the trend is expected to continue.

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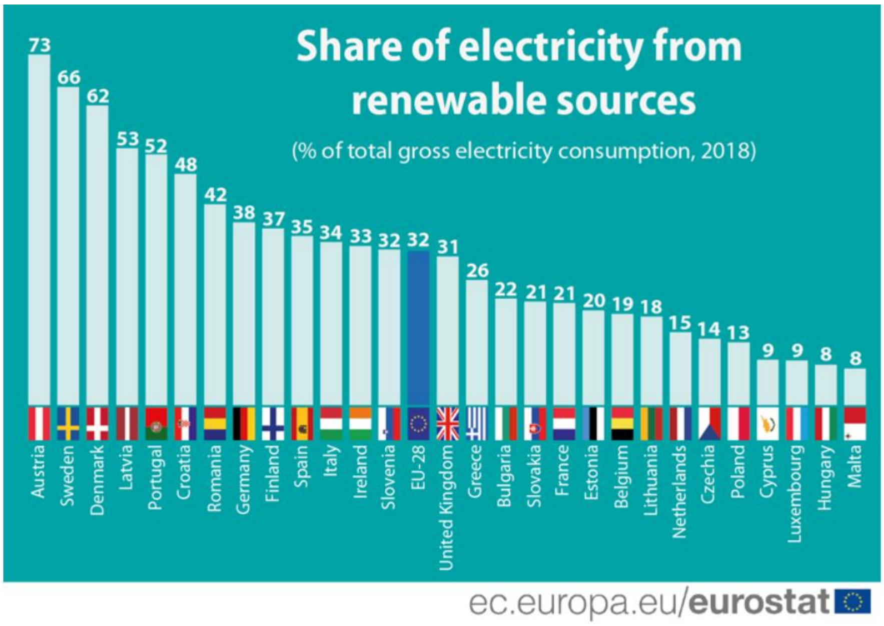
[93] ibid
[94] Ibid
[95] Agora Energiewende and Sandbag (2020): The European Power Sector in 2019: Up-to-Date Analysis on the Electricity Transition
[96] Ibid
[97] Jones and Moore (EMBER Climate Project), Renewable beat fossil fuels, July 22, 2020.

Figure 30. Share of renewable energy in the electricity consumption of each EU Member State in 2018



Source: Eurostat 2018

The share of renewable electricity in electricity production varies greatly from one country to another: from 8% in Malta to 73% in Austria in 2018 (see Figure 30). These differences are not related to deposits (France has a renewable-energy rate well below the European average even though it lacks neither sun nor wind), but to public policies that support the development of renewable energy to varying degrees.

In March 2020, six member countries called on the European Commission to provide a 100% renewable scenario to achieve climate neutrality[98]. Countries allied around a revival of nuclear power (mainly France and Central Europe) did not take part in this appeal.

