LUISS

Degree program in International Relations

Course of Energy and Climate Change Policy

# The possible contribution of nuclear to the European energy transition: a French insight.

Prof. TARABORRELLI
SUPERVISOR

Prof. MAGNANI
CO-SUPERVISOR

Grégoire KINOSSIAN
Mat. 652192
CANDIDATE

Academic Year 2022/2023

## Abstract

This thesis proposes to analyze and support the possible role that nuclear energy could play in the overall energy transition of the European Union.
Based on the three main criteria foreseen by the REPowerEU plan, we identify the assets and limits of nuclear energy in terms of geopolitical hedging, low-carbon generation, and security of supply. All these elements will enable us to answer the question "to what extent can nuclear help the EU achieve its decarbonation and energy independence targets?".
Considering specifically the French case, we investigate the political, economic, and legal implications of a massive nuclear program both in terms of domestic and foreign policy. Our main point is that nuclear energy is strategic to secure the future of an economic system oriented toward productivism in a context of massive electrification and that it can, parallelly, adapt to the deep penetration of the electricity grid by renewable energy sources. Yet, the nuclear industry will have to face a barrage of challenges caused by the uncertainties of climate change and international politics, in relation to or in addition to the well-known flaws of its overall fuel cycle and the potential failures of nuclear safety. Therefore, this thesis acknowledges that neither a full-nuclear nor full-renewables system are sound. Conversely, a mix of low-carbon energy sources, where nuclear can play a role as baseload dispatchable source of energy would thus be desirable.

# The possible contribution of nuclear to the European energy transition: a French insight.

## Table of contents

## Introduction

On December 7, 2022, the French satirical newspaper *Le Canard enchaîné* released a piece of information about the French-Russian cooperation in the process of uranium enrichment immediately shared by the anti-nuclear NGO Green Peace: despite the war and multiple sanctions upon the Russian exports of fossil fuels in Europe, in 2022, France has paid €345 million to Russia to import 290 tonnes of enriched uranium (Greenpeace, 2022). In September 2022, the same NGO had already warned about the risk inherent to shipping mixed uranium and plutonium to Japan from Cherbourg Harbour in a troubled international context (France Info, 2022).

From the global scale to the French case – at once independent from and embedded into the European history and development of the industry – nuclear energy is everywhere a multidimensional matter. In fact, some technical aspects (related to physics and chemistry) should not obscure its key stakes in terms of international political economy and politico-social controversies. Moreover, the current context of energy transition brings two main features in the assessment grid of each generating technology: it must not harm the environment and guarantee a certain energy independence to European member states.

### *Functioning and externalities of nuclear energy.*

Technically, this primary energy source is categorized as fissile because it is radioactive heat, released from the core of atoms, and then used to activate a steam turbine eventually generating electricity. Due to the dangerousness of this technology, a team of about ten people per reactor must constantly monitor the generation process (De Monicault, 2016). Precisely, most of the French reactors are maneuvered in a way that permits them to go from their low power level (half power) to their rated power in ten minutes – as of 5% of power rated every minute (Lokhov, 2011). Their rated power ranges from 900 megawatts (MW) to 1450 MW (EDF, 2023). As fissile energy, nuclear is distinct from fossil fuels such as coal, natural gas, and oil and some deem nuclear to be a low-carbon source of energy[1].

[1] We will see that this assessment rarely considers the whole nuclear fuel cycle, especially the pollution occurring during the mining of nuclear's raw material: uranium (Hecht, 2020).

However, nuclear fuel is generally made of uranium-235 (U-235). This isotope rarely naturally exists in some parts of the world. Therefore, to satisfy the needs of global consumption at an industrial scale, artificial U-235 is created through the enrichment (i.e., chemical processing) of a more naturally abundant uranium isotope: U-238 (Galindo, 2022). Mixed oxide (MOX) fuel is also marginally used as nuclear fuel (World Nuclear Association, 2017). The latter recycles plutonium – Pu-239 – created during the fission of uranium. It is deemed that nuclear industries able to process Pu-239 and depleted uranium can cut their nuclear wastes by up to 5 (Orano, 2023).

Also technically, generating nuclear energy has upstream, midstream, and downstream negative externalities. Mining, milling, and enriching uranium - upstream phases - emits carbon dioxide and methane (Taylor, 1997), not mentioning ionization during upstream phases (UNSCEAR, United Nations, 2017). Besides, the midstream phase (electricity generation) notably causes thermal pollution of surrounding rivers or sea used to cool nuclear reactors that dramatically affect wildlife and could aggravate issues related to climate change (Hoerber, 2012). Finally, we have mentioned plutonium (Pu-239) in relation to downstream nuclear activities. The latter stands, with minor actinides, among the longest-lived and most ionizing nuclear wastes (Long-Lived, High-Level Wastes – LL-HLW). When they cannot be recycled, wastes must be isolated from the biosphere for hundreds of thousands of years before their radiotoxicity level drops back to a relatively safe level. In 2016, HLW represented about 0.13% of the total volumes in storage and disposal (IAEA, 2022).

There is no universal management model for nuclear waste but rather two competing methods. On the one hand, the “open” nuclear fuel cycle consists of storing them as safely as possible pending a technology able to dispose of them. This method is used by the United States of America (the US), Canada, and Sweden. On the other hand, the “closed” nuclear fuel cycle uses MOX in order to reduce its consumption of fresh uranium and, mechanically, the amount of HLW[2]. France, Russia, the UK, and Japan are the main adepts at this second method (Caurant & Majérus, 2021). Varying national preferences for one or the other method can be explained by the balance of contextual economic and technological pros and cons (Bunn *et al*, 2003).

[2] According to EDF, 120 tonnes of MOX can substitute about the equivalent of volume of enriched uranium, sparing 1.000 tonnes of ores (EDF, 2023)

It must be said that, currently, even under the conditions of a closed fuel cycle, nuclear wastes cannot be fully recycled.

### *Nuclear: an industry embedded into the global supply chain.*

Second, the nuclear industry is a matter of international political economy, notably due to its global supply chain. We have already mentioned several drawbacks of nuclear energy and the total world resources of uranium are not known but certainly limited (World Nuclear Association, 2022). Therefore, contrary to solar, wind, and hydropower, nuclear energy is not classified as renewable. Besides, uranium mining operations often occur in another country, even another continent, and fresh uranium (called *yellowcake*) is then exported where the nuclear industry needs it. For instance, France has historically imported fresh uranium from African territories in a postcolonial context (Hecht, 2014) and closed its own uranium mines in the late 1990s (Bretesché & Ponnet, 2013).

We will later show that the yellowcake is not the only transnational component of the nuclear industry which has, overall, marked geopolitical implications. For instance, the idea that nuclear industry can work on a national level without international collaboration (Hoerber, 2012) must be moderated. On the one hand, it is true that France and the United Kingdom (the UK) have individually developed reprocessing plants. Historically, the French Commissariat à l'Énergie Atomique (CEA) - established by General De Gaulle in 1946 - has tried and somehow managed to be technologically independent from the US and other foreign potential suppliers (see Vaïsse, 1992 and Soutou, 1991). The French diffidence vis-à-vis the US industry is a long-term trend we observe through the reluctance shown by the French legislative and executive branches to transfer technology in 1974 (Debré, 1974), and still in the most recent years (Merlin, 2020, p. 15). On the other hand, reprocessing plants are merely the midstream phase of the whole industry. Roughly speaking, the UK, France, and Russia reprocess the nuclear wastes (including spent fuel) of about all European countries that are currently running a nuclear program or used to run one and still must decommission their infrastructures (IAEA, 2022). And yet, Hoerber

(2012) himself acknowledges that even two big nuclear states, the UK and Japan, cooperate to dispose of their spent fuel (a downstream operation).

All in all, numerous international and cross-continental connections make the upstream and downstream phases of the nuclear sector possible.

---

*Environmental concerns surround the nuclear option. We can also wonder to what extent this source of energy actually secures the energy independence of the State that owns it.*

---

***Nuclear: a controversial technology.***

Third, nuclear energy has three major grounds for socio-political controversy. Chronologically, it starts with its dual use (a), then with its contextual economic relevance (b), and eventually its ecological label (c). These three controversies echo the three main legitimizations used by nuclear's supporters since the 1950s: a peaceful technology, the guarantee of energy security, and a low-carbon source of energy.

a) Firstly, because of Pu-239 created during the fission process, (civilian) nuclear power plants' owners are able to gather enough plutonium to produce a nuclear arsenal. Consequently, easing the proliferation of these plants worldwide – the midstream phase – for business reasons parallelly increases the risk that new countries undetectably accumulate plutonium (Lovins A. , 1980). Yet, the international Treaty on the Non-Proliferation of Nuclear Weapons (NPT) that entered into force in 1970 is wanting safeguards against nuclear supply to non-parties (Hoerber, 2012). The principal reason is likely that during the 1950s – when President Eisenhower explained his doctrine of *Atoms for Peace* (1953) and the consecutive establishment of the International Atomic Energy Agency (AIEA) under the aegis of the United Nations (1957) – the risk of proliferation eased by civilian technologies has clearly been underestimated. Indeed, the world nuclear field ambiguously tried to find a balance between scientific internationalism and the pursuit of national interest in the early Cold War[3]. After losing the monopoly of the atomic bomb, the US tried to establish its civilian nuclear hegemony by providing “abundant electrical energy in the power-starved areas of the world” (Krige, 2006, p. 162) notably thanks to the encouraging starts (in 1951) of the pressurized water reactor (PWR) based in Shippingport (Pennsylvania). Subsequently, about thirty bilateral research agreements were signed by the US worldwide from 1955 to 1961.

This is the context that surrounded the establishment, in 1957, of the European Atomic Energy Community (EAEC, Euratom Treaty) by the 6 countries of the European Coal and Steel Community (ECSC). The same ambiguity *vis-à-vis* the dual use eventually features the Euratom treaty that leaves some member states free to develop nuclear dissuasion (Vaïsse, 1992, p. 25). Notably, the aforementioned CEA alongside the French military was contrary to a pervasive and demilitarizing supranational control of the domestic nuclear policy (Vaïsse, 1992). Yet some more Europeanistic French lobbies (e.g., Prime Minister Mollet in 1956) fostered the generation of a European nuclear energy via the co-financing of a common isotopic separation plant. But Mollet’s project turned economically irrelevant after the US offered cheap enriched uranium (Vaïsse, 1992). Finally, the Euratom Treaty and its further use by signatory parties bring Hoerber (2012) to assert that EAEC became stuck in national prerogatives both in the defense and energy sector.[4] The consequent fragmentation of the European industry has important supply and technological implications (Le Renard, 2017) that notably hamper future common research (Soutou, 1991).

b) Secondly, discussions in the House of Commons of the UK in 1972 related to the Vinter Report on nuclear reactor policy show that nuclear was considered “on the wave of the future” compared to the finiteness of fossil fuels (Palmer, 1972). This idea echoes the bold

[3] In France, the doctrine of Bertrand Goldschmidt (CEA) – who was particularly reluctant to limit the exportation of nuclear technology to countries like India in the 1970s and to criminalize nuclear proliferation – perfectly echoes this dilemma (Pouponneau, 2013a, pp.103-4).

[4] In the long run, France has proved to be among the main disruptors of European unity in terms of nuclear research and centralized supply of uranium especially because of its military nuclear program (de Montesquiou, 2000).

conjecture made by *Électricité de France* (EDF) in 1955: by a couple of years, the cost of nuclear electricity will match classical sources of energy.[5]

The second part of the 20th century teaches us that nuclear electricity is not cheap or expensive in absolute terms but that this assessment is extremely contextual. Let us remember that, up to the early 1950s, nuclear energy was deemed a strictly military technology by private investors who were reluctant – even in the US – to bet on the development of a civilian industry to generate electricity (Krige, 2006). Discussions in the UK's House of Commons mentioned above are a perfect example of how international contingencies can make nuclear energy competitive. Indeed, these discussions took place in 1972 and 1973[6], during this period, alternatives to oil became suddenly extremely competitive compared to an oil price that rocketed by 4 in late 1973. This is, furthermore, the reason invoked by French Prime Minister Messmer the 22 November 1974 when launching a large-scale nuclear program – that had officiously been planned since the 1950s by EDF (see above). As an answer to the high price of energy in an all-oil economy (Baillot, 1973), the Messmer government decided on an "all-electrical, all-nuclear" alternative aimed to secure the French energy supply in the future. His plan aimed to build up to 170 reactors by 2000 (Topçu, 2013, pp. 31-32).

[5] Yet, the French CEA was more cautious regarding both EDF's economic outlook and alleged timing in deploying a large-scale nuclear industry in France. These two French institutions have disagreed for a long time on the industrial and financial features of the French nuclear industry. As a matter of fact, the CEA was looking for independence vis-à-vis US technology, but – in 1969 – EDF convinced the French government to build PWRs that produce electricity 20% cheaper per kilowatts hours than the *uranium naturel graphite gaz* (UNGN). In compensation, the French CEA alongside the state-owned company entitled to supply uranium (Cogema, then Areva and, today, Orano) obtained funds to pursue its expensive research for a fast-breed reactor able to equip France with a fully closed fuel cycle in the future (Soutou, 1991).

[6] Beyond the well-known fourth Arab-Israeli war (in October 1973) this period was featured by the end of the Bretton Woods systems decided by President Nixon in 1971. This shift in the international financial system notably affected the value of petro-dollars owned by oil exporters that suffered from the US dollar's competitive devaluation. Moreover, the result of cheap oil in advanced economies was a low oil price that impoverishes exporting countries (OPEC). Hence, due to the war in Kippur, the Organization of Arab Petroleum Exporting Countries (OAPEC) declared an embargo against the US and Netherlands (deemed Israel's allies) and, due to the low oil prices, the broader OPEC decided to cut its oil production and thus to raise prices (International Monetary Fund, 2023).

c) Thirdly, the last and likely most important controversy related to nuclear energy is about its environmental impact. This controversy stems from the activism that thrived notably in opposition to the French nuclear program. In fact, the environmental impact of the nuclear industry was criticized, even before the first major accidents (Three Mile Islands, 1979 and Chernobyl 1986). Since the early 1970s, grass-root (mainly non-violent) movements opposed several nuclear projects. But these movements quickly institutionalized and start a technocratic battle of expertise with the government that contributed to specializing them on exclusively environmental matters. Because of this evolution, they lost their initial capacity to make various political claims converge and thus reach a larger public (Ollitrault & Villalba, 2014). Parallelly, within the scientific community, the literature on nuclear started to split in two (also in the 1970s) because of the anti-Weberian clash between scientists loyal to the nuclear program's raison d'être and scientists who opposed it but were gradually moved away from firsthand data (Topçu, 2013). It results that nuclear technology stands among the most politicized[7] matters in France that have never enjoyed a proper debate.

   Issues such as nuclear safety, the French capacity to supply enough uranium to its reactors, and the management of nuclear wastes are *de facto* a matter of opinion. For instance, after the Brundtland report on sustainable development (1987), nuclear lobbyists started, in the late 1990s to stress the alleged carbon-free feature of this technology and promoted the European/Evolutionary Pressurized Reactor (EPR, III+ generation) to achieve sustainability. Yet, they completely neglect alternative models based on renewables, obscure the irreversibility (because of wastes) of the nuclear option, and forget that this technology has empirically not brought France to reduce its consumption of oil since the 1970s (Chateauraynaud, 2011).

[7] Interestingly, expertise in non-proliferation also triggers tensions between the scientific and political interpretation of military nuclear programs. In this case, social sciences (Political Science and International Relations) compete with hard sciences (Physics) in interpreting the danger of some countries' nuclear enrichment programs (Pouponneau, 2013b, pp.476-477).

*The nuclear option is challenged by environmental concerns and doubts about its effective self-sufficiency. Moreover, the accumulation of controversies undermines its appeal, especially in a democratic context. Nevertheless, we can wonder to what extent crafting an energy policy is a democratic process.*

***On energy systems and democracy.***

Fourth, energy systems often escape genuine democratic control because of their time length and their complexity. An initial political impulse will quickly face the conditions defined by the industrial sector. According to Smil (2010), once determined the mix of primary energies, it must be defined which prime movers will transform them and, eventually, the final use of energy. All this happens in a context framed by material and immaterial infrastructures that bring inertia in time. Basically, transiting from one energy system to another would lay on substituting prime movers with others. Yet, Lovins (1979) stresses the political barriers imposed by a technocratic and centralized energy system - the "hard path" relying on fossil fuels and nuclear fission - to an alternative system he calls the "soft path" which is made of (decentralized) renewables and a sober final use of energy. Given the economic and social stakes of one system or the other, we understand that the choice is essentially political and that people who benefit from the dominant system are not keen to move to the alternative one.

For instance, Evrard (2013) describes the French energy system dominated by nuclear as extremely centralized and technocratic. French citizens keen to stop or, at least, decrease nuclear power generation and follow Lovins' soft path strongly oppose the prevalence of the ones deemed "true experts" (engineers trained in *corps des mines*[8] and specialized lawyers and economists[9]) in influencing the national energy policy (Topçu, 2013). Even in Germany, deemed the European leader in renewables, Evrard observed that the affirmation of the soft path took long and had to win several battles against forms of "bilateral meso-corporatism" (Szarka,

[8] *Le corps des ingénieurs des mines* gathers engineers who are French public servants. It is strongly linked to the Minister of Economy and Finance. They can be described as an independent and powerful hard path lobby rather than as public servants (Cf. Delanglade, 1997).

[9] These systematic nuclear supporters and maximizers are often called "*nucléarocrates*" by their opponents.