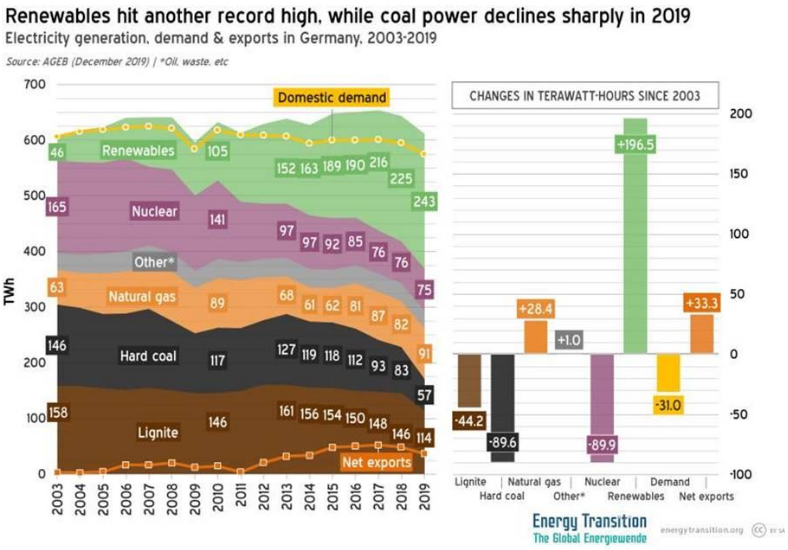
In Germany

CO_2 emissions are falling sharply. It is often said that because it opted out of nuclear power, Germany has seen its coal consumption and CO_2 emissions increase. This is misleading. There was a slight increase in emissions in 2013, but it was only temporary. Since then, CO_2 emissions have continued to decline (in 2019, they had dropped 36% since 1990)[99]. This is also true for the energy sector: its CO_2 emissions have almost halved since 1990[100]. The reduced carbon footprint is linked to a) the increase in renewable energy (36% of production in 2018[101] and 42% of production in the first

[98] EurActiv, 6 EU Member States join call for 100% renewable scenario, 16 March 2020.
[99] German Ministry of the Environment, https://www.umweltbundesamt.de/en/indicator- greenhouse gas-emissions#at-a-glance
[100] Ibid
[101] Bernard Laponche, Allemagne: trois contre-vérités sur la sortie du nucléaire, *Journal de l'Energie*, 12 March 2020 (in French).

half of 2020)[102]and b) the concomitant decline in coal (29.3%) in the German energy mix. Since the decision to phase out nuclear power in 2011 (the last plant will be shut down in 2022), the share of nuclear power has decreased from 22 to 11.7% of the electricity mix and the production of renewable energy has increased tenfold (literally tenfold: from 19 TWh to around 200 TWh). It has largely compensated for the decline in nuclear and coal production. The trend is set to intensify: Germany plans to shut down 4.3 GW of coal in 2020 (the equivalent of five nuclear reactors).

Figure 31. Evolution of the German electrical mix between 2003 and 2019



Source: [Agora Energiewende et Sandbag](), 2020

Electricity that still emits too much CO_2. Unfortunately, despite this boom in renewable energies, coal continues to represent a large sector of activity and a large source of CO_2 emissions in Germany. According to figures from the German Environment Agency (UBA) published in April 2020, each kilowatt-hour produced in Germany emitted on average 401 grams of CO_2 in 2019. Although this carbon footprint declines every year (468 grams in 2018 and 485 grams in 2017), it remains enormous compared to France.

A coal lobby that remains very strong. Make no mistake: the German transition is complicated not because of the nuclear phase-out, but because of a strong historical, economic and social dependence on coal. Indeed, coal is to Germany what nuclear power is to France: a massive, very powerful industry, anchored in the collective imagination and in the DNA of society. That said, Germany, along with its nuclear exit plan, has also initiated an exit from coal: since 2011, several coal-fired power plants have been removed from the system, and many power plant construction projects have been cancelled. Following the Coal Commission's conclusions in 2019, the government agreed to phase out coal in Germany and negotiated financial compensation with industry: by 2038, Germany will no longer produce electricity from coal at all. It is possible and

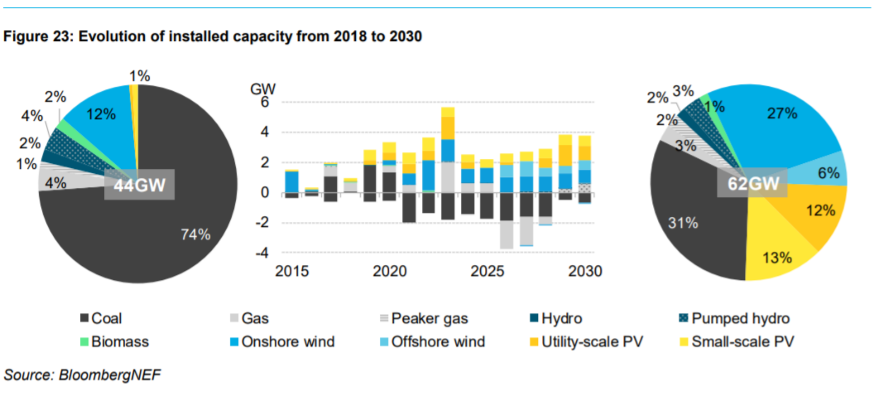
102 Jones and Moore (EMBER Climate Project), Renewable beat fossil fuels, July 22, 2020.

necessary to accelerate the closure of coal-fired power plants by attacking coal lobbies that are working to slow the closure of coal-fired power plants to a minimum. Take the case of the Datteln 4 coal-fired power station being commissioned in 2020, at the same time that France was closing the Fessenheim power station. No, this coal-fired power plant was not started to meet energy needs following the closure of Fessenheim, but because of the political power relationship between the state and the coal industry. The decision to build it dates back to 2005 and it should have come online in 2011 – almost 10 years ago. Since then, the context has changed: it does not meet a need and its production cost will be very high compared to the production costs of German electricity today. As a result, Datteln 4 started for political reasons only: the Coal Commission recommended that the government refuse to start Datteln 4, but no financial agreement was reached between Uniper (which asked to recover all of its €1.5 billion investment) and the German government to prevent it coming online.

In Central Europe

It is often said that unfortunately, in heavily coal-dependent regions such as Central Europe, renewable energies would not be able to replace coal and that new nuclear power stations would therefore have to be built. A report by Bloomberg New Energy Finance[103] debunks this idea: it would be possible to move away from coal rapidly in these countries thanks to renewable energies, which produce electricity cheaper than coal and gas-fired power stations. In the report's "low-cost" scenario, renewables could account for nearly half of electricity generation by 2030. This presupposes policy that is proactive (the pace of capacity installation must be accelerated) but not unrealistic (the quantity of renewable energy installed is capped per year). Furthermore, Bloomberg estimates that in most of the countries studied, the nuclear option represents a higher cost, poses deployment problems, and leads to a smaller drop in emissions than in the renewable energy scenarios. The case of Poland, often taken as an example to defend a necessary nuclear stimulus, is interesting: Bloomberg New Energy Finance's scenario makes no room for the construction of nuclear power plants (see Figure 32).

Figure 32. Transition from fossil to renewable energy: a 2018-2030 scenario for Poland



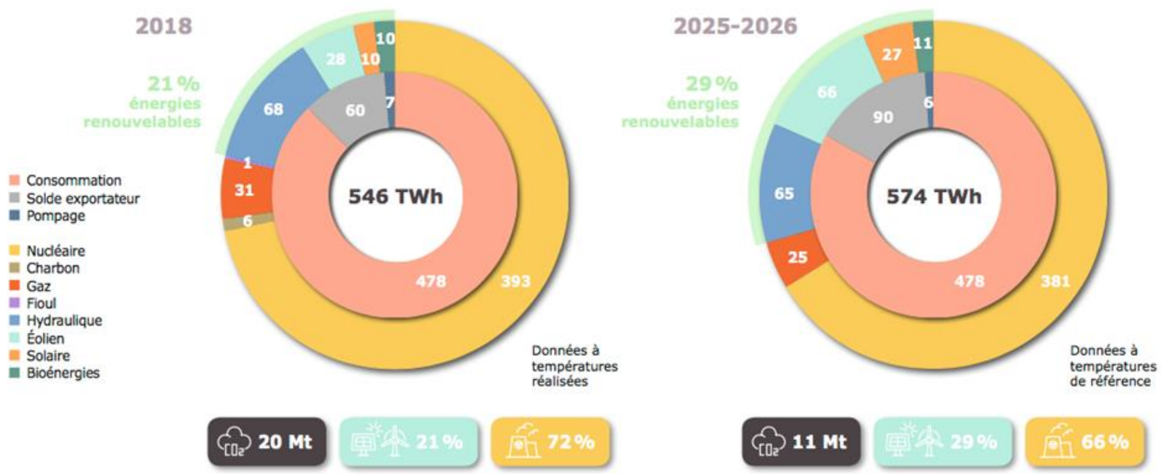
Source: Bloomberg New Energy Finance, 2020

103 Bloomberg New Energy Finance, Investing in the recovery and transition of Europe's coal regions, July 2020.

In France

Increasingly – and despite France lagging behind – renewable energy is lowering the electricity system's CO_2 emissions, because it replaces fossil fuels. RTE estimates that in 2019, renewable energies prevented 22 million tonnes of CO_2 per year (five million tonnes in France and 17 million tonnes in neighbouring countries)[104]. That is the equivalent of the CO_2 emissions of three million individuals according to the Ministry of Ecological Transition[105]. In 2019, emissions from the electrical sector decreased by 6%, while nuclear production also decreased. In particular through the increased use of renewable energies. According to RTE forecasts[106], power sector emissions will be halved again by 2025 (from 20 million tonnes to only 11 million – see Figure 33) thanks to increased renewable generation, the final shift away from coal and a decrease in gas production. This halving of the carbon footprint will be possible even though nuclear production will be in decline and the net export balance will be very high.