2011) where the interest of large industries prevailed upon the logic of decentralized energy generation. In this case, the democratization came bottom-up (through the long-term mobilization of anti-nuclear movements) and not from the Parliament, even though the mobilization permitted, in the early 2000s, the influence of Green MPs in German politics to grow at the expense of traditional supporters of the hard path. Eventually, such a shift has not been absolute since it was bound by compromises, notably on the gradual phase-out of traditional sources of energy (nuclear in particular). On the contrary, a grass-root decision from these movements would have chosen an immediate and radical turn. In France and Germany, we observe a similar duel between 'democracy' (diffuse interest groups, pro-soft path) and 'energy technocracy' (business groups, pro-hard path) which has, for now, produced different outputs.

Europe is consequently fragmented in terms of democratization of the energy system. In some countries, the *demos* is far from holding the *kratos* – even through its representatives – while others further democratized this sector. However, the sudden decision taken in 2022 to reopen coal-fired thermal plants and to extend the coal mine of Lützerath (with consequent expropriations) shows that democracy can easily be bypassed in case of an apparent emergency in Germany too.

### *Concept: energy transition.*

Fifth, among the three historical controversies we hinted at[10], the economic and environmental ones are certainly the most contemporary in relation to what is called the European energy transition (de la Esperanza Mata Pérez & al., 2019). Indeed, in a context of global political and scientific awareness about the anthropogenic causes of climate change – disseminated by the International Panel on Climate Change (IPCC) under the aegis of the United Nations (UN) since its second report published in 1995 (Chateauraynaud, 2011, p. 134) – multiscale institutions (see, e.g., Bulkeley & Kern, 2006) are trying to mitigate (primarily through cutting carbon dioxide – $CO_2$ – emissions) and adapt to meteorological, geological and biological fast shifts that affect human life and customs.

[10] See the fourth section of this introduction, "*Nuclear: a controversial technology*".

Energy policy is one of the main instruments currently used to reduce $CO_2$ emissions. We have already mentioned other factors (geo-economic and geopolitical ones) that have historically pushed governments to massively modify the structure (i.e., the kind of primary energy sources) of their country's primary energy supply. According to the scientific literature, the concept of 'energy transition' is multi-dimensional. For instance, about energy transitions in general, Grubler (2012) stresses the role of both supply and demand in terms of quality and quantity observed in all energy transitions since the Industrial Revolution. Besides, Mejía-Montero *et al* (2020) remind the complexity of a process that combines a techno-economic decision with social (thus political) consequences. Regarding specifically the current transition, Nakagaki (2021) highlights the three megatrends of decarbonization, decentralization, and electrification with the increasing presence of variable renewable energy. Furthermore, Valkenburg & Gracceva (2016) stress problems of governance related to uncertainty vis-à-vis climate change and the ambiguity of the concept of energy security in this context.

When it comes to address the substance of the transition, Lovins' distinction between the hard path and the soft path is particularly relevant. Indeed, the energy sources of the future should be carbon-free or, at least, low-carbon. Which is, in principle, favorable to the soft path because fossil fuels are, de facto exluded, or turn costly because of the research in and the deployment carbon capture and storage capacities. However, the soft path takes time and requires a favorable business and political context that enables citizens or energy communities to purchase the infrastructures they need in a decentralized way. Futhermore, the entire economic system must have the time to move toward a less productivist pattern (degrowth) to reduce the final energy consumption to a level that can be covered by renewables alone. And yet, there is no time for slow adaptation anymore. For instance, the European Union is going to ban new combustion engines in merely twelve years (by 2035) while the automotive industry was planning a way slower path (Bloomberg Finance LP, 2016). "Action now" is required worldwide (Guterres, 2020). Green deals in the US, in China, and likely in the EU embody the hard path and the consequent return of international tensions mostly fueled by the scramble for key resources and standards (Aykut & Dahan, 2022). The emergency context hence favors a centralized (state-led and technocratic) model of large power plants supplying entire populations. And the subsequent effect is a major one since the centralized model reframes energy sources' relative assets, and drawbacks by imposing two main criteria: having the best ratio of land used to power generated and securing the supply of a still productivist economy.

Hence, on the one hand, while nuclear should have disappeared from the soft path, it will likely accompany the revival of the hard path. On the other hand, though renewables lose part of their appeal in the hard path, they are still essential to achieve decarbonation but are used and produced in a centralized way. However, an alternative to the hard path model can exist and is, today, embodied by energy communities (Debizet & Pappalardo, 2021) and other local initiatives that present valuable assets in case of extreme environmental shift that could lead to an industrial collapse (Semal, 2017). All these parameters show that a mix of sources rather than a "100% nuclear" or "100% renewables" plan is the soundest choice for this transition.[11]
In a nutshell, electricity generated from either carbon-free or low-carbon sources is going to play a key role in the energy transition, but climate change and international political tensions cause hesitancies that exacerbate concerns about choices that must be made in terms of type and quantity of primary energy sources and final consumption – bearing in mind that quantity and type are intertwined due to the varying ratio (net capacity factor) between installed capacity (kilowatts) and delivered power (kilowatts hours) from one technology to the other.

### *The energy transition of the EU.*

Sixth, at the political level, the President of the European Commission von der Leyen stated without hesitancy that "after the pandemic, there can be no backsliding. No return to economic activity based on fossil fuels, at the expense of climate and nature."
This statement indeed goes a step further than what has been proposed since the 1970s by the European Communities (then European Union) in terms of environmental policy. From initial not legally binding provisions to the ratification of the Kyoto protocol by the EU and its member states – and a proper European directive (2003/87/EC) aimed to limit $CO_2$ emissions in the common market through a trading scheme, and from mere 'environmental protection' to efforts vis-à-vis 'climate change', European member states have historically proven to be aware and innovative in the field (Hoerber, 2012).
The main limit to this European ambition is that, in accordance with art. 192 and art. 194 of the Treaty on the Functioning of the European Union (TFEU), the EU's ordinary legislative

[11] To that regard, see, e.g., the idea of an electric mix balancing nuclear and renewables in France in the last section of this introduction "*Multiple market frameworks in the EU: the French case*".

procedure cannot directly police the energy mix of European member states. As a matter of fact, a member state enjoys the "right to determine the conditions for exploiting its energy resources, its choice between different energy sources, and the general structure of its energy supply" (art. 194.2), and provisions that substantially affect a member state's choice in determining its energy mix must be taken by the European Council at unanimity (art. 192.2.c). Nonetheless, art. 194.1.c TFUE clearly states that energy efficiency, energy saving, and the development of renewables are the three grounds of environmental solidarity between member states and art. 194.2 entitles the EU legislator to police these sectors through the ordinary legislative procedure. Directive 2009/28/EC on the promotion of the use of energy from renewable sources typically goes in this sense. Indeed, art.3.1 set national targets (by 2020) for the share of energy from renewable sources in the gross final consumption of energy and has consequently affected the composition of every member state's electricity mix. Directive (EU) 2018/2001 is approximately a repetition of directive 2009/28/EC with more ambitious targets in terms of investments in renewable primary sources of energy and is currently affecting the energy policy of member states up to 2030. Both texts also include provisions regarding energy efficiency and energy saving.

Besides, the milestone of the last two years is the EU regulation 2020/852, so-called "green taxonomy", which aims to direct investments within the European Union towards sustainable projects and activities (European Commission Finance, 2022). This has been, to some extents, the 'moment of truth' for the labeling of nuclear energy in Europe: in or out of sustainable activities and project? Stakes were high for some self-interested pro-nuclear member states like France[12]. Indeed, a European precedent was unfavorable to nuclear: during COP-6 in the Hague (in 2000), France and Finland – two self-interested European nuclear expansionists - lobbied in favor of the introduction of nuclear power in the UN Clean Development Mechanism while other EU-15 member states opposed (Szarka, 2011, p. 166). In the post-Chornobyl era, only a minority of EU member states deem nuclear to be an energy of the future compatible with environmental goals. Nevertheless, in 2021, the in-house science and knowledge service of the Commission assessed that nuclear energy generation "does not significantly harm" EU environmental objectives at thus does not conflict with art.17 of regulation 2020/852 (EU

[12] See the still actual importance of nuclear for France in the last section of this introduction ("*Multiple market frameworks in the EU: the French case.")*.

Commission JRC, 2021).[13] This fundamental assessment reminds the environmental controversy that surrounds nuclear since the 1970s, especially in a European nuclear landscape dominated by France which amounts to more than half of the EU gross nuclear electricity production (Eurostat, 2022) and where several countries have decided to phase out their nuclear program after Chornobyl (1986) or Fukushima (2011).

Eventually, in front of the ongoing war between Ukraine and Russia and its effect on natural prices, the EU launched, in late 2022, an energy plan – REPowerEU – with clear geoeconomics targets such as getting rid of unreliable fossil suppliers (e.g., Russia) in the short run thanks to a hedging supply strategy by every member state (European Commission, 2022). Hence, in addition to the goal of decarbonation, the EU energy policy also aims at getting relative strategical independence.

---

*Despite multiple concerns and oppositions, certain nuclear activities are part of the options EU member states can use in their (centralized energy transition. Besides, the additional criterion of relative strategical independence has not affected this right. Remains the question of a European market adapted to hybrid energy systems.*

---

***A short introduction to the European electricity market.***

Seventh, the EU green taxonomy proves that economic considerations and financial frameworks are paramount to make the energy transition. Based on the EU objectives by 2050, both renewables (and related flexibility technologies) and nuclear plants would require capital expenditures (CAPEX) that amount for hundreds of billions of euros every year (ENEL, 2022). Therefore, a primary understanding of the market's regulatory framework a Reverdy (2014,

[13] In reference to international political economy, this technical report provides an interesting insight about the current (in 2020) distribution of uranium's enrichment capacity in the world. Russia is the global leader with about 46% of the capacity. France alone about 12.5%. The UK, Germany and Netherlands together amount for about 22.6% (EU Commission JRC, 2021, p. 95). It means, on the one hand, that, for now, European enriching capacities are satisfying. On the other hand, there is a risk of dependence to Russia in case of enriched nuclear fuel shortage in Europe.

pp. 51-74) explains that, since the 1980s and Jacques Delors' *White Paper on the completion of the internal market* (1985), the European Commission has created a legal way to lead the policing of the European single market and to apply European competition rules to network industries (such as the energy sector) that used to be ruled by every single State based on the economic principle of the natural monopoly. The European Commission was indeed trying to gain political influence and revive European integration and has been helped by the removal of member states' veto power in internal market matters established by the Single European Act (SEA) in 1986.

In 1996, 2003, then 2009, major directives have been taken to rule the single electricity market. Their enforcement (translation into national law) in France has been unpopular among the country's politico-administrative *élite* (not convinced by the major economic performance of competition in the energy sector) and EDF's workers. Conversely, EDF's managers were favorable to this liberalization of the European market that served their strategies of internationalization. This discrepancy notably led to clashes between member states provided that the French government was trying to slow the enforcement of European directives while EDF was increasing its market shares into neighboring countries which governments mechanically pushed their French counterpart to apply the principle of reciprocity. This situation brought diffidence among EU member states: European countries criticized the French overall freeriding of the new system.

A parallel effect of the liberalization in the EU is the massive corporate restructuring of big electricity producers like EDF which bought large shares of foreign companies like London Electricity (UK), EnBW (Germany), and Edison (Italy) in the 2000s. The particularity of EDF in the European panorama is that, with the Swedish Vattenfall, they are the only highly internationalized state-owned enterprises (SOE). The European single energy market is also unequal country to country in terms of substantial competition. E.g., in 2010, in France, ex-public monopolies (EDF and GDF Suez) owned about 80% of the national market while, in Germany, the biggest company held less than 20% of market shares (Reverdy, 2014, pp. 103-124). This information is crucial because the French SOE EDF has kept the monopoly of exploitation of all nuclear reactors based in France (Ministère de la Transition énergétique, 2021).

Furthermore, it must be said that both renewables-generated and nuclear electricity have benefited from derogations to competition rules because the European Commission acknowledged market failures in the achievement of political goals such as preserving the environment and nuclear safety. Consequently, states subsidies have been, to a certain extent, accepted in relation to the development of renewables and nuclear projects. The latter was particularly controversial among EU countries since some of them (e.g., Austria) had withdrawn their nuclear program in the aftermath of Chornobyl and were contrary to the continuation of nuclear projects in their neighborhood (Reverdy & Marty, 2019, pp. 137-138). One could note that state aids and large CAPEX are favorable to Lovins' ideal type of hard path (technocratic and centralized). Yet, free competition and market incentives alone are not likely to enable the EU transition, especially in a growlingly state-led global race to clean energies (Aykut & Dahan, 2022). Decentralization could be undermined by the reality of the global supply chain. Conversely, the centralized and technocratic nuclear option could be somehow favored by this pro-state-aid context.

*From a financial and legal standpoint, nuclear energy is a peculiar technology that, alongside renewables, has enjoyed derogations from the EU competition rules. We will wonder to what extent this infringement of free competition could become the norm to achieve the EU transition. Moreover, it appears that, despite EURATOM, nuclear energy is not a federative vector in the EU. We will wonder whether this undermines or not the sustainability of the nuclear option.*

***Multiple market frameworks in the EU: the French case.***

Finally, considering the vital importance of electricity supply to the industry (Bourgeois, 2012), European governments have been interested in creating favorable pricing conditions for companies based on their territory. Once more, the French case since the 2000s is particularly relevant. In fact, prices had increased since 2004 in the (European) wholesale market of electricity despite the stability of the national nuclear electricity costs of production. Between 2004 and 2006, French institutions and industrial groups tried to protect themselves from the wholesale market, first through the signature of an exclusive long-term supplying contract with EDF, then through a legislative project aimed at creating a regulated price applied to industrial customers. Both initiatives would have enabled French industrials to benefit from the competitive cost of nuclear electricity, abundant in their country. Therefore, DG COMP[14] twice prevented what appears as an unlawful state subsidy to happen. Subsequently, the French State tried to secure a mechanism that enabled the industry to constantly access the favorable price of nuclear electricity produced by EDF rather than the volatile and expensive one of wholesale market. For this, it has had to find a tradeoff with DG COMP in creating competition (though artificial) in the French electricity supply market. This is the genesis of the current regulated price called *Accès Régulé au Nucléaire Historique* (ARENH) planned to last until the 31st of December 2025 by *Loi "NOME" n°2010-1488* (December 7, 2010). Provided that this price binds EDF to sell one-quarter of its production to competitors at a regulated (constant and relatively low) price, the company has lost, since 2011, a substantial part of its potential revenue. This mechanically affects its capacity to maintain nuclear power plants and invest in new projects (Reverdy & Marty, 2019, p. 140) as we will see later.[15]

Despite all these issues, French Prime Minister Borne announced in June 2022 that her plan for the French energy transition will be based on energy sobriety and massive electrification balancing nuclear and renewables (Woessner & Siraud, 2022). In February 2022, President Macron had already revived the nuclear option with, fundamentally, Messmer's argument (1974) that nuclear will secure the French power supply in the future (INA, 2022) and added the environmental argument. Yet, compared to the 1970s, the energy situation is way different since, in 2021, 85% of the French net primary production of electricity came from nuclear electricity and hydroelectricity – with a blatant nuclear predominance (Enerdata, 2022). Hence, planning massive electrification that balances nuclear and renewables in France is less about increasing nuclear capacities than renewables ones.

[14] DG COMP: the branch of the EU Commission dedicated to the enforcement and monitoring of EU competition rules in the single market.

[15] A new market design is under discussion at the EU scale (European Commission Law, 2023). The EU Commission stresses the need to adapt rules to the externalities of the Russo-Ukrainian war upon natural gas prices a (short-term imperative), but the idea is also to provide a market design that fits the needs of the EU energy transition (long-term imperative).

*France is unambiguously planning to wage a new nuclear program deemed consistent with EU environmental and geoeconomic goals.*

*Firstly, we note that extending the lifespan of existing nuclear reactors and building new reactors refer to two distinct logics provided that the latter faces a range of incertitude that almost does not affect the former.*

*Secondly, this new program will likely be completed by some restructurings that will affect the national nuclear industry, the national electricity market rules, and the country's international trade relations. Yet, will these evolutions be enough to enable the nuclear sector to adapt to future challenges such as climate change and the potential return of international wars?*

*

To sum up, nuclear energy is now a potential option for EU member states in the energy transition. Nonetheless, this official label is a technical attempt to obscure both intra and inter-countries' permanent conflicts. Moreover, it does not investigate enough stakes such as gaining energy independence vis-à-vis non-EU countries and adapting to a fast-changing environment. Therefore, paying particular attention to the French strategy and industrial reality, this thesis will try to answer the following key question:

**To what extent can nuclear energy help achieve the EU's decarbonation and energy independence goals?**

This question triggers a preliminary observation.
*Hard scientist Kurt Zenz House acknowledged that* "no energy option will be the cheapest, cleanest, and safest. Crafting an energy policy is about managing these trade-offs as best we can." (House, 2008). It is now crystalline that implementing a large-scale nuclear industry is not exclusively a question of engineering, but mainly a matter of conflicting perspectives that directly refers to political sciences.

Epistemologically, answering our question can be a purely scientific enterprise in Max Weber's sense if it clarifies the issues at stake and the rationally expected consequences of a specific choice (Weber, 1963). Moreover, we acknowledge that adopting one perspective rather than another in a scientific debate is acting like a "little prophet preaching the truth of his god" (Weber, 1963, p. 115). Yet, sticking to this scientific exercise would produce a descriptive thesis. Conversely, our ultimate aim is to take a position and write an argumentative thesis in favor of the nuclear option though acknowledging the drawbacks and incertitude of this choice.

Therefore, we will defend in the first section the potential of nuclear energy in relation to the EU's goals as a technology of the present and the future (I).

In fact, nuclear energy will help low-carbon electrification and contribute to hedging the overall energy supply of European Member States. Beyond critics, the nuclear option has multiple assets (I.A.) ranging from the reliability of its low-carbon and financially sustainable power supply to innovative technological perspectives of adaptation to more hybrid grids including a deep penetration of renewable sources. Hence, we can deem it a technology of the future. Moreover, the nuclear industry's experience (II.A.) will be valuable in a comprehensive energy and raw material hedging strategy. Eventually, also based on its experience, the French nuclear industry is a marketing landmark in international trade that the country cannot spoil.

Nonetheless, the sector is facing and will face a series of limits and incertitude often obscured by nuclear supporters (II). A first group of limits (II.A.) gathers multiple key political and social clashes at the national and international levels that, eventually, affect the nuclear industry and undermine its future as we can observe in France. A second group of limits (II.B.) regards the risks and incertitude of the future: a fast-changing environment, a risk of raw material shortage, and international political instability. In front of these critical issues, our thesis will try to determine what the nuclear sector and governments already do and plan to do to adapt, and what is still uncertain and would require sound interventions potentially up to a nuclear exit.

# I. "Go nuclear, go large"[16]

In chapter one, we assert that nuclear energy will help low-carbon electrification and contribute to hedging the overall energy supply of European Member States.

Beyond critics, the nuclear option has multiple assets (I.A.) ranging from the reliability of its low-carbon power supply to innovative technological perspectives of adaptation to more hybrid grids including a deep penetration of renewable sources. We can deem it a technology of the future. Moreover, the nuclear industry's experience (II.A.) will be valuable in a comprehensive energy and raw material hedging strategy. Also based on its experience, the French nuclear industry is a marketing landmark in international trade that the country cannot spoil.

## I.A. Nuclear energy: the partner we need in Europe.

This section investigates the prospective assets of nuclear energy in a politically tense international context. We support that nuclear can contribute to the hedging of the EU's low-carbon energy supply (I.A.1), that nuclear programs can be financially sustainable (I.A.2), and that the technology is still promising and hence deserves further investments into its research and development (I.A.3).

### *I.A.1. The war in Ukraine and REPowerEU show that energy supply hedging is an overriding priority to build the future.*

This paragraph contextualizes the EU environmental and energy policy in the current international landscape. We, first, investigate the interesting direct geopolitical and geoeconomic implications of the EU green transformation, notably vis-à-vis Russia. Subsequently, we outline the relevance of the nuclear option in a context that requires low-carbon solutions, technologies able to secure the dispatch of electricity, and crucial hedging strategies in a highly competitive global context.

[16] Borrowing from Boris Johnson's Sizewell C speech on September 1, 2022.

The story could start in 2010, when the European Commission declared, after COP-15 in Copenhagen, that becoming "the most climate friendly region in the world" so the EU to acquire a convincing global leadership "is in the EU's self-interest" (European Commission , 2010, p. 8). Thirteen years later, we understand that this ambition is essentially symbolic. Indeed, considering the figures about the distribution of carbon dioxide emissions from energy in the world, it is patent that acting at the EU scale is globally irrelevant. According to BP Statistical Review of World Energy (2022, p. 12), in 2021, Europe's $CO_2$ emissions amounted to 3793.7 million tonnes, i.e., 11% of global emissions. Attention should be paid to the fact BP includes all countries that are geographically associated with Europe (like the UK, Turkey, Ukraine, etc.). It means that the strict EU's share of global emissions is even lower than this 11% (see chart 1).

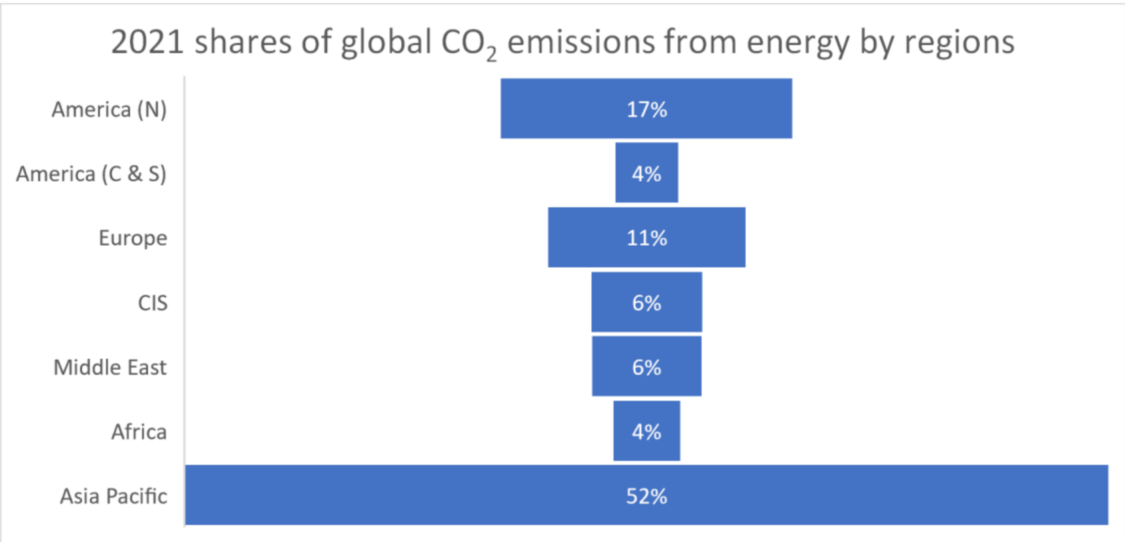



*Chart 1: Elaborated by the author based on data from the BP Statistical Review of World Energy (2022, p.12).*

Arithmetically, the EU cannot deceive the world's States and international organizations by pretending to solve global climate change through its efforts to become the most virtuous continent. The assumption according to which the European Union tries to develop an environmental soft power is consequently the most convincing one. This implies that the EU energy transition is, first and foremost, a matter of international relations and geopolitics. Hence, it goes far beyond climatology.

According to the "European climate law" (Regulation (EU) 2021/1119), the European Union's 2050 long-term strategy aspires to transform its economy into a net-zero greenhouse gas one by the half of the century through a socially-fair and cost-effective transition (cf. recital (14)). The European Commission has furthermore set, as an intermediary target, the reduction of greenhouse gas emissions by 55% in 2030 compared to 1990 levels.

From an energy perspective, however, it is unlikely that the European climate law's goals will match what the International Energy Agency (IEA) calls the net-zero emissions (NZE) scenario. The EU targets rather represent what IEA deems to be the announced pledges scenario that shares features with the NZE one (e.g, fast electrification by 2040) but is, overall, less ambitious. According to the IEA, the combination of EU targets converges towards a rapid reduction of natural gas use in power and building sectors (IEA, 2022, p. 69).

In 2021, President of the European Council Charles Michel depicted Europe as a 'driving force' for ecological transition. To him, it is above all a 'moral duty', and a 'concrete manner of defending our values'. In practical terms, Charles Michel expected 'climate diplomacy' to incentivize global actors to follow the European path so to avoid a form of European green isolationism adversely affecting the EU's international trade (Michel, 2021). Yet, in the interview with *Le Grand Continent,* he never mentioned the relations between the European Union and the Russian Federation. Almost one year after the launch of the Russian so-called special operation in Ukraine, his answers seem particularly EU-centric and naïve.

In fact, President Michel feared global environmental dumping to undermine EU firms' competitiveness, whereas European firms have primarily suffered from the rocketing of energy prices in the single European market driven by natural gas price (Hollinger, 2022). The pattern was not unprecedented, though, since both Ukraine and the EU had already suffered from a geopolitically based (Belyi, 2009) commercial dispute on the supply of Russian natural gas in 2009 that took ten years to be settled (Pirani, Stern, & Yafimava, 2009). This repetition of history in a very short time period brings us to investigate the causality dilemma: is the 'weaponization' of energy (Dimistrina, 2022) a mere tool in the context of hybrid wars (Rühle & Grubliauskas, 2015) or are energy sources – and specifically the phaseout of fossil fuels in the EU – one of the key bones of contention between Russian and European interests? We support the latter hypothesis.

Firstly, oil and natural gas are paramount in the Russian economy: they represented 60% of Russian exports and amounted to 39% of the federal budget revenue in 2019 (Davydova, 2021).

Provided that more than half of the Russian oil exports go to the European market (Smith-Nonini, 2022), the EU environmental policy cannot but significantly affect the Russian economy and political stability. In fact, Davydova (2022) says Russia is a "taker rather than a maker" of the world energy trends represented, notably, by the European Green Deal which puts "external pressure on Russia".

Secondly, according to Susanne Nies (2014), since the end of the Cold War, Moldovia, Ukraine, and the Baltic States stand in a buffer zone between a "Brussels-ruled" energy area and a "Moscow-ruled" energy area due to their "ill-defined membership" while their energy supply often still heavily relies on Russia. The export of electrical material and (energy) network connection from the US-led NATO alliance to Eastern Europe has, indeed, been extremely geopolitical from the 1950s to the 1990s (Lagendijk, 2008, p. 246). And some suggest that these rules from the Cold War have retroactively applied to Ukraine's 2020 decision to buy Westinghouse's nuclear fuel (Kraev, 2021) and to the 2021 decision to purchase nine Westinghouse (US) reactors rather than what the Russian Rosatom could have offered (World Nuclear News, 2021).

Furthermore, after the 2014 annexation of Crimea by the Russian Federation, Ukraine and Moldova have chosen to integrate the European Network of Transmission System Operators (ENTSO-E), i.e., the Brussels-ruled electricity area. Indeed, on 28 June 2017, TSOs of Continental Europe signed, with Ukrenergo and Moldelectrica, agreements about the conditions of the future interconnection of the power system of Ukraine and Moldova with the power system of continental Europe with ambitious goals in terms of technical requirements adaptation by 2022 (ENTSO-E, 2017). It was, moreover, clearly expressed in Ukrenergo's 2020 strategy that integrating ENTSO-E's network was and will be its priority (full membership was expected by 2025) and an "increasing demand for electricity in neighboring EU countries" was classified among "opportunities" (Ukrenergo, 2020). Not surprisingly, the war urged ENTSO-E and Ukrenergo to bring forward the connection of the newcomer to ENTSO-E's power network in March 2022 (Mann, 2022). In addition, the main private investor in the Ukrainian energy market, DTEK, started being a member of the European associations Eurelectric (Eurelectric, 2022) and Euracoal (Pudil, 2010) in 2010. For now, Ukrenergo holds the mere status of "Member Observer" within the European Network of Transmission System Operators (ENTSO-E, 2022), but it already means that, as far as electricity is concerned, Ukraine has left the Moscow-ruled area and is integrating the Brussels' one. Considering this accumulation of factors, the Ukrainian will for economic and energy independence vis-à-vis the old USSR's patterns could be a cause of the ongoing war (Arte, 2022).

We conjecture, with Bueno de Mesquita, that international conflicts are rational enterprises where the attacker considers the utility of the attack before acting (Bueno de Mesquita, 1980) and we acknowledge that limiting Putin's decision to go to war against Ukraine to energy considerations involving the European Union would be too deterministic. However, we cannot exclude that a long-lasting war in Ukraine is also aimed at undermining both the Ukrainian attempt to unfasten the Russian geo-economic influence and the unity of the European Union - striking two of its core vulnerabilities: the lack of consistent common energy and foreign policy (Müller, 2016). As a matter of fact, bringing discord among the EU's member states could be a rational Russian way of slowing down the implementation of the EU environmental policy. It should, indeed, have been hard for the EU to get rid of more than one-third of its natural gas imports, one-fifth of its coal imports, and a quarter of its oil imports (see chart 2) as an immediate reaction to the invasion of Ukraine in February 2022.

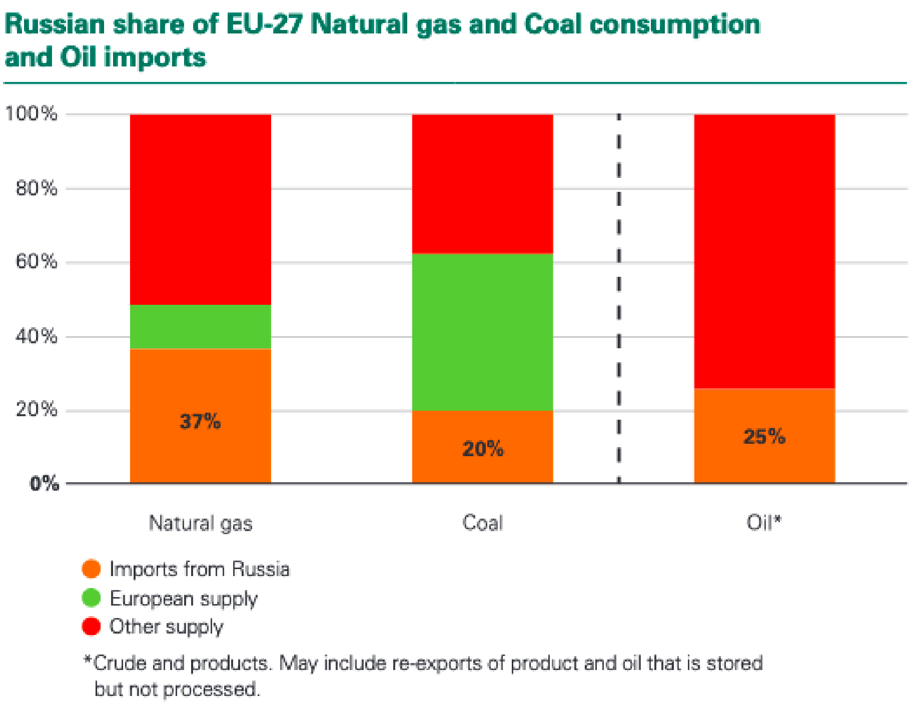



*Chart 2: Source: BP, 2022 (p.7), based on data from the year 2021.*

Yet the REPowerEU plan has proven such an expectation to be wrong. Relying on a European discord after the invasion of Ukraine was either a losing bet or the fruit of an initial misperception (Jervis, 1976) of European affairs. Indeed, between May and December 2022, the European Commission, European Member States, and the EU Parliament agreed upon a plan not least to secure the EU energy supply free from Russian natural gas in large part through a hedging supply strategy based on multiple bilateral agreements in the short and long term (with Israel, Egypt, Norway, Azerbaijan…).

Not only the supplier but also the typology of natural gas will change since the hedging strategy mainly requires liquefied natural gas (LNG) whereas it has been marginalized by Russian pipelines for decades. LNG - by overcoming some geographical barriers (e.g., long distances through shipping solutions) - allows flexibility in the commodity supply. This is the key stake in a fiercely competitive global energy market (IEA, 2022).

*Prospective geopolitical implications: the limits of natural gas in the energy transition.*

Though LNG broadens import perspectives in many EU member states, it cannot overcome all obstacles, especially when it comes to geopolitics. As a matter of fact, natural gas, even liquefied, will be a problem more than a solution in several virtually or physically landlocked states. On the one hand – in case of long-lasting tensions with Russia – Romania, Bulgaria, Finland, and even Sweden to a certain extent can be deemed virtually landlocked because their shipping roads are at risk. On the other hand, Hungary, the Czech Republic, and Slovakia are geographically landlocked whatever the context. If LNG becomes the new normal, these countries will face an additional cost due to the resource’s intermediate land transportation. And this can appear as a prohibitive economic parameter since, according to Gergely Molnar, “the transport segment alone can account for over 50% of the costs occurring through the value chain of internationally traded natural gas” (Molnar, 2022, p. 23). Consequently, whereas countries like Germany bet on tens of gigawatts generated by gas-fired power plants by 2030 to alongside renewables (Spasic, 2023), nine EU member states firmly plan to rely on another dispatchable energy source: nuclear. We will soon explain why renewables need to be completed by a baseload dispatchable source.

Before this, let us point out that the perception and distribution of nuclear energy generation in Europe have radically changed since the early 2000s. Once deemed the energy of “rich countries” (de Montesquiou, 2000), it appears today as counter-cultural in western Europe, especially after the catastrophe of Fukushima in 2011 (Roar Aune, Golombek, & Hallre, 2015).

Belgium, Germany, Netherlands, Slovenia, and Spain, which are currently using nuclear energy, plan to phase out this technology by 2050 (EU reference scenario 2020, 2021). Conversely, as we will see, in Central and Eastern European countries, where the gross domestic product was nowhere superior to €700 billion in 2022 (Eurostat, 2023), nuclear energy is included in national electric mixes by 2050.

*Supplementary issue: renewables (RES) cannot be by themselves.*

For now, all over the world, the state of technology makes RES unreliable because of their intrinsic intermittency and the absence of large-scale storage solutions called "flexible resources", e.g., batteries[17] (IEA, 2022, p. 311). For instance, on the evening of February 23rd, 2023, in Alberta (Canada), while meteorological conditions allowed wind farms to generate only 0.4% of their capacity and solar panels only 33.2% of their capacity, dispatchable fossil fuel-based power has been necessary to secure the supply of households (Raso, 2023). Therefore, countries must include baseload dispatchable energy sources in their mix, and the most common low-carbon solutions for this are natural gas (in perspective, with carbon capture and sequestration) and nuclear, as an alternative to the highly carbonized – though cheap – coal and lignite (Forsberg & Omoto, 2017). This is the main explanation for the eventual inclusion of natural gas and nuclear (under certain conditions) into the European green taxonomy in 2022.[18]

On a larger scale, we can observe that, in Germany, the overall power generation has increased thanks to renewables in the last two decades. Yet, the quantity of gigawatts generated from fossil fuel[19] is stable (74.2 GW in 2002 and 74.7 GW in 2022) or, even worst, has increased in the last years (natural gas – every year – and lignite, in 2020). The only source that has blatantly decreased since 2002 is nuclear (see chart 3.).