Figure 33. Predicted trends in the 2018 to 2025-2026 electricity mix according to RTE



Source: RTE, Bilan électrique 2019 (in French)

To go even further in eliminating electricity sector CO_2 emissions, we must take action on electricity consumption, especially during "peak" periods: renovating homes to limit heating, improving the energy efficiency of appliances, and changing energy-use patterns.

[104] Réseau de Transport d'Electricité (RTE), Note: précisions sur les bilans CO_2 établis dans le bilan prévisionnel, 2019 (in French)

[105] Every French citizen emits a little over six tonnes of CO_2 per year (this figure rises to 11 tonnes if the import-related carbon footprint is included). To obtain this figure of three million people, the Ministry of Ecological Transition bases itself on the value of six tonnes of CO_2.

[106] Réseau de Transport d'Electricité (RTE), Bilan électrique 2019 (in French).

Focusing on electricity and energy savings

The best energy is the energy you don't use. Because a truly “green” energy does not exist. All forms of electricity generation have an impact in terms of resource depletion or alteration of the environments in which the facilities are installed. Moreover, no low-carbon energy will be able to replace every unit of fossil fuel energy consumed today fast enough. It is therefore essential to influence energy consumption, not just production. Energy savings in the electrical sector are based on two pillars: energy efficiency on the one hand, and a sober use of energy on the other. According to the IPCC, policies and measures to reduce demand for energy and electricity are the most efficient and compatible levers for reducing greenhouse gas emissions with the sustainable development goals set by the UN[107].

Around the world

Electricity and energy consumption today is far from being controlled on a global scale. Although energy efficiency policies are being developed, they remain an underutilized global vector. Between 2015 and 2018, improvements in energy efficiency reduced energy-related emissions by 3.5 gigatonnes of CO_2, the equivalent of the energy-related emissions of an industrialised country like Japan. But the International Energy Agency points out that these efforts are well below potential[108]. In any case, energy efficiency will not suffice due to “rebound effects”: for example, the more energy efficient appliances become, the less expensive it is to use them, and they are likely to be used more often. Similarly, as insulation improves in buildings and they are easier to heat, consumers heat more and more. These rebound effects raise another question: that of the moderate use of electricity-consuming appliances, on which action must be taken in parallel. The challenge is to reduce electricity consumption, because the less electricity we consume, the less greenhouse gases we emit (see Figure 28 for the emissions prevented between 2017 and 2018 thanks to energy efficiency).

In France

Electricity savings

In the case of France, if we want to further reduce the carbon footprint of electricity and speed up the closure of fossil fuel production facilities, we must act on electricity consumption, particularly when peaks are experienced (linked to heating for example) that require recourse to back-up power plants (gas or coal). Indeed, almost all year round, France only uses part of its nuclear fleet. It is oversized and operated at full power only in the heart of winter when electricity consumption suddenly explodes due to electric heating. According to RTE[109], *"In winter, consumption increases by*

[107] Intergovernmental Panel on Climate Change (IPCC), Special Report: Global Warming of 1.5°C, 2018.
[108] International Energy Agency, Energy efficiency 2019 (2019).
[109] Réseau de Transport d’Electricité (RTE), Bilan électrique 2019 (2020) (in French).

2,400 MW per degree lost. Electricity consumption in France is highly dependent on temperature, especially during the winter months due to the large number of electric heaters." The problem is that, in these cases, the peak is so high that even France's nuclear fleet are no longer enough, forcing the country to use very expensive "emergency" means: it fires up coal and gas power plants, or imports carbon-intensive electricity from its neighbours. By acting on electric peaks, we kill two birds with one stone: we reduce CO_2 emissions and the need to have that many means of producing electricity in France.