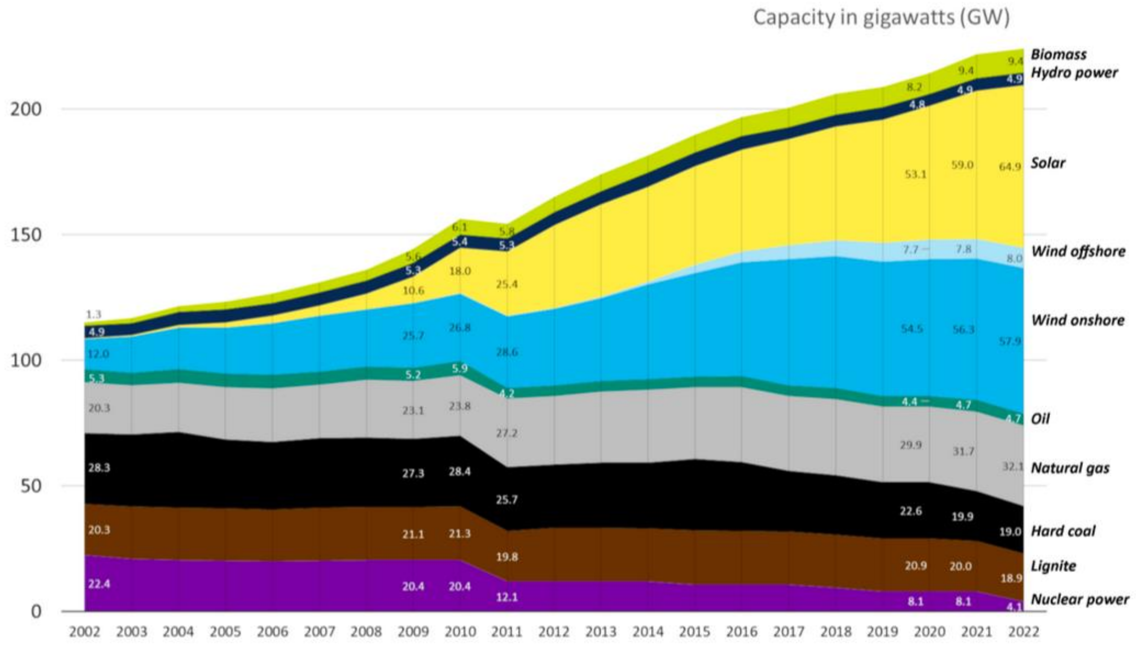
The German electric mix proves that an impressive penetration of renewables combined with a nuclear exit does not reduce the quantity of fossil fuel consumed. On the contrary, Germany

17 We will see in section I.B.1. that batteries require critical raw materials and are geopolitically bound technology.

[18] Of course, we can add that both the gas and nuclear industries have been advocating for this output through their interest groups that, ironically, also represent Russian companies via their European subsidiaries (see, e.g., Greenpeace European Unit, 2022 and Wheaton, 2022).

[19] Namely: oil, natural gas, hard coal, and lignite.

tends to keep burning fossil fuels since they are the unique baseload dispatchable source of energy available once nuclear production stops.




© Clean Energy Wire

*Chart 3: Elaboration by Clean Energy Wire based on Fraunhofer ISE 2022 data.*

It is now certain that Germany will have to build (transitory? long-lasting?) gas-fired power plants to compensate for the void created by the joint phase-out of nuclear and coal by 2030 (Lauer, 2023). According to the German regulator BMWK, Germany will even turn to be a power importer and thus depend on its neighbors in coming years *(BMKW, 2023)*.

We could wonder to what extent this situation will be legal since, according to recital (59) EU Electricity Directive 2019/944 of 14 June 2019, Member States must secure the energy supply of energy households. Opportunistically, Germany will likely receive its neighbors' power surplus so the actual energy supply of German households should not be at risk. Yet it could ironically bind the country importing French nuclear made-hydrogen[20] in the future (Bourgery-Gonse, 2023). Conspicuously, if all member states would follow the German path, the European energy system would collapse, and the energy transition would consequently fail.

[20] Hydrogen used to be deemed too dangerous in the 2000s, due to its instability and related explosions. It seems that its assessment (and technological guarantees) has favorably evolved in the ultimate years. And, in fact, the reserves expressed in 2006 towards this source of energy and storage was far from being fatalist: "the balance of safety, costs and benefits associated with hydrogen is dynamic and path-dependent" (Ricci *et al*, 2006, p. 15).

Moreover, the recent focus on slashing methane emissions by the European Council is likely to make the conditions of natural gas and coal mining and use tenser in a couple of years (European Council, 2022). On the contrary, the emissions of the overall nuclear cycle have been judged comparable to, or even better than, the emissions of renewables' value chains concerning most greenhouse gases (EU Commission JRC, 2021, p. 5).

*The potential of nuclear as a necessary additional*
*low-carbon baseload dispatchable option in the EU.*

Accordingly, all the flaws of natural gas are assets for its nuclear alternative. And the two transitional sources are not necessarily mutually exclusive as we can see from the Polish projected electric mix by 2050 (see annexes). After all, why cancel low-carbon options in a world that incentivizes hedging strategies? Hedging is the new keyword and this concept intimates being substantially able to choose between different energy sources.
We acknowledge that a nuclear program is ambiguous in that regard, because, as we will hint several times in this thesis, it requires a deep commitment in the long run by the state which chooses it. Hence, it could logically be deemed contrary to hedging and flexibility. And should, thus, disappear from the set of options. Nevertheless, hedging is relative to context. In the current context, the price and logistical issues of natural gas are a deterrent. Moreover, this technology, CCUS method apart, emits around 9 nine times more CO2 than nuclear power (Serin, 2022) in addition to worrying methane emissions[21] (Borunda, 2020). Besides, coal is radically contrary to the goal of cutting CO2 emissions, and - without satisfying storage solutions – the intermittency of renewables is unsustainable. Parallelly, the grass-root injunction to act “now” for the sake of future generations (Okumu, 2022) and the will to urgently compete with US and Chinese subsidies for their own industries (Hancock, 2023) de facto limit the potential political room left for temporizing in the wait of eventual technological breakthroughs (particularly in terms of CCUS and energy storage). In this precise context, nuclear energy – though cursed by the unsolved question of waste management and grounded doubts about its safety – rationally appears as an additional low-carbon option (IEA, 2022, p. 20).

[21] According to United Nations Economic Commission for Europe, methane ($CH_4$) has a global warming potential way superior (factor 34) to the one of $CO_2$ both in the medium - 20 years - and long run - a century - (UNECE, 2023).

Therefore, although this energy source was almost disappearing from the European landscape, international politics, a sense of emergency, and the growing global demand for low-carbon energy sources have revived nuclear energy as a strategic option. It is hence not surprising finding substantial shares of nuclear energy in the projected electric mix by 2050 of nine EU member states (EU reference scenario 2020, 2021).

Nonetheless, the overall prospective contribution of nuclear must be qualified since – according to this reference scenario – in 2050 the European Union could have cut its overall nuclear production by 67% even though the volume of power generated could increase by 23% compared to 2020.

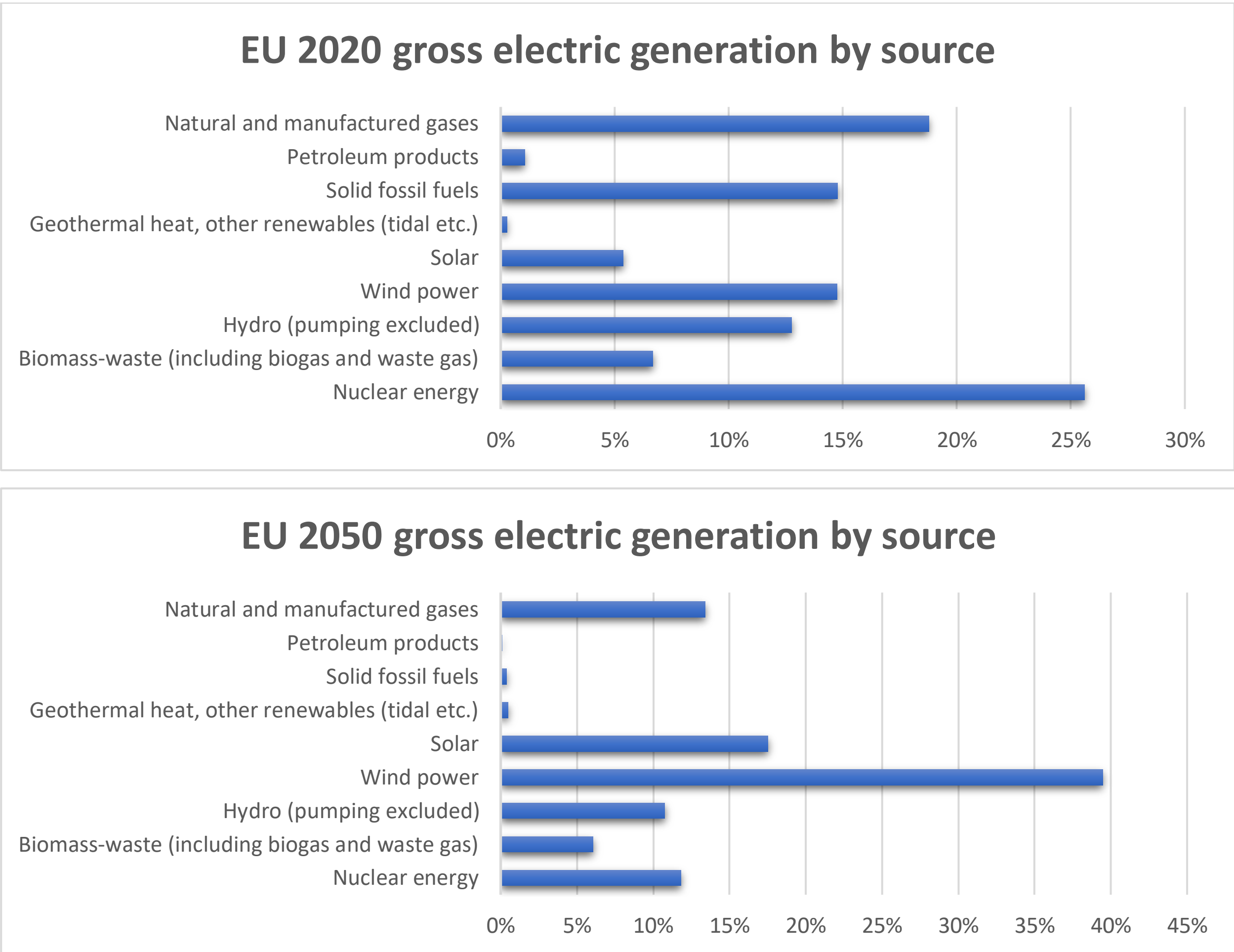



*Chart 3: Elaboration by the author based on the REF2020 scenario.*

*Nuclear: neither an exclusively French obsession nor a widespread choice.*

EU member states can be distinguished into four groups in relation to nuclear energy.

- 12 countries that have not used nuclear it in their gross electricity production since at least 2005:
  Austria, Croatia, Cyprus, Denmark, Estonia, Greece, Ireland, Italy, Luxembourg, Latvia, Malta, and Portugal.
- Lithuania has not produced nuclear electricity since 2010.
- 5 countries currently using nuclear in their gross electric generation and that are phasing out nuclear by 2050: Belgium, Germany, Spain, Netherlands, and Slovenia.
- 9 member states plan to rely to different extents on nuclear in 2050[22]:
  Bulgaria, Czech, Republic, Hungary, Finland, France, Poland (from 2035 onwards), Romania, Sweden, and Slovakia.

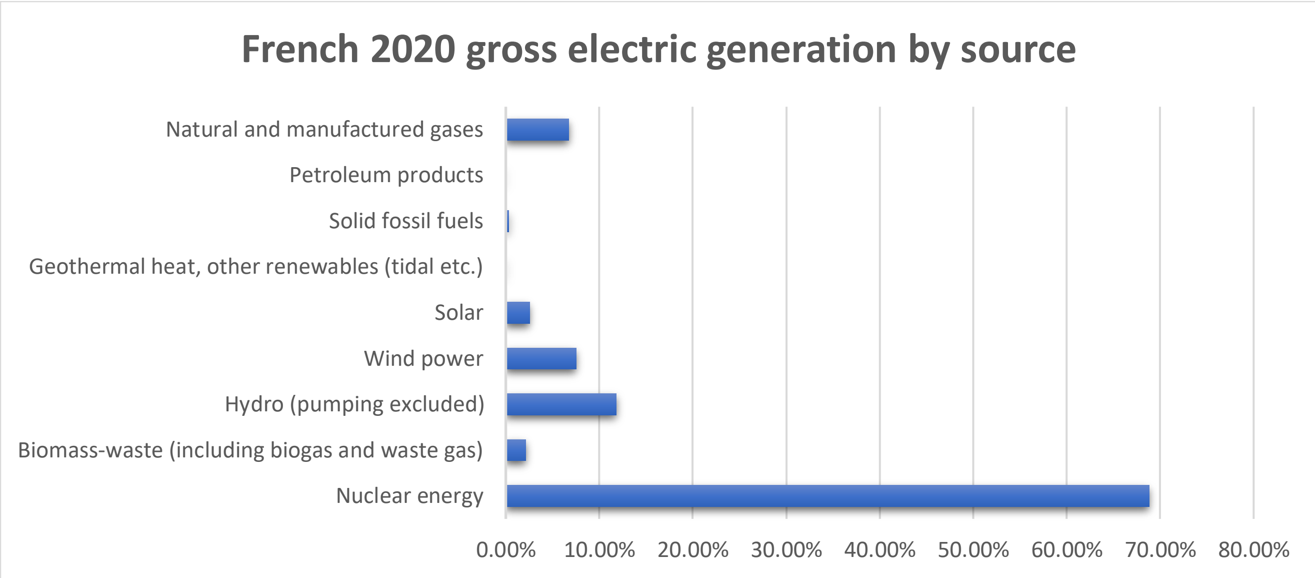
Among the nine pro-nuclear States, there is recent evidence that they are moving forward with new nuclear programs. In fact, Romania should launch the construction of two new reactors in the spring 2023 (AFP, 2022). Bulgaria has secured its nuclear fuel supply with the French Framatome until 2035 (Bocquet, 2022). Slovakia has connected a new reactor to its grid in early 2023 (Forum nucléaire Suisse, 2023) and is planning to build new reactors after 2040 to supply the growing domestic electrical needs (Hudec, 2023). Hungary plans to build two new reactors by 2030 (Alexandrowicz, 2022). And, finally, the Czech Republic plans to build a new reactor that should be operational in 2036 (Les Echos, 2022).

Besides, the list of member states interested in nuclear has ultimately grown up to eleven rather than nine countries. In fact, the Netherlands and Croatia now officially stand among French-led nuclear supporters in the EU (Lohez, 2023).

With the exception of the two newcomers, the last evolutions tend to confirm patterns observed in the 2020 reference scenario where most of the countries that would rely on nuclear electricity would increase both their power production and their nuclear production. However, France and Sweden are two notable exceptions to this general trend. Indeed, France could increase the volume of its power generation by 4% but, parallelly, divide by 2.1 the volume of its nuclear production - with an intermediary cut of 28% by 2030 - compared to 2020. Yet, these projections seem to be based on the French multiannual energy plan as announced in 2018 (Vie

[22] See their detailed 2050 electric mix in the annex.

Publique, 2019) while the national legal cap to nuclear generation could eventually be canceled by French MPs (Le Point, 2023). Regarding Sweden, the volume of power generated could increase by 7% but the volume of its nuclear production be divided by 1.46 compared to 2020. In absolute terms, nevertheless, France would keep its leadership in the EU with about 165.258 TWh, i.e., more than thrice the Polish volume which could become the second biggest EU producer by reaching 52.147 TWh in 2050.



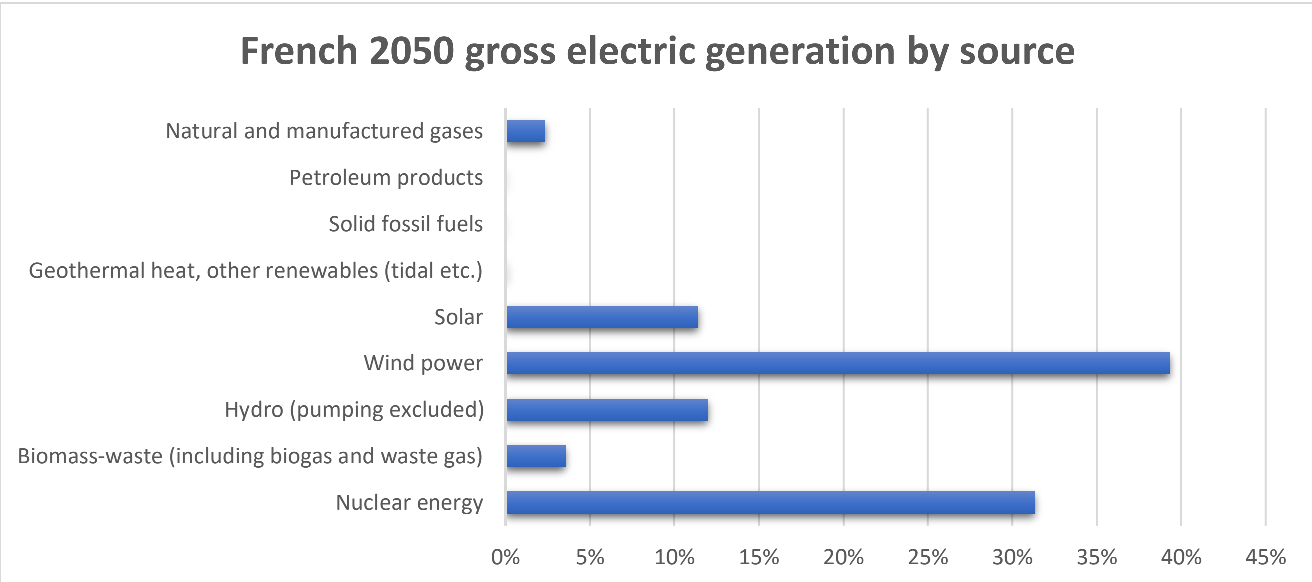




*Chart 4: Elaboration by the author based on the REF2020 scenario.*

This paragraph has highlighted several limits of renewables and natural gas in terms of security of supply and gas emissions and argued in favor of the introduction of nuclear generation, as a baseload dispatchable source, in the electric mix of interested states within the European Union. Rather than a competitor of the two other low-carbon sources, it would be an interesting alternative solution that would empower EU member states with more energy hedging capabilities. Yet, as we will see in paragraph I.A.2., though theoretically appealing, the nuclear option requires strong financial guarantees to be reliable.

*I.A.2. An inframarginal technology: ideas to build a sustainable financing framework for nuclear activities.*

This paragraph deals with the nuclear economy and the financial implications of a nuclear program. Within a new financial context not least featured by the apparent decline of the Energy Charter and the rise of the EU green taxonomy, we try to identify potential solutions for States interested in building a nuclear fleet in coming years.

*Costs: an extremely complex comparative assessment.*

Policymakers could be tented to use comparisons to assess, support, or fight a certain technological choice for electricity generation. The levelized cost of electricity (LCOE) is the conventional tool used for this purpose. It measures lifetime costs divided by energy production (€/MWh) and enables the comparison of technologies with unequal life spans, project size, different capital costs, risk, return, and capacities (U.S. Department of Energy, 2015).
Yet, as appealing as LCOE could seem, it is misleading when it comes to deciding the composition of a mix of electric sources in the long run (Cour des comptes, 2021, pp. 74-75). Beyond the arithmetical distribution of generating technologies, policymakers must take into consideration their marginal costs and the infra-annual profiles of the electricity demand. Moreover, the overall calculation should include storage capacities, flexible resources and demand-side response, and grid connection. An in-depth assessment is fundamental since the genuine conclusion drawn by LCOE would be that renewables are the most economic and efficient technology (E3-Modelling, 2021)… While an overall assessment would show much higher related costs and grid problems. Furthermore, planning the future energy system (a 30-year-long projection) is full of incertitude about the costs of maturing technologies, the future volume of electricity required, and the flexibility of the demand. Consequently, no simple and absolutely reliable index can distinguish a right from a wrong decision in terms of energy

planning. This is notably why a deep understanding of the nuclear economy and related politics is paramount.

*The nuclear economy's Trinity.*

From an economic perspective, nuclear energy is divided into three categories of costs: the initial investment (capital expenditure, CAPEX), operating and maintenance costs (OPEX), and external costs.

First, like renewables, nuclear is a highly capital-intensive industry in which the share of capital costs decreases after the initial depreciation period[23] (Faudon, 2022, p. 133). To illustrate the practical implications of this feature, remember that Italy banned nuclear activities by referendum in 1987 after the Chornobyl accident and thus spoiled a fair share of the about €6.7 billion (13 thousand billion of Italian *lire*) that had been dedicated to the national nuclear program from 1981 henceforth (Catino, 2013). Moreover, as we will see in paragraph II.A.4., having stopped building nuclear reactors for ten to fifteen years has undermined the European and US nuclear industries' competitiveness compared to "younger" industries such as the Chinese one and this could likely cause some CAPEX over costs[24]. In fact, in terms of investments, construction is the most uncertain part in cost and time span. Conversely, once built, OPEX is predictable and low. Obviously, first-of-a-kind (FOAK) reactors are more expensive and uncertain than the following ones. This is not least why it convenes building large fleets and reactors in series (Épaulard & Gallon, 2001). On this ground, while first European Pressurized Reactors (EPRs) are particularly infamous due to their costs and life span overrun, the industry is optimistic about twice shorter and more economic future reactors of this kind (Faudon, 2022). So far, nuclear energy economics has been favorable to large plants in a technological system where the cost of the kWh is inversely proportional to the installed

[23] In France, nuclear power plants have been built to pay for themselves after twenty and their technical lifespan has been expanded up to forty years old (de Montesquiou, 2000, p. 37). In that regard, the classification of maintenance operations on nuclear reactors is variably CAPEX or OPEX based on management practices in the energy companies involved (Cour des comptes, 2014, p. 52).

[24] Sectorial associations like Eurelectric identify also long permit-granting processes as a cause of delay in the development of no-carbon and low-carbon generating plants in the EU. This issue affects all generation technology. Accordingly, all the electricity industry advocates for faster permitting and spatial planning procedures.

power *(Wajsbrot, 2021)*. Nevertheless, some optimistic observers tend to think that Small Modular Reactors (SMRs) – comparatively to the empirical length time and cost of construction of large reactors (e.g., Flamanville 3, about 17 years and €19.1 billion) – enjoy many assets and will turn more competitive than large reactors in a close future *(Nieuviaert, 2023)*. The perspective of being able to build small modular reactors in series by 2030 is also encouraging and could further cut the costs of nuclear programs. Echoing paragraph I.A.1. and the hedging argument, nuclear supporters claim that a fair share of nuclear in future energy systems will make deep decarbonization (the goal of the global energy transition) cheaper than a 100% renewables policy or else, not least thanks to spiller of low-cost nuclear technologies (Buongiorno, 2018, p. 19).

The second category, OPEX, is one of nuclear energy's assets. Indeed, this overall cost is low compared to marginal technologies (natural gas and coal) mainly thanks to the negligible influence of the raw material (uranium) on the total costs of generation. Nuclear fuel costs amount, on average, to 5% of the total cost of generation. Hence even in a pessimistic scenario where uranium price should rise by 50%, the mechanic increase of the cost of generation of nuclear electricity would be merely 5%. Therefore, in the European electricity market built on the merit order principle, nuclear power is called after renewables and before thermal generation, and its benefits often stem from the difference between its cost and the price of thermal electricity (Faudon, 2022). For this reason, nuclear is deemed an inframarginal (or quasi-inframarginal) technology and has recently been subject, like renewables, to the special tax on super profits made during the turmoil of natural gas (Rauline, 2022). We would add that in case of low electricity demand or large penetration of the grid by intermittent renewable energy, base-load plants such as nuclear plants risk having to sell power at near-zero or even negative prices. This would have a dramatic impact on OPEX costs' coverage. Nuclear-based hydrogen could then be a relevant stabilizer to avoid shutdown and startup costs for nuclear plants (Jong, Boardman, & Bragg-Sitton, 2018). In fact, the paradox of hydrogen in the electricity is that it is profitable when the electricity price is low because the cost of generation by electrolysis is positively correlated to the price of its fuel, i.e., electricity (Ruth & Cutler, 2017).

Eventually, nuclear has very specific external costs. While thermal technologies must limit and compensate for their air pollution, the nuclear industry must cope with stringent rules when decommissioning its plants and disposing of burned fuel and nuclear wastes. For instance, in

France during the 2013-2017 period, external costs amounted to about €138 billion and were mainly related long-term storage capacities and the management of spent fuel pools (Cour des comptes, 2019). Besides, in case of a serious accident, the State must carry out the costs (Faudon, 2022).

Now, prospectively, we must understand how further nuclear activities could be financed in the EU, especially in France. Yet, this requires a preliminary acknowledgment of issues faced under the current investment framework, especially in terms of CAPEX.

*CAPEX: turbulences in Treaties.*

Remember, in the first place, that the entry into force of the Energy Charter Treaty (ECT) in 1998 lowered the financial risk by protecting investors in the energy sector. As a matter of fact, the fourth goal expressed by ECT is promoting and protecting investments notably by the establishment of investment risk guarantee schemes and high-level legal security by signatory states. ECT also foresees the resort to international arbitration to solve disputes and the right to repatriate profits and other payments relating to an investment (Ministerial Conference on the International Energy Charter, 2015, p. 8).

Yet, the context is apparently changing. The new deal is mainly due to concerns related to the ECT regarding the signatories' ability to support the energy transition. Indeed, withdrawing States claim that the Treaty will hamper their action by protecting investments in fossil fuels (Tropper, 2022). And, in fact, the prohibition of certain projects can be denounced by investors under the Treaty and bind the State to pay high compensation to the complainant (Saheb, 2021). In other words, States will lose time and money in compensating for fossil fuel or mining projects when enforcing laws cutting gas emissions (GHG) rather than being able to invest substantially in low-carbon projects. Remember that, in parallel, the mere decarbonization of the power sector requires tens of billions of euros annually by 2050 (ENEL, 2022). Therefore, Italy paved the European way in 2016 by withdrawing from the ECT. In 2022, seven other EU member states (Spain, the Netherlands, France, Belgium, Germany, and Slovenia) announced their intention to follow Italy. Nevertheless, the European Commission and Euratom are also signatories of the Treaty and do not intend to withdraw but rather to advocate for amending the Treaty. This is more than a detail if we follow the view of Prof. Lalive[25] since – in the European

[25] Professor Pierre Lalive is a highly authoritative source of modern international arbitration.

(multinational or transnational) public order, established notably by art.85 and 86 of the European Economic Community (ECC) Treaty of Rome (Lalive, 1986, p. 357) – the European Commission is the public order guarantor. Furthermore, a sunset clause is contained in art.47(3) ECT, and secures investments made prior to the shift for another 20 years after the effective withdrawal by the signatory. The path of modernization (amendment) of the ECT chosen by the European Commission seems, hence, sounder. It could, notably, reduce to ten years the protection of investments already made in fossil fuels and exclude fossil fuels from the protection framework nine months after the entry into force of the modernized version (DG Trade - EU Commission, 2022). The ad hoc Conference planned in late April 2023 in Mongolia could adopt amendments to the current ECT (IEC, 2022).

In front of such a complex situation, one could think about the virtues of the new EU "green taxonomy" (Regulation (EU) 2020/852) in providing an alternative framework to the ECT. Yet, they do not perform the same role. From its recital (11), Regulation (EU) 2020/852 aims to develop financial products consistent with the goals of the EU environmental and energy policy to incentivize investments into sustainable activities. In relation to the fourth goal of ECT (protecting and promoting investments), supported green bonds can be seen as a trust builder in financial markets and thus limit the financial risk of such investments. Moreover, regarding nuclear specifically, the Complementary delegated act of climate change mitigation and adaptation covering certain gas and nuclear activities relatively incentivizes investments in nuclear energy. Yet, market reactions to this further step in the green taxonomy did not spark great enthusiasm since Cicero labeled French and Canadian nuclear-related green bonds "medium green" and not "dark green" (Davasse, 2022) due to several concerns that echo arguments we will develop in chapter II. Besides, contrary to ECT, the EU green taxonomy does not foresee any resort to international arbitration. Consequently, we can hardly conceive that regulation (EU) 2020/852 and the ECT are equal in investors' minds.

Eventually, we note that the EU green taxonomy, especially its art.10(2)(b), externally pressures states when it comes to establishing public or market schemes to fund the construction of new infrastructures or the maintenance of previous ones because investing in the allowed "transitional" source (i.e., nuclear and natural gas) must not hamper the mandatory investments in the development and deployment of low-carbon alternatives (e.g., renewables).

*A permissive EU framework.*

We explained, in the introduction, the liberalization process that took place in the EU electricity market in the late 1990s and early 2000s. In that regard, it must be said that though deterring private nuclear initiatives, this liberalization does not prevent a government from developing nuclear projects (de Montesquiou, 2000, p. 46).

The Euratom Treaty, in its art. 40 and 41, regulates investments in nuclear projects in the EU. According to art.40, the EU Commission should regularly publish nuclear illustrative programs (soft law) suggesting electronuclear generation goals and various investments in nuclear activities to member states. Yet, in the late 1990s, the programs turned more and more evasive and not prescriptive because of the growing anti-nuclear approach of some EU member states. Eventually, they tended to focus and the imperious necessity to guarantee nuclear safety and let governments free to develop or not their pacific nuclear program (de Montesquiou, 2000, p. 133). The last nuclear illustrative program was published in 2016 (in the post-Fukushima era) and focused on nuclear safety and security, waste management, and, interestingly, the diversification of nuclear fuel supply (EU Commission, 2016). Yet, no clear indication was given in terms of investment for further nuclear programs in the EU. One could think that Article 10(2), point (b), of Regulation (EU) 2020/852 impacts future nuclear investments since they should not hamper investments in alternative low-carbon solutions. But this point is rather evasive too: we will see that a state could develop nuclear plants and nuclear-based hydrogen in a consistent nuclear program. The lack of clarity and coercivity of the EU Commission in the merit can be explained by a past judicial battle lost against the French Republic before the European Court of Justice that ruled the EU Commission largely incompetent in nuclear investment matters while the EU Council's regulation on nuclear investment has not been sued (Södersten, 2014, pp. 138-41). We hence understand that the EU framework does not substantially bind States in terms of investments in nuclear programs if not in safety matters (Représentation permanente de la france auprès de l'UE, 2022).

Though EU legal sources are poorly instructive, recent political orientations are insightful. In 2022, EU Commissioner for Energy Kadri Simson estimated the cost of new nuclear programs to secure a 14-16% share of nuclear energy[26] in the EU electricity mix in 2030 and 2050 between 350 and 450 billion euros of CAPEX. Moreover, to her, expanding the lifespan of

[26] We note that this share lightly overcomes the 12% foreseen by the REF2020 scenario (see I.A.1.).

some existing reactors would cost about 45-50 billion euros (Simson, 2022). The French nuclear program is, of course, part of it.

*The French public path: no taxpayers, no nuclear industry.*

Firstly, the French government and the SOE EDF have already secured and must secure further resources to maintain existing reactors.

We note that Commissioner Simson's second point matches the budget estimated by EDF (€48.2 billion) for its 2014-2025 maintenance program. This program, called "Grand Carénage", aims to improve nuclear safety and extend the technical lifespan of existing reactors beyond forty years old (EDF, 2020). Prospectively, taking into consideration the scenario of deep penetration by intermittent energy, we note that maneuvering nuclear plants in a flexible dispatchable way (load-following mode) rather than generating power at a constant level further affects the infrastructures, especially valves. It is thus expected that maintenance costs "slightly increase" (Lokhov, 2011, p. 48) when making dispatching from nuclear plants more flexible in a hybrid energy system with a deeper penetration by intermittent renewable energy sources. Yet, EDF is in financial trouble. We have already mentioned, in the introduction, the economic pressure caused by the ARENH regulated price and should add the additional cost of emergency measures to limit energy prices (introduced in November 2021 and extended until December 2023) also borne by EDF. The current group's debt is €64.5 billion euro. 10 billion are linked to the ARENH and about 18 billion were lost in 2022 (Clavier, 2023). Moreover, the catastrophic experience of the two FOAK EPR reactors in Hinckley Point (UK) is also largely responsible for this debt. At the end of the day, French taxpayers pay the bill (Crampes & Léautier, 2016) since the French government injects equity capital into EDF and has not been taking and will not take dividends for a few years though it holds 93.11% of the company's shares (EDF, 2023). This public financing is not surprising in France since the domestic electricity market is substantially state-controlled contrary to most of the EU countries where the market is liberalized and rather pluralistic (Reverdy & Marty, 2019). It results that the French method and framework are hardly exportable. Nevertheless, since, as mentioned in paragraph I.A.1., the French nuclear program is and will be the largest one in the EU, we will focus on its possible financing.

Secondly, external costs – especially downstream nuclear operations – must be financed.

The French Parliament adopted, in 2006, law n.2006-739 that selects deep geological repositories as the storage technic for French long-lived nuclear wastes. Law n.2006-739 was later completed, in 2016, by law n.2016-1015. Henceforth, the Cigéo project (industrial center for geological storage) must be prepared, financed, and achieved by 2035. Its estimated cost is €25 billion that should be financed by the nuclear industry itself (i.e., the two SOEs – EDF and ORANO – and a public administration – the CEA) under the "polluter pays" principle (Ministère de la Transition Écologique, 2023). In other words, here again, French taxpayers finance the project.

Thirdly, governments have different options to finance the huge nuclear CAPEX.

Based on the most recent experience – the two EPRs of Hinkley Point C in the UK –, a market scheme such as contracts for difference (CFD) could be used. In France, the CFD model would be problematic in relation to ARENH which lowly caps EDF's strike price and thus hamper the payback of initial investments in the construction of the nuclear plant. The combination of ARENH – as it exists – and CFDs is a powerful deterrent for investors and likely the less sustainable financial framework. Hence ARENH should be reformed and fixed at a higher level (at the expense of the final consumer). However, RTE recommends not using CFDs for a future nuclear program (RTE, 2022, p. 510). We tend to agree with RTE's assessment since amending ARENH in a sound way seems extremely complex if not impossible unless the EU law itself changes radically.

Otherwise, France could opt for the *Regulatory Asset Base (RAB)* model used in the UK (Norton Rose Fulbright, 2022). This public scheme would bring more guarantees to the developer (EDF) by sharing the financial risk between the developer and consumers since consumers will contribute through a small amount of money either added to the energy bills (like in the UK) or through a special tax. *To Sir John Armitt, "no developer is prepared to build a new major nuclear plant without government support*... Using the RAB model will get these schemes going, but the decision to put the cost on energy bills, not taxation, will mean consumers pay upfront." (Plimmer & Pickard, 2022). Yet, in a country (France) where the electric mix is dominated by nuclear energy[27], we can wonder whether there is a substantial difference or not between making the consumers pay for the construction of new plants through their bills (the contribution is then reversed by the distributor to the developer) or citizens through taxation

[27] Even though the share of nuclear should be counterbalanced by renewables in the future.

(that will be reversed to the developer by the State). Obviously, the effect would largely depend on the kind of tax applied (progressive or flat).