RTE and Institut Négawatt[110] have each listed a number of measures to reduce electricity peaks and prevent the use of fossil fuel power plants: speeding up the renovation of housing by 2022, replacing electric wall heaters, controlling electric water heaters that heat water all the time and unnecessarily, modernising public lighting, but also encouraging moderation such as regulating Christmas lighting, switching off advertising screens, turning off buildings and shop windows at night, etc. (see Figure 34). In its 2019 report, RTE also recalls the importance of efficient household appliances (class A+++), which would halve household electricity bills. These measures, if generalized all year round, would reduce electricity consumption in a sustainable way and accelerate the closure of fossil and nuclear reactors.

In the building sector, there is much to be done to reduce greenhouse gas emissions, starting with energy-efficient renovation standards ('BBC' in France) for the most energy-intensive housing, known as "energy sieves". According to a scenario developed by Rénovons[111], renovating the 6.7 million energy-intensive dwellings in France would eventually make it possible to:

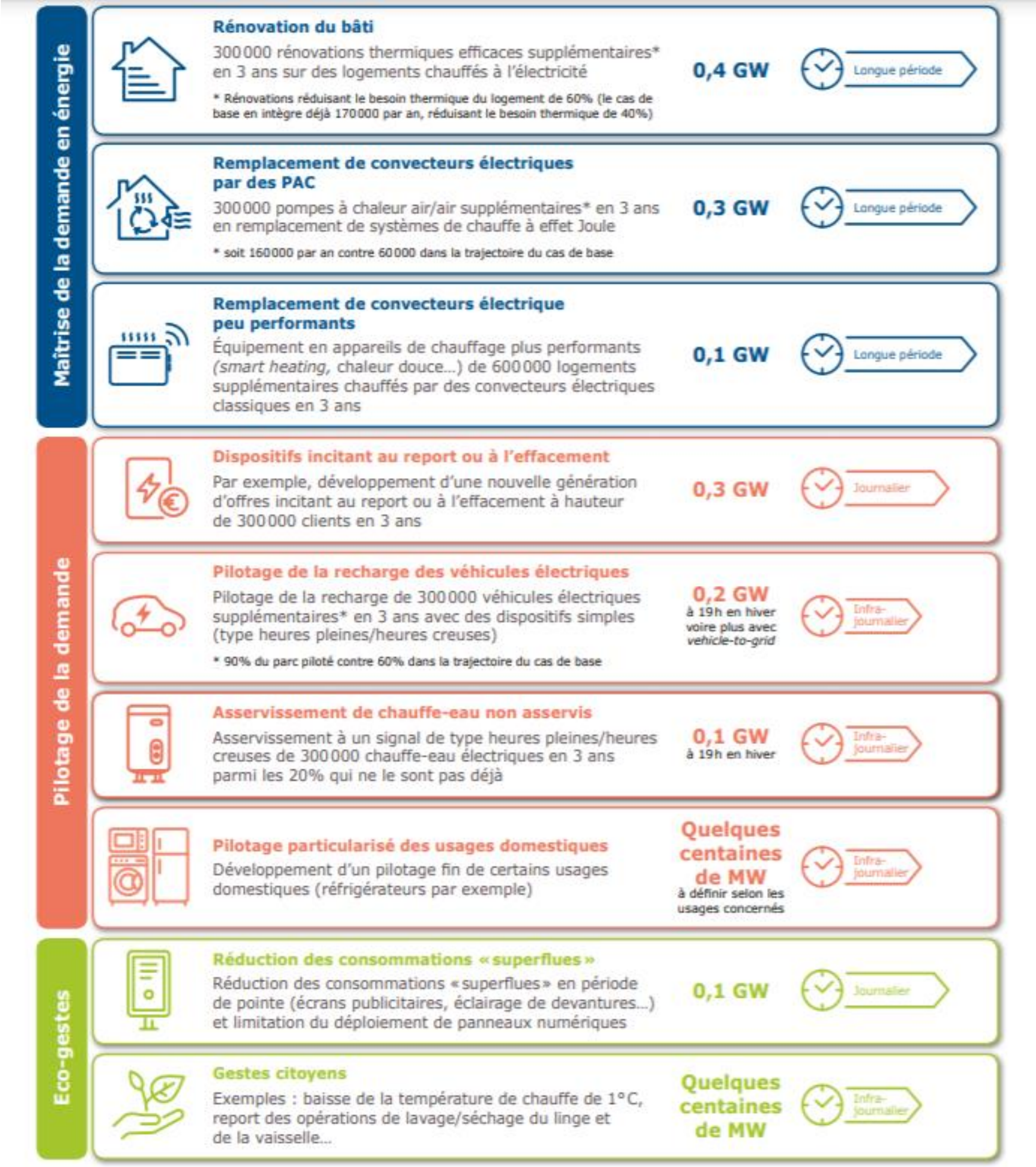
- Reduce annual primary energy consumption (electricity, oil, gas) by 105 TWh[112] and reduce the energy bill by 2.4 billion euros per year.
- Reduce greenhouse gas emissions by 14.67 million tonnes per year.
- Save €1,100 per year for households in fuel poverty.
- Create up to 93,000 jobs between 2020 and 2030.
- Allow the French government to recover €1.13 in net profit per euro invested.