A third option, fully based on a public scheme is currently being studied in France: mobilizing the savings of French bank accounts (the so-called livret A) to finance nuclear activities. Indeed, Minister Panier-Runacher claims that the government is seeking a public scheme that would neither create a new tax nor affect the competitiveness of the price of electricity in France *(Pannier-Runacher, 2023)*. To her, this option would be legitimate to the extent that the nuclear program represents a strategic investment of the French State that will benefit the overall population in the long run. Yet, anti-nuclear could challenge this view stating that investing billions in renewables is more coherent with ecological policies than spoiling time and resources in a nuclear program. Moreover, dedicating French savings to the program is socially controversial because it conflicts with its current use in funding low-income housing and urban renewal in the country. Such a solution is thus politically tricky for a pro-nuclear government that risks facing a convergence of anti-nuclear and social claims. We acknowledge that, though it would simplify the funding of the new nuclear program, resorting to the Livret A must be carefully assessed and calibrated to prejudice as less as possible other commitments of the State, especially social ones. Otherwise, it would be easy to caricature in a somehow Marxist way the nuclear program as a mere instrument of rich and powerful people to enrich at the expense of poor workers and small savers. It would be a political mistake to cause such an output when the reality is obviously more complex. We will deepen the overall (civilian and military) importance of nuclear in France in section I.B.3.

Therefore, in this paragraph we made it clear to what extent characterized nuclear OPEX, CAPEX, and external costs, highlight the turbulences caused by the energy transition in the traditional investment framework and the limits of innovative tools like the EU green taxonomy in mitigating the financial risk of investments in energy facilities. We subsequently argued in favor of a sound public scheme supporting future nuclear investments as a sustainable solution. Yet, our major acknowledgment is that, though the French electricity market fits this solution, it will be hardly exportable. Hence, likely, most of the interested governments will have to consider alternative options such as RAB or CfDs.

Now, we will investigate the potential of the nuclear industry in terms of technological improvement. As we have had the opportunity to hint in this paragraph, the technology itself affects the various costs and the financial risk of an investment in energy facilities. In the case of nuclear, it is also crucial to improve nuclear safety by design for a reason of technology acceptance.

*I.A.3.* *<u>Nuclear: a technology already mastered… and still promising.</u>*

Launched in the 1950s, nuclear electricity – once deemed revolutionary – tends to be labeled as a technology of the past, especially in comparison to emerging sources of solar and wind power and potential flexibility resources. Conversely, in this paragraph, we frame it as a technology of the future by introducing and analyzing the main potential further technological improvements in nuclear energy. Most of them provide the response of the nuclear industry to the legitimate criticisms it has faced after Chornobyl and Fukushima. Furthermore, forward-looking preoccupations like adapting to hybrid energy systems, closing the nuclear fuel cycle, and potential technological spiller on other necessary net-zero emissions industrial transformations are also addressed. From a geo-economic perspective, we eventually insist on the relevance of keeping investing in research and development for EU countries to avoid future technological dependence on emerging major nuclear actors in the world.

*Small modular reactors: the nuclear industry's savior?*

We detailed in the previous paragraph the problem of cost and time-construction overrun experienced in the last EDF's projects of large reactors. Since the FOAK-based justification does not convince everyone, the nuclear industry has been seeking a radical solution to cut its cost and time construction in addition to improving its offer in front of new requests such as major dispatching, safety, and polyvalence.

We have already hinted at the revolutionary solution that emerged from this reflection and research and development efforts that are small modular reactors (SMRs). As we explained, they challenge the orthodoxy of nuclear economics by contesting the absolute truth of economies of scale. As a matter of fact, SMRs supporters deem them to be able to drastically cut construction costs that represent 55-60% of the CAPEX of large reactors according to current estimations (Faudon, 2022, p. 60). They go even further claiming that they could be overall more competitive than large reactors. To justify such an improvement, they put forward four key assets. SMRs are smaller in size, more affordable, and easier to build and operate. SMRs projects have existed since the 2000s.

We are talking about reactors able to generate around 300 MW per module. It is also question of micro-modular reactors generating less than 10 MW (IEA, 2022). Their size does not necessarily bind the technology used since research projects encompass water, gas, liquid metal, and molten salt-cooled reactors and any type of fuel cycle. SMRs are designed to be factory-built-in modules that can be transported[28] to the site where they will be operating.

In terms of use, SMR could easily replace traditional dispatchable thermal plants without requiring heavy (and expensive) modernization of the existing grid. Specifically, they could replace decommissioned coal plants on site and thus avoid the further occupation of lands. The key challenge here is to improve the flexibility of nuclear generation to make it perfectly dispatchable in a hybrid energy system (Vella, 2019). There would be no grid imperative since SMRs could be installed in a concentrated way (several reactors in a single area, like current nuclear plants) or decentralized with minor additional costs of connection to the grid. Yet, two drawbacks are already identified in relation to the decentralized solution: first, more dispatched supervising personnel could be required if no technological improvement allows their connection to a single control room, and second, the cybersecurity and physical protection of the plant would be more complex (Raynal, 2023).

Besides, SMRs would help solve major issues of the future, notably the ones caused by climate change. Indeed, they could be equipped with desalination facilities and hence perform a water treatment role in addition to genuine power generation (Alunaimi & Khuwaileh, 2022). Another function could be hydrogen generation by coupling SMR with different kinds of electrolysis[29] (Locatelli, Boarin, & Fiordaliso, 2018). SMRs moreover provide interesting perspectives for generating power in remote or complex geographical areas like islands, mines, or Siberia and Northern Canada and could be installed directly in energy-intensive industrial areas (Faudon, 140). Finally, this technology could contribute to decarbonizing the shipping sector as a low-carbon propulsive power (IEA, 2022, p. 88).

[28] In some cases, the pre-built cores could present a new risk for nuclear security since some projects foresee cores that must be fully fueled before being transported (IEA, 2022, p. 79).

[29] Framatome (part of EDF Group) says it has already developed hydrogen production units connectible to nuclear plants in co-generation or separately (Framatome, 2023).

Eventually, SMRs' features could even interest private developers if they achieve their promises of eased installation, increased safety, and low waste generation that would tend to rather normalize these generators compared to renewables and others. Of course, high nuclear safety and security standards should still be guaranteed by the hosting State. In fact, this new family of nuclear technology will require an ad hoc regulatory framework. To this end, a research program called ELSMOR has recently been carried out under the Euratom Treaty to identify the key components of a safety design for light-water SMRs compliant with regulations and expectations about nuclear capacities (Buccholz, Ricotti, & Martin, 2020). The conclusions include a set of mandatory and desirable criteria regarding both the design of the module and the use of the system it will be connected to (Playez, Courtin, & Ammirabile, 2020). The current decade will be crucial for various SMRs' prototypes that will have to show overall substantial economic benefits compared to traditional large reactors to compensate for the diseconomies of scale they would induce in energy systems.

According to IEA, thirteen relevant prototypes of SMRs are under development in the world. Only two of them are in Europe, and the EU is merely represented by the EDF-led consortium's NUWARD$^{tm}$ project (IEA, 2022, p. 82). This small modular reactor would use pressurized water technology and have an installed power capacity of 170 MW. The demonstration could happen in 2030 and the SMR could be operational in 2035[30] (Raynal, 2023). Among NUWARD's safety goals, we note the deployment of passive safety systems and the need of a boron-free operation to reduce the toxicity of power generation. The prototype is also designed to match the highest safety standards of the post-Fukushima era (Hanus, 2022). From an economic standpoint, the ambition of the French SMR is to generate electricity costing €50-60/kW (Raynal, 2023). The French government is investing €1 billion to support NUWARD$^{tm}$ expected to improve the French management of nuclear wastes and be coupled with electrolysis for hydrogen generation (Gouvernement, 2022). The Italian government has ultimately shown great interest in this project through the SOEs Ansaldo Energia and Ansaldo Nucleare[31] which

[30] In comparison, the US-Japanese joint venture (General Electric-Hitachi Nuclear Energy) could make its BWRX-300 operational in 2029 (Rapacka, 2022). Blatantly, the EU and Euratom are paying for the years of doubts and consequent inertia that have surrounded nuclear energy while other regions of the world have already massively invested in it.

[31] Ansaldo Nucleare is hold at 100% by Ansaldo Energia. The Italian (mainly public) investment bank CDP Group holds 88% of Ansaldo Energia's equity (Ministero delle Imprese e del Made in Italy, 2023).

signed a letter of intent with EDF and its Italian subsidiary Edison in March 2023 (Edison, 2023). In January 2023, EDF had already managed to attract the Polish private company Respect Energy to develop nuclear projects in Poland based on the NUWARDtm technology (EDF, 2023).

Finally, we share part of the optimism regarding SMRs. Yet, they are today as speculative as large EPRs were in the early 2000s. The European nuclear industry is currently using them as an appealing product to incentivize the EU policymakers allowing Member States to subsidize them under the facilitated framework of Important Project of Common European Interest – IPCEI – (Nuclear Europe, 2022, p. 16). To our view, in waiting for convincing large-scale demonstration by 2035, we are inclined to reckon them as a potential complement to traditional reactors. In fact, only the future will tell us whether they can achieve all their promises and completely substitute traditional large reactors. Moreover, we understand that they could be appealing to a country like Poland that will really launch its nuclear program only from 2030 onwards. Conversely, for France, a rather risk-averse strategy would rather bet on the immediate construction of large EPRs instead of betting on potentially operational SMRs in 2030 when the technical life span of existing plants could not be further extended.

*Nuclear in the seas: the next frontier?*

Using seas for nuclear activities is not a completely new ambition.

In 2011, already, a French industrial consortium aimed to develop submerged small modular PWRs called "Flex-Blue" (Techniques de l'ingénieur, 2011). Not surprisingly, DNCS[32] and AREVA-TA[33] were part of it. The goal was to offer offshore nuclear, i.e., SMRs installed between 60 and 100 meters deep and a few kilometers distant from the coasts. Nuclear electricity would have been transmitted to the continent via cables. The long-life core would not have needed any on-site refueling (PoliMi, 2023). This solution would have been interesting for remote areas such as islands and developing countries with weak power grids (Madelin, 2011). Yet, the project was launched in a twofold unfavorable context. First, in the aftermath of the 2007 financial crisis, projects suffered from a liquidity crunch. For instance, the US nuclear startup NuScale was bound to suspend its operations in 2011 for this reason (Kanellos,

[32] *Direction des Constructions Navales Services*, today Naval Group, specialized in naval defense.

[33] Today TechnicAtome specialized in nuclear propulsion.

2011). Second, the nuclear disaster of Fukushima in March 2011 made the promotion of nuclear investments unpopular. The combination of these two factors likely explains why Flex-Blue – which was waiting for the result of two technical assessments before launching its prototype – was never achieved.

Offshore nuclear remains a smart perspective vis-à-vis the potential problems that onshore nuclear power plants could face in the future in their cooling operations (cf. paragraph II.B.1.). Besides, we note that a consortium very similar to the one of Flex-Blue is currently developing NUWARD$^{tm}$, hence this industrial logic is proving to be resilient.

At the moment, another maritime perspective regards nuclear energy: the shipping sector will have to turn climate neutral in the future. This is made particularly concrete by the current Norwegian discussion on the future regulation of gas emissions in the world heritage fjords (Norwegian Maritime Authority, 2023). In Norway and even more at the world scale, nuclear-propelled vessels could be a relevant opportunity for the shipping sector. In fact, alternative sources of energy (LNG, ammonia, and hydrogen) all share the drawback of requiring fueling capacities in every harbor they will stop at. Conversely, molten salt nuclear reactors (MSRs) could constitute a fuel-for-life reactor system (Safety4sea, 2022). Compared to traditional reactors like PWR, MSR can be fueled by thorium that does not require to be enriched and thus limit nuclear wastes (Britz, 2022). The initial investment would be huge, but this kind of ship would be paid for itself through long-term contracts notably through the economies realized out of the non-consumption of additional fuel during its lifespan. And, in fact, the Norwegian shipbuilding company Ulstein Group is currently developing a molten salt reacotr that can be installed in vessels destined to be mobile charging stations fueling the batteries of electric boats (Ulstein, 2022). This civilian use of nuclear energy in ordinary naval operations would complete the existing panel that already counts nuclear icebreakers powered by KLT-40 reactors built by the Russian Rosatom (TASS, 2021). The idea has reached a level of maturation to the extent that the United Kingdom could pass a bill regulating the use of nuclear power in merchant shipping by 2030 (The Maritime Executive, 2022).

*Closing the nuclear fuel cycle.*

Challenging conventional reactors like the pressurized water reactor (PWR) with innovative ones (e.g., the MSR) is a third perspective for the nuclear industry. The stake is, especially, to close the nuclear fuel cycle by going further than the already mastered partial recycling of spent fuel (the MOX, cf. the introduction) with full recycling. Managing nuclear waste, in the long run, should indeed be the main preoccupation of States launching a nuclear program (Bouttes, 2022). Since the current irreversibility of this choice lies in its long-term externalities, it is legitimate to wonder to what extent the technology itself can absorb them. Otherwise, the two alternatives are storing long-term nuclear wastes on the surface (as it is currently done) or in a deep geological repository (as is planned in some countries). Remember that throughout its fifty years of nuclear generation, France has produced 10 000 $m^3$, i.e., 50 tones of highly ionizing wastes that the technology is, for now, unable to retreat.

Storing the wastes is, to our view, an unsatisfying option that hinder the potential recycling of nuclear wastes. In fact, once burnt, the MOX is physically hotter than non-recycled nuclear wastes, it means that it takes longer to cool and will occupy more space in a deep geological repository. It also increases the overall cost of waste management since the various types of wastes – i.e., vitrified wastes, compacted wastes, used MOX, and reprocessed uranium – must be treated and stored differently while non using MOX at all (in an open fuel cycle) enables the nuclear industry to simply treat every waste as long-lived and highly ionizing ones (Commission nationale du débat public, 2020). So far, this additional cost has often deterred nuclear countries to invest in semi-closed (mono-recycling) fuel cycle since the substantial economy made from sparing the fresh uranium was hidden by the low cost of the commodity (Bunn *et al*, 2003, p. 4). Tomorrow, the context could be different if emerging nuclear countries worldwide enter the market and boost global demand for uranium. Fresh uranium would mechanically turn more expansive and mono recycling – already possible under EPR technology (Bouttes, 2022) – would consequently be a valuable hedging tool. In France, the CEA is working on the further empowerment of PWRs to allow multi recycling from these reactors by 2040 but the substantial investments and experiments will take place during the current decade (Ministère de la transition écologique et solidaire, 2020, p. 145). Yet the nuclear industry could go even further and tackle both the issue of fuel supply and final nuclear wastes. In fact, what is called the fourth generation of nuclear reactors should provide solutions to close the nuclear fuel cycle. Fast neutron reactors (FNRs) could, indeed, burn the totality of plutonium generated during the initial fission process and any kind of uranium isotope (thus substantially reduce the operations and cost of preliminary processing of the nuclear fuel). This would decrease the heat (thus the lifespan) and toxicity of residual nuclear wastes (CEA, 2021).

The European project MYRRAH carried out in Belgium is investigating three new nuclear technologies that could make the fourth generation: a new coolant, the lead-bismuth eutectic (LBE), a long linear accelerator for the fission process under fast-neutron reactors (linac) and a proton target facility (PTF) that not least combines laser and electrodes (MYRRAH, 2023). All these applications are aimed at improving the efficiency of the nuclear process – by reducing both fresh uranium consumption and final waste generation – and nuclear safety through less toxic and more performant coolants for future nuclear reactors. Besides, thorium is frequently studied as an alternative to uranium for future nuclear fuel. Finally, the CEA stresses that FNRs are not expected to fully substitute PWRs but rather complement them in an overall nuclear fleet. As a matter of fact, FNRs would be used to permit the multi-recycling of wastes generated by PWRs (Béhar, 2014, pp. 158-159).

Besides, FNRs are not the only promising perspective. Molten salt fast reactors (MSFRs) could also achieve impressive improvements (Pitois *et al*, 2022). First, their cooling system would not depend on external last resort capacities since the fuel itself would be the coolant. Moreover, refueling could be done without requiring stopping the reactor. These two features would make the reactors much more adaptable to the actual power demand by acting directly on the process of ramping-up/ramping-down – a key asset in hybrid energy systems (Zhou *et al,* 2020). Remember that, from an economic perspective, flexible nuclear production would prevent from generating and selling nuclear electricity at a negative price when wind and solar power will be strong (Forsberg & Omoto, 2017, p. 40). Second, MSFRs would be large and powerful reactors[34] (3 GW) using a combination of thorium ($^{232}$Th) and uranium ($^{233}$U) thus offering a supply hedging solution in addition to the recycling benefits. Furthermore, the use of chloride salt (MSFF-Cl) would enable the solubility of plutonium ($^{239}$PU) and the currently problematic minor actinides in the fuel/coolant. Nuclear security (non-proliferation) could be enforced by design making the reactors incapable of enriching the fuel beyond the threshold of 93% of plutonium.

All in all, these perspectives deserve, to our view, a consistent investment in research and development. Yet, we acknowledge that nuclear fission, despite its potential improvements, appears less fashionable than nuclear fusion though the latter is way more speculative.

[34] Simple molten salt reactors (MSRs) would fit small modular reactors. Conversely, MSFRs a priori better fit large reactors.

*Nuclear fusion: the perpetual dream.*

Two aphorisms perfectly depict the quest for nuclear fusion: dreams never die, and fashion trends are cyclical.

In the 1920s and 1930s, the combined works of physicians like Robert d'Escourt Atkinson, Fritz Houterman and Ernest Rutherford paved the way to the hope for exploiting the of fusion hydrogen nuclei and creating helium and tritium (EUROfusion, 2023). The idea is to generate, on the Earth, the equivalent of the stellar nucleosynthesis by heating gases with a temperature that is ten times superior to the one of the Sun's core. Since 1958, IAEA tries to coordinate the world research in this field (Barbarino, 2020). To achieve nuclear fusion on Earth, research project aims to build a heating device called tokamak which would basically be the reactor of a nuclear fusion plant. It should be noted that nuclear fusion is still, at the moment, a highly speculative technology. In fact, it seems that fusion's promoters are promising the moon: an inexhaustible fuel with insignificant price, inherent nuclear safety, and a negligible environmental impact (Entler et al, 2018). In other words, nuclear fusion is presented as the absolute solution to the energy transition.

Nonetheless, mere small scale technological improvements have ultimately enjoyed an apparently disproportionated media coverage (San, 2022). We believe it is a great news for attracting investments but should not deceive populations: nuclear fusion is still not for tomorrow.

In fact, this technology could be a genuine global common good since China, the European Union, India, Japan, Korea, Russia, and the United States are committed in the main research project. Yet, this makes the good endeavor of the research partly hostage of international tensions (Krige, 2006). Historically, ITER is the first fusion project that has overcome bipolarism during the Cold War. In fact, in 1985, four years before the destruction of the Berlin wall, the current ITER stakeholders gathered their scientific efforts in the field of nuclear fusion. Previously, an exclusively European international project (the Joint European Torus, JET) had been launched in 1973 (EUROfusion, 2023). Based on this precedent, ITER should be relatively immune from the state of international relations. And, actually, this "jurisprudence" has ultimately applied to the delivery, by the Russian Federation, of a one of the six crucial magnets aimed at surrounding ITER's tokawak in February 2023 despite the ongoing war in Ukraine (Usine Nouvelle, 2023).

Yet, all research projects in nuclear matters are blatantly not immune (O'Malley, 2022) and this could, to some extent, affect even the research in nuclear fusion due to potential spillovers. It is already certain that the war in Ukraine hampers nuclear scientific cooperation between the EU (Euratom) and Ukraine (European Commission, 2022, p. 2). Moreover current tense international relations show that technology (especially energy technologies) can be weaponized in a large panel of manners that go from rivalries upon the power to impose standards (Toner, 2022) to the proper destruction of existing critical infrastructures (Scahill, 2023). The post-Cold War "unipolar moment" in which ITER project thrived has certainly helped global scientific cooperation in the last decades, but the concentration of power by the US has also caused distrust (Waltz, 1988) and triggered revisionist States within the international order. Now this order is growingly multipolar. Multipolarity is "complex, flexible and full of options", a State or a group of States deemed "creative expansionist" (Posen, 2009, p. 352) could take advantage of this situation at the expense of other States or regional organizations, notably using energy technologies as a powerful leverage.

We believe that the last fifteen years, with the 2007 financial crisis and the more recent Covid-19 crisis, have largely reshaped the international distribution of power in a multipolar way. International trade and industrial schemes have been affected, as proven by the EU Commission's recent policy activity (e.g., the Chips Act and the Net Zero Industry Act). Consequently, European countries should keep investing in nuclear research and development, not only in nuclear fusion but also in fission improvements. In fact, relying mainly on non-EU technology will be a handicap because the partners of yesterday could turn the rivals or the unfriendly suppliers of tomorrow. Accordingly, the value chain should be, as much as possible, a regional matter. To our view, the EU must hedge its own technological potential, and this apply to every technology of power generation of the future, including nuclear ones.

**Conclusion of section I.A.:**

This section has investigated the geopolitical, geo-economic, financial, and technological assets, potential, and specificities of nuclear power. It results that, prospectively, nuclear and advanced nuclear facilities like nuclear-based hydrogen will be – overall – a relevant complement to renewables and other sources within hybrid energy systems. Namely, they will be an electricity price and supply stabilizer and, tantamount, a hedging tool in a tense international context. Therefore, investment in nuclear research and technology should be adequately supported. To strengthen what argued in this section, the following one (I.B.) will stress the key benefits of the European nuclear experience and the improvements already made in reaction to the criticisms the nuclear industry and European institutions have faced notably concerning upstream (i.e., mining) and midstream nuclear operations. We will moreover explain why nuclear is so important for France.

## *I.B.* ***The historical answer to global energy turmoil***

Beyond its speculative potential, our trust in the nuclear option is grounded on the observed benefits of nuclear countries' experience. This section aims to stress the improvements and clarifications permitted by the confrontation of the nuclear industry to criticisms both in relation to extra-EU affairs (I.B.1.) and intra-EU affairs (I.B.2.). Besides, the French case helps us understand that, in a few countries, nuclear is not a mere matter of energy policy crafting but, to some extent, the backbone of foreign and economic policies (I.B.3.).

### *I.B.1. Current and future hedging benefits of nuclear energy in terms of trading of minerals.*

This paragraph first shows that the European – and especially the French– supply of uranium is diversified. Second, considering the raw material required by battery-based storage systems, it stresses the necessity to include nuclear in hybrid energy systems to lighten the specific demand for critical raw materials.

*State of the diversification in uranium supply.*

In the introduction, we hinted at the context of the 1970s. During this period – featured by the energy and economic turmoil combining the end of the Bretton Woods system and tensions between Western (oil importing) countries and oil exporting countries – the energy architecture of European countries had been challenged. In fact, while the 1960s had been favorable to the take-off of nearly all-oil systems, French and UK Parliaments started to discuss the relevance of such a choice and stressed alternative sources of energy like nuclear power (see,e.g., Baillot, 1973 and Palmer, 1972). We have, moreover, already explained that the main framing of and preoccupations about nuclear energy have evolved decade after decade: from doubts about its pacific use to fears related to nuclear safety and the overall pollution of the nuclear fuel cycle.

Undeniably, nuclear has flaws. Among them, we will introduce, in paragraph II.A.1. the environmental and sanitary failures of French uranium mining operations in African countries, especially Niger. Yet, the sector is never static and manages to provide upstream, and (as we have seen in I.A.) midstream and downstream hedging solutions to a set of identified problems. Regarding specifically upstream mining operations and the consequent supply of fresh uranium, one could think that the growing rejection of the traditional French presence in Western Africa and the regional competition with Russia and China (Vircoulon, 2023) will affect the French nuclear industry. However, operators like the SOE Orano have anticipated this shift and hedged their portfolio of suppliers in the world (RFI, 2022).

What is or was the problem? The 56 nuclear reactors operated by EDF need commodities proportionate to the fleet, i.e., they require between 8.000 and 10.000 tones of fresh uranium per year (Breteau, 2022). Meanwhile, the mediatization of Areva/Orano's mining operations in the Sahel region during the 2000s (BBC, 2017) tended to over-represent the importance of African uranium for France. It is true that the 2021 report of the Euratom Supply Agency (ESA) identifies Niger as the first supplier to the EU – Nigerien fresh uranium covers about one-quarter of the EU demand (ESA, 2022, pp. 15-20). The second is Kazakhstan (about 23%) and the third is Russia (about 20%).[35] Yet, the order is different when it comes to the specific supply of France (Orano) between 2005 and 2020: Khazakstan is first (covering 20% of the demand), followed by Australia (18.7%), Niger (17.9%) and Uzbekistan (16.1%) (Breteau, 2022). EDF can, besides, contract supply agreements with other partners than Orano if this would bring economic and security benefits. The French Court of Auditors has indeed stressed in 2014 that EDF's strategies permitted the company to conserve the cheapest uranium supply in OECD nuclear countries i.e. at a price inferior to 2007 one (Cour des comptes, 2014, p. 39). Hence, we are not saying that EDF's nuclear reactors are immune from African politics, but their supply is, today, fairly hedged though we can qualify Orano's acting CEO's statement about the additional protection permitted by the fact that more than 40% of the French supply in uranium comes from OECD countries (Knoche, 2020). In fact, in business, and especially in the energy sector, the deals between OECD countries are not essentially safe and geoeconomics can also fiercely apply to them (see, e.g., Pierucci, 2021).

[35] Interestingly, Western suppliers (e.g., Australia and Canada) are last, likely because they are often the more expansive ones both for long term contrats and on the spot market.

In waiting for the technological improvements promised by the fourth generation of nuclear reactors (see I.A.3.), we know that the European nuclear industry has secured its supply of fresh uranium for the coming years.

*Diversifying sources of generation will lighten the demand for specific critical raw materials.*

We go further arguing, once more, that what the EU will import in fresh uranium is roughly what will not be required in other critical materials necessary to the energy and industrial transition towards net-zero emissions. In fact, taking a step backward from mere nuclear energy and screening the whole energy sources and storage capacities that will compose the hybrid energy systems of tomorrow, we posit that the nuclear industry is strategical to better distribute the overall needs, while a 100% renewables scenario would dangerously raise the global demand for specific ferrous and non-ferrous metals that are, as any natural resource, limited (Geldron, 2017). To some extent, we could draw a parallel with the 1970s, when the stake was to diversify an energy system excessively dependent on oil – when oil started to be weaponized and investments in extractive capacities to be more expensive.

As hinted at in paragraph I.A.1., the EU environmental policy and its goals can have geopolitical causes and consequences. For instance, some evidence suggests that part of the Russian paramilitary group Wagner's activities in Ukraine are driven by its interest in critical raw materials notably present in Crimea. That would complement the extractive business the group has already built in Africa (Lazard, 2022). We, therefore, posit that, among the stakes of tomorrow, one will be diversifying the overall demand for essential resources (Kissane, 2021) from the mere ones of RES generators and flexible resources – thanks to the nuclear complement – to lighten the pressure upon related markets. Remember also, that, from a practical perspective, small modular nuclear reactors could fuel mining operations (see I.A.3.) benefitting, at the end of the day, the industry of renewables.

We can reverse the anti-nuclear criticism that accuses the nuclear industry of having simplistic views that ignore natural constraints (Meyer, 2023), by wondering to what extent wind and solar radical supporters take their overall value chain into consideration when comparing them to nuclear electricity or natural gas. It appears that, in terms of infrastructure, they require way more minerals per MW than conventional generators (IEA, 2021). Besides, infrastructures are only one part of the phenomenon and attention should be paid to ancillary services inherent to renewables. In particular, the concept of "flexible resources" – the ones supposed to balance the intermittency of RES through, e.g., storage solutions – says nothing about their actual components. Indeed, we know that power dispatching from RES (solar and wind power) will require battery-based storage systems (BSS) (Simões & Farret, 2022). First of all, energy storage for renewables will very likely require digitalization, i.e., the use of the Internet of Things (IoT) to connect the generating plants to storage facilities so to avoid the adverse effect of excess generation on the grid (Singh & Akram, 2022, p. 14). From an environmental standpoint[36], digitalization is critical since the proliferation of continuously running data centers poses problems related to fueling the IT equipments, on the one hand, and cooling them, on the other hand, (McMahon, 2018, p. 8). The phenomenon has reached an intensity such as the carbon footprint of the digital economy is now comparable to the one of the aviation industry (Jungblut, 2019). Second, considering batteries per se, the lithium-ion technology is currently the most widely used in the world (Schoenfisch & Dasgupta, 2022). Yet, the essential resource, lithium, needs to be extracted with a pretty negative environmental impact and foreseen risk of shortage (Campbell, 2022). Furthermore, the current main recycling method (pyro-metallurgy) is highly energy consuming, releases toxic gases (Friends of the Earth Europe, 2013), and is unable to properly recycle the most valuable resource, i.e., electrolytes (Erdyn, 2022). Though some suggest that hydro-metallurgy could solve this issue, this alternative requires substantial investments in all the steps of the recycling process. In particular, the treatment of wastes caused by lixiviation is challenging. It has first been supposed that fuelling their accelerated 'natural' evaporation with biogases would have been cost-efficient and helpful in fighting climate change because of the low related $CO_2$ emissions (Bouchet, 2014), but the unavoidable methanization could constitute an additional long-term problem in the mitigation of global warming and be hampered[37] by the EU strategy to reduce methane emissions that should complete the EU environmental policy by 2030 (European Commission, 2020).

Accordingly, the accumulation of drawbacks with lithium-ion batteries urged the batteries industry to offer alternatives. And the most reliable one is vanadium flow batteries. Despite

[36] One could also think about the greater vulnerability of energy systems vis-à-vis cyberattacks even though experts seem to be optimistic about the resilience of smart grids stressing that high decentralization makes the attack less lucrative than disrupting a regional or even national hub (McDonald, 2021). However, if the purpose of the cyberattack is not economic but political, this argument turns irrelevant.

[37] More stringent norms against methan gas leaks will make more methanization costly.

numerous technical assets – among which a low degradation that makes the battery more durable, in addition to a better adaptation to the grid's needs compared to lithium-ion –, vanadium often needs to be extracted from a few countries like Russia, China, and South Africa and its price is highly volatile (Stauffer, 2023). Ironically, vanadium can be a byproduct of uranium mining (Chenoweth, 1981) and high prices incentivize vanadium suppliers to co-investing in uranium projects to simultaneously extract vanadium (World Nuclear News, 2018). Eventually, this state-of-the-art of technological solution for BSSs shows that the most optimistic supporters of renewables also tend to neglect the impact of the overall value chain of an energy system heavily relying on renewables generators. Renewables are not self-sufficient nor free from polluting and expensive commodities (lithium, vanadium, etc.). Therefore, as it happens with nuclear energy, arguing in favor of deep penetration of national grids by renewables calls upon speculative technological improvements. In the case of renewables specifically, these improvements should mainly occur in storage capacities. Interestingly, a second key similarity with pro-nuclear argumentation is the ambition to 'close the cycle', i.e., on the one hand, closing the nuclear fuel cycle (see paragraph I.A.3.), and, on the other hand, being able to recycle the most essential components of batteries aimed to store intermittently generated electricity. We deem that, though anti-nuclearism advocates tend to distinguish nuclear and renewables industries, they share a similar pattern and, in specific situations, even similar features. This acknowledgment strengthens our initial argumentation in favor of hedging our future needs in critical raw materials by building proper hybrid systems rather than excluding nuclear energy by principle. Nuclear would thus be part of the solution vis-vis extra-EU trade relations, as it has been in the 1970s.

Now, from an intra-EU perspective, let us understand how European judicial institutions have absorbed the growing nuclear politico-judicial problem after the catastrophe of Chornobyl (1986).

### *I.B.1. A favorable European jurisprudence.*

This paragraph introduces the legal ground of the pro-nuclear European jurisprudence developed by the Court of Justice of the European Union throughout the last years in response to the Austrian anti-nuclear judicial activism.

In the introduction, we have mentioned the controversial dimension of nuclear projects between EU member states, especially after the 1986 Chornobyl nuclear accident. If, as seen in paragraph I.A.1. eleven EU states may be labeled pro-nuclear, we can posit that the other sixteen are, to various extents, anti-nuclear. As soon as this technology is abandoned or not used for concerns about its security[38], it seems logical that Chornobyl's 'cloud' has created a precedent that worries non-nuclearized countries neighboring nuclearized ones. Though the ionizing potential decays with the distance, a meteorological conjuncture can help ionization cross national borders and harm the neighbor's population and land (AFIS, 2021). A 2014 (i.e., post-Fukushima) amendment to the Euratom Treaty notably imposes obligations of transparency to nuclearized states (art.8 Council Directive 2014/87/Euratom) vis-à-vis regulatory authorities of neighboring States both about normal nuclear activities and cases of incidents and accidents (Council of the European Union, 2014).

Nonetheless, judicially particularly active anti-nuclear member States such as Austria are not satisfied with the permanent eventuality of a nuclear accident on the EU territory and – following an absolute precautionary principle – sue nuclear projects waged by nuclearized member states before the Court of Justice of the European Union (CJEU). Case T-101/18 (Austria v. Commission) judged by the General Court (CJEU) in November 2022 is the perfect illustration of the geographical roots of the Austrian anti-nuclear judicial activism since the Republic of Austria tried to disrupt a nuclear project (Paks II) planned by the neighboring Republic of Hungary (CURIA, 2022). Based on two important judicial cases of the last decade that have opposed the Republic of Austria to the European Commission before the CJEU (case C-594/18 P, judged in 2020, and case T-101/18 judged in 2022), we can draw two main lessons. First, 36 years after Chornobyl and 11 years after Fukushima, the European jurisprudence is favorable to nuclear projects in the sense that the Republic of Austria has lost its trials, even in appeal. Second, the protection of the environment and nuclear safety never constitute the core of the judicial referral nor of the legal reasoning. In fact, the Republic of Austria challenges the compliance of state aid to specific nuclear projects with EU law, especially competition law within the Single Market. Hence, the crucial legal ground for both contesting and legitimizing

[38] One could also think about its cost though we have seen that even the poorest EU member states can be interested in building nuclear plants.

state aid to nuclear projects in the European Union is Art. 107(3)(c) of the Treaty of the Functioning of the European Union (TFEU):

> 1. *Save as otherwise provided in the Treaties, any aid granted by a Member State or through State resources in any form whatsoever which distorts or threatens to distort competition by favoring certain undertakings or the production of certain goods shall, in so far as it affects trade between Member States, be incompatible with the internal market.*
>
> *(…)*
>
> *3. The following may be considered to be compatible with the internal market:*
>
> *(…)*
>
> *c) aid to facilitate the development of certain economic activities or of certain economic areas, where such aid does not adversely affect trading conditions to an extent contrary to the common interest*

Remember that, whereas Art.107(2) lists aid that "shall" be compatible with the Single Market, Art107(3) uses the term "may". It is established in Law that 'shall' is an imperative command whereas 'may' refers to facultative permission (Cornell Law School, 2021). The discretionary margin lying on 'may' is extremely political. It is not surprising, hence, that a revisionist state vis-à-vis Euratom like the Republic of Austria (Bianchi, 2021) insists on this article, at least, to trigger a debate and try to gain a judiciary victory that would balance the pro-nuclear roots of the first European Treaties established in the 1950s (*acquis communautaire*).