[110] Négawatt, La maîtrise de la consommation d'électricité, levier pour fermer les dernières centrales à charbon ? July 2019 (in French).

[111] Rénovons! Coûts et bénéfices d'un plan de rénovation des passoires énergétiques en 10 ans, 2020 (in French).

[112] Three million homes are still equipped with fuel oil heating. For nuclear power in particular, these improvements would permanently halt the equivalent production of four to six nuclear reactors – or only 2.5-3.5 reactors if not everything is renovated to the best standards in application. For more information, read the Négawatt analysis on this topic (in French).

Figure 34. Means proposed by RTE over the next three years to reduce consumption peaks in the middle of winter



Source: Bilan électrique 2019 and synthèse du bilan prévisionnel 2019, RTE (in French)

Electricity AND energy savings

In any case, using less electricity will not be enough. Electricity accounts for only 24% of the end-use energy consumed in France[113], and only 10% of the country's greenhouse gases. Low-carbon electricity therefore does not prevent France from largely exceeding its carbon budgets. Action is therefore needed on energy consumption more broadly.

France has set a goal of halving energy consumption by 2050, but is far from achieving it[114]… The Energy Transition Act has set a target to reduce energy consumption by 20% between 2012 and 2030, and the PPE has set interim targets of -7% in 2018 and -12.6% in 2023, compared to 2012. Adjusted for climate change, final energy consumption decreased by only 0.2% between 2012 and 2018. In 2018, energy consumption exceeded the target by 4.5%. In 2019, the Energy Act shifted the 2023 targets so that France would not be too out of step.

Yet solutions exist to reduce our energy consumption and CO_2 emissions; they are simply not implemented. The transport sector now accounts for the largest share of greenhouse gas emissions and 30% of the energy consumed in France. France, however, continues to build highways, subsidize air travel and the sale of SUVs, rather than invest in a passenger and freight rail system, urban bicycle paths, and accessible and ample public transport.

Urgent systemic changes in the most CO_2 emitting sectors

Here, we must remember that the planet must act on three main types of greenhouse gas emissions: emissions from electricity generation (mainly coal and gas), emissions from energy production (mainly oil) and greenhouse gas emissions from deforestation and farming activities.

For the most part, the nuclear debate is only about the first problem, because nuclear power can only produce electricity. As a result, low-carbon nuclear power is far from a miracle solution. Consider France: 70% of French electricity is produced from nuclear energy, but this does not prevent France from exceeding its targets for reducing greenhouse gas emissions (4.5% above the target in 2018, for example). The French have even doubled their carbon footprint since 1990, amounting to 11 tonnes of CO_2 per capita per year, according to data from the Ministry of Ecological Transition.

Even if some of the uses were electrified, nuclear power could not meet all energy needs or help avoid all greenhouse gas emissions. It can therefore by no means be enough to solve the climate crisis: action must be taken as quickly as possible on the 80% of greenhouse gas emissions that are not linked to electricity production: in the transport sector, petrochemicals, deforestation, industrial agriculture and livestock farming, etc.

[113] CGDD, Key Energy Figures, September 2019 (in French).
[114] See the Observatoire Climat-Energie of the Réseau Action Climat (in French).

There is no quick fix for getting out of this climate crisis, and any mirage that might make us believe this must be deconstructed. Agrofuels in our airplanes, electric cars for all, "natural" gas, carbon capture and storage and low-carbon energy will not reduce greenhouse gas emissions fast enough, and will have serious environmental consequences if we do not first address the root of the problem: how we produce and consume. We need to rethink regional travel and planning, transition to more sustainable agricultural models, fight over-consumption, and shape an economic system that meets basic needs and fights inequality.

CONCLUSION

A turning point for France in terms of energy

This world of tomorrow must also be prepared in France. The country is at a crossroads and must choose what to invest in to build the world in which we want to live tomorrow. It must reduce GHG emissions as quickly as possible, but with what tools, trajectory and values? Alternatives exist. We know that low-carbon electricity and the reduction of greenhouse gas emissions is possible without nuclear power: via renewable energies, energy efficiency, controlling consumption in all sectors of the economy, developing alternatives to road freight, private cars and planes, the transition to sustainable agriculture, as well as the fight against over-consumption, advertising of climate-toxic products, the oil and gas industry and lobbies and against those responsible for deforestation.

France's nuclear power plants are ageing, and not eternal. Even if their life cycle is extended, many reactors will have to shut down in the coming years. The question of what comes after comes now: do we want to invest our money in nuclear power by building new reactors and preparing to manage and finance additional nuclear waste? Or do we want to change course, choose a low-carbon energy model based on energy savings and on renewable, more decentralized, democratic, and less dangerous energy sources?

Some will say "why choose, let's do both: let's invest in nuclear power and in renewable energies!" But the current situation already shows us that it does not work: Nuclear power locks down and slows the energy transition. As long as France puts its eggs in the nuclear basket, alternatives will not grow fast enough, and will not attract massive investment. Energy savings are far from being a priority in current policies. All too often, renewable energy is viewed as an adjustment variable, and will continue to be so long as the state supports nuclear power and a plan to build several EPR nuclear reactors. In 2018, public energy utility EDF invested €6.6 billion in nuclear energy and only €1.3 billion in renewable energy[115]. Every year, the majority of public budgets allocated to energy research and development are spent on nuclear energy (68% in 2017[116]), compared to only one third on renewables.

This time a choice must be made.

When will this choice be democratic?

Today, we are not given an opportunity to make a choice. Democratic debate on nuclear power has always been lacking and history is repeating itself. For many months, the government and the nuclear industry have methodically assembled the pieces of the puzzle to prepare the ground for the construction of new EPRs in France: a European tender launched by EDF for engineering work on several EPR "pairs"; ongoing reform of regulated access to historical nuclear electricity (ARENH) to mask the costs of the Flamanville EPR and impose the purchase of nuclear electricity at a fixed

[115] Greenpeace calculation based on EDF 2018 annual report.
[116] CGDD, Les dépenses allouées à la R&D énergie en 2017 (datalab 2019) (in French).

price for all suppliers; intensive lobbying in Brussels to integrate nuclear technology into the taxonomy of green investments and attract investors; nuclear technology integrated into the "ecology" chapter of the stimulus package, etc. Of course, officially, the decision to build new EPRs is not and will not be made before the next presidential and legislative elections or before the Flamanville EPR comes online, but the day this is announced will be long after the decision was actually taken. *Fait accompli* politics are in action. To date, there are no plans to formally ask citizens for their opinion. Government and industry have decided to proceed differently, creating the false perception that pursuing the nuclear route is an imperative that cannot be avoided. The notion of choice is swept under the carpet.

Whatever our age, background, or concerns, we have the right to form an opinion on the future of nuclear power. Nothing is mandatory: no force of nature or scientific authority imposes nuclear technology. **It is a societal choice** to decide in which energy system we wish to invest and in which world we wish to live.