Besides, when it comes to assessing the 'common interest', we must bear in mind that, according to Art.194(1)(b) TFEU, the security of energy supply in the EU is paramount. On this occasion, we re-hint at, the prospective doubts expressed in paragraph I.A.1. about Germany's capacity to supply its households and companies with electricity in the coming years.

*… But founding Treaties are the tool of the powerful.*

The EU administration (the Commission[39]) is empirically supporting the construction of new nuclear reactors in the UK (Hinkley Point) and in Hungary (Paks), and the Curia has not been eager to challenge the Commission on sensitive issues such as procedural rules and the limits of administrative autonomy (Munchmeyer, 2023). Moreover, the CJEU's jurisprudence teaches us that art.10(2)(b) of Regulation (EU) 2020/852 (see paragraph I.A.2) is not powerful yet. Indeed, in Case T-101/18, Austria tried to stress that the billions of euros of state aid for Paks II would be prejudicial to renewables developers. The Court objected that, on the ground of Art.194(2) TFEU, Member States are free to craft their energy mix (Munchmeyer, 2023). In other words, the founding Treaty – in this situation prone to State's sovereignty – has prevailed upon a regulation aimed at harmonizing the European energy market through supranational competencies. Furthermore, in its judgment in the appeal of Case C-594/18P, the Court remembers that the Euratom Treaty and the TFEU have the same legal value (cf. Art.106a(3) Euratom) and acknowledges the pro-nuclear orientation of the Euratom Treaty as it exists. In terms of investments, state aid to nuclear projects is deemed, by the Court, compatible with the Treaty's objectives to build nuclear power stations and the creation of new nuclear energy generating capacity (CURIA, 2020). In a nutshell, the combination of Art.106a(3) Euratom and Art.194(2) TFEU currently tames the Austrian judicial ambitions and protects the European nuclear industry. Consequently, the well-known nuclear accidents of the past decades have not altered the pro-nuclear European jurisprudence.

It appears that neither extra-EU nor intra-EU affairs jeopardize the nuclear option at the moment. On the contrary, the issue of raw materials can support the complementary status of nuclear energy in a hybrid energy mix and European political and judicial institutions are far

[39] We acknowledge that the UK's state aid for Hinkley Point C has been allowed by the second Commission Barroso in October 2014 (EUnews, 2014), and the Hungarian one for Paks II by the Junker Commission in March 2017 (European Commission, 2017). We simplify this dynamic political reality with the use of the generic expression 'the Commission' since, all in all, successive EU Commissions have adopted a similar position on nuclear projects. Furthermore, Mrs. Vestager who signed the decision favorable to Paks II in 2017 as Eu Commissioner for Competition has conserved her position within the von der Leyen Commission. Therefore, we approach the different EU Commissions as a continuum.

from hampering nuclear projects. Now, we will see that, for the French Republic, the incentive to maintain a strong nuclear industry goes beyond strict energy and environmental considerations.

### *I.B.3. Beyond the energy transition, the "French touch": why France sticks to the nuclear option.*

This paragraph outlines the economic and diplomatic importance of nuclear technology for Frances since the mid of the XX$^{th}$ century.

We have already highlighted the French peculiarity within the European landscape. Compared to several neighbors, the French economy has a dirigiste tradition. Among the most notorious evidence, the decades of national economic growth that followed World War II stems from Monnet's post-war reconstruction roadmap (Appelqvist, 2008) and the impulsion given by Charles de Gaulle. Indeed, the latter early identified three key sectors where investing for securing industrial, technological, and economic prosperity in the long run: aeronautics, spatial and nuclear (Coldefy, 2015). Today, this trinity is obviously affected by environmental concerns and the conditions of international trade have evolved notably due to decolonization. Yet, as far as nuclear is concerned, the fulfillment of the Gaullist ambition by his successors still has a substantial consequence on the present of France. On the one hand, the country welcomes the second civilian nuclear fleet in the world – 56 reactors – after the US – 94 reactors – and is the third nuclear generator in the world – 338.7 TW.h – after the US – 789.9 TW.h – and China – 344.7 TW.h (IAEA, 2021, pp. 5-6). On the other hand, the French Republic is the only EU member state holding the means of nuclear deterrence. Discussing the military dimension of nuclear energy would go beyond the scope of this thesis, but remember that this tool is mainly perceived as an explanation to the obsolence of major conflicts as a factor of stability in the international system (Gaddis, 1986). It must be said that the French nuclear doctrine supports the dual use of nuclear energy. For instance, the spatial sector is aware of the couplings between its technologies and the civilian nuclear industry's technologies (Lewandowski, 2021, p. 72). Cooperation also exists between Framatome (typically oriented towards civilian nuclear), the CEA, and Naval Group to develop the nuclear submarine propellers[40] of tomorrow (Framatome, 2022). We consequently understand that, in France, nuclear falls under the category that Didier Brugère calls 'industries of sovereignty' (*industries de souveraineté*) since nuclear is a dual-use high technology developed by a strictly regulated sector and sold on a market featured by its monopsony[41] (Brugère, 2014, p. 198). We will hence try to understand in more detail to what extent the nuclear industry serves the French 'sovereignty'. Our analysis will be twofold: we are going to investigate, first, the impact of the sector on French international relations and, second, its role in the domestic economy.

*The nuclear structures the French prestige in international relations…*

One month after the invasion of Ukraine, the first official talk between a European leader and President Putin was with President Macron (Ljunggren, 2022). Why not the President of the European Commission or the High Representative of the European Union for Foreign Affairs and Security Policy? Certainly because, in Putin's realist views (Loftus, 2022), as long as the European Union is not a State, it is irrelevant in international politics. Then, why the French President rather than, for instance, the freshly appointed chancellor of Germany? From a geopolitical standpoint, Germany is historically closer to Russian expansionism than France and was particularly concerned by the important issue of the new natural gas pipeline Nord Stream 2 (Marsh & Chambers, 2022). Yet, as many other EU member states, Germany is neither a permanent member of the UN Security Council nor an atomic power. In fact, remember that the first two months of conflict have been particularly intense in terms of nuclear escalation and de-escalation (Arndt & Horovitz, 2022), limiting the role of non-nuclear powers in potential talks. We hence posit that the French overall international prestige, notably granted by the nuclear weapon, enabled President Macron to call President Putin on March 22, 2022.
Moreover, the ongoing war in Ukraine is almost anecdotic in the decades of nuclear history the world has known since the establishment of the International Atomic Energy Agency in 1957. One could think about the growing importance of the Iranian nuclear industry in the preoccupations of the *Quai d'Orsay* since the early 2000s (Therme, 2020). As hinted at in the

[40] The four French nuclear submarine propellers, *sous-marins nucléaires lanceurs d'engins (SNLE)*, are the furtive and portable component of the French nuclear deterrence around the world. Their reactors lie on the pressurized water technology (Ministère des armées, 2023).

[41] The State, through EDF or the Army, buys nuclear assets as an exclusive customer.

introduction, the question of nuclear proliferation has been and is still, to some extent, a contested issue. This notably explains the twenty-five bilateral agreements signed by the French Republic on nuclear matters around the world between 1972 and 2014. In parallel, France is part of several multilateral international treaties related to the civilian and military use of nuclear energy (IAEA, 2022). From a quantitative perspective, we understand that nuclear affairs are a driver of French diplomacy. Qualitatively, we can draw attention to extremely prestigious bilateral signatures with key nuclear players like the Russian Federation and the People's Republic of China.

In a nutshell, nuclear has been an important item of French diplomacy throughout the last decades. But the French Republic is not a genuinely benevolent international actor. The country has its self-regarding interests in a globalized context. In other words, the means of the State are also used to support the export of French services and industrial products through the well-known 'international economic diplomacy' (Saner & Yiu, 2006). Remember that the French Republic is suffering from a long-lasting trade deficit since 2007. It is mainly caused by an excessive deficit showed by the goods balance and not compensated by good performances in services export and a positive income balance (Banque de France, 2022).

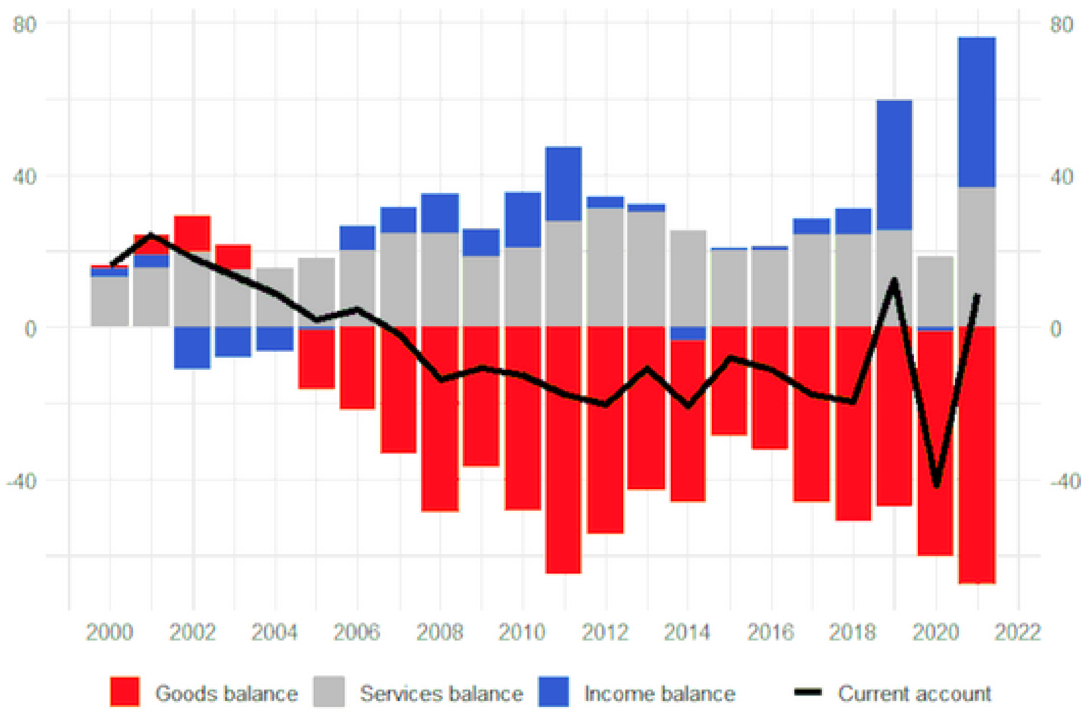



*Chart 6: Current French account balance and its components (€ billion). Source: Banque de France.*

We understand that, in such a perspective, genuinely environmental considerations compete with national economic goals. In fact, we know that nuclear technology has historically been a point of entry for French international trade as an appealing product used to subsequently offer a series of other 'made in France' goods and services (Pouponneau, 2013). The low-carbon profile of nuclear technologies appears as a godsend, but we mainly comprehend it as a pretext to develop a sector where the French already hold a comparative advantage built out of decades of massive investment. As put by Mycle Schneider in the late 2000s:

*"The State-owned French nuclear industry is the most powerful nuclear player in the world. It controls significant market shares in all business areas from uranium mining to nuclear waste management. The development towards this position has been possible because it was designed and implemented by a small technocratic elite that operates outside of election considerations and democratic control. The French nuclear industry also profits from a unique fuel chain that does not distinguish between civil and military uses."* (Schneider, 2009, p. 37). This assessment is still largely true more than ten years later considering that EDF is the most important company managing a nuclear fleet in the world, that the CEA stands among the world leaders in nuclear research and development, that Orano (ex Areva and Cogema) is a world-leading company in uranium mining and enrichment (upstream operations[42]), and that Framatome – a historical leading company in the design, construction, and revamping of nuclear reactors – holds maintenance contracts with 380 reactors in the world (Lewandowski, 2021, p. 71). All these companies are SOEs and public research agencies and their joint success is anything but casual. Indeed, the sector has enjoyed exceptional political support notably in carrying out its business abroad. The case of Areva starting direct contact with Lybian officials in 2007 before any formal intergovernmental agreement (Schneider, 2009) shows that the French executive arranged to not hamper business operations even in diplomatically sensitive situations[43]. It is not surprising since, already in the 1970s, the CEA enjoyed a large same autonomy vis-à-vis the executive branch when exporting industrial products (Pouponneau, Les changements de la politique française d'exportations nucléaires (1974-1976) : un triple double jeu, 2013). Some suggest that, in the late 2000s, the French government has been seeking to support domestic

[42] Orano is also expert in downstream operations, i.e., in nuclear waste management notably in producing MOX in its factory based in Melox (France).

[43] Remember that Libya was then ruled by Colonel Al-Gaddafi who came to power after a coup in 1969 and who has been subjected to an international arrest warrant in 2011 for serious human rights abuses (Vampouille, 2011).

and foreign demand for French nuclear reactors – despite the absence of an objective need for new reactors – in order to maintain the competencies of this industrial sector (Schneider, 2008) in a pure logic of preservation of industries of sovereignty. In fact, President Sarkozy himself finalized a huge deal (€ 8 billion) between Areva and Chinese operators to sell two EPRs and a long-term contract in uranium supply during his state visit to China in November 2007 (Szarka, 2011, p. 169). Subsequently, the *Agence France Nucléaire International* (AFNI) was established in France. This short-lived (2008-2019) state agency was supposed to accompany interested foreign governments in preparing the institutional and technical framework and the human capital necessary to wage a nuclear program[44], based on French expertise. AFNI's guiding committee gathered representatives of the Prime Minister, the Ministry of Finance and Budget, Foreign Affairs, Economic Development, nuclear safety agencies, and the CEA. The exact raison-d'être of AFNI is unclear and made even more cryptic by its abrogative decree alongside a laconic notice that claims the cancellation aims to simplify the structure of the French institutional support to nuclear energy and its understanding by international partners. We thus guess that, in eleven years of existence, AFNI has completely failed to achieve the goal of art.1 of its founding decree. Yet, considering the late 2000s context, a centralized agency treating international deals could have seemed relevant. Indeed, the Sarkozy administration (2007-2012) negotiated nine new bilateral nuclear trade and nuclear cooperation agreements (Schneider, Nuclear France Abroad History, Status and Prospects of French Nuclear Activities in Foreign Countries, 2009). President Sarkozy advocated for the normalization of nuclear products to boost sales. He notably rhetorically asked during a 2007 official visit to Morocco "We have it [nuclear power plants] in France, why shouldn't they have it in Morocco?". And we believe that, in front of such a proliferation-prone presidential impulsion, the rationalization of the French civilian nuclear offer through AFNI was justified.[45] Though not existing anymore

[44] See art.1 Décret n° 2008-441 du 9 mai 2008 autorisant la création de l'Agence France Nucléaire International au sein du Commissariat à l'énergie atomique, Journal Officiel de la République française n°0109 of May 10, 2008.

[45] Interestingly, in 2017, President Macron used to criticize the lack of awareness of the cost of nuclear safety in France in an interview with the World Wide Fund for Nature (WWF) (Le Monde, 2022) At that time, although he did not clearly state an antinuclear doctrine, his main argument was that nuclear energy is too expensive and that France should diversify its electricity mix. Although it is not enough to prove that, between 2017 and 2019, the French government tried to tame the nuclear industry, it is patent that the abolition of AFNI happened after a

and having a poor overall assessment, AFNI symbolizes the crucial place of the nuclear industry in the French economic diplomacy. Our research did not identify an official successor to AFNI. Nevertheless, an ongoing study case in India provides us with some insights about players and methods used to promote the export of French nuclear facilities. In fact, we know that I2EN alongside GIFEN[46] participated in a promoting event - the 5th EDF Suppliers' Day in Mumbai, on December 9, 2021 - related to the Jaitapur Nuclear Power Plant (JNPP) project. This event took place 7 months after EDF submitted a techno-commercial offer to the Nuclear Power Corporation of India – NPCIL. Now, the French delegation (gathering EDF, GIFEN, I2EN, and the French ambassador in India) is trying to persuade the Indian counterpart to sign a General Framework Agreement (EDF, 2021). We posit that the trio EDF-GIFEN-I2EN has informally substituted AFNI in its role of 'preparing the terrain'. This could mean that the French nuclear industry will henceforth exclusively target mature or quasi-mature nuclear markets where a framework of nuclear expertise already exists and where the competencies of the CEA are not indispensable. However, we acknowledge that we can hardly draw reliable conclusions from a study case about which talks started a decade ago (Vella, 2019) – when AFNI was still in place. Nuclear is thus fundamental in French foreign policy both for the question of nuclear deterrence and as a trade facilitator in economic diplomacy. We will see that these external benefits have a domestic spiller effect.

*…And benefits the French industry and economy.*

Crafting an economic policy in favor of the supply or the demand is a classic question in economics though not always relevant. In fact, in 2014, while EU member states (OECD countries in general) were struggling with the aftermath of the 2007 financial crisis, economists acknowlege that the European single market was experiencing a crisis of its demand for goods and services that worsened the economic conjuncture of every single member state excepted

succession of political events that seriously challenged a field that used to be protected by successive French Presidents.

[46] The 'Groupement des industriels français de l'énergie nucléaire' (GIFEN) was created in 2018. This interest group gathers French stakeholders in the generation of nuclear electricity. The International Institute for Nuclear Energy (I2EN) s a French public initiative that has existed since 2010 and focuses on nuclear research and the development of the academic offer in universities and engineering schools to form nuclear experts abroad.

Germany that benefited from the margin of public investment left by its low original public debt (Passet, 2014). The stake was then to find solutions to escape the vicious economic circle France was struggling with. In reality, as we have already higlithed, the French Repubic still has not yet found a way to reverse its trade deficit since 2007. Among the key problems, the French industry has lost value added and is unable to enrich the country anymore (see chart 7).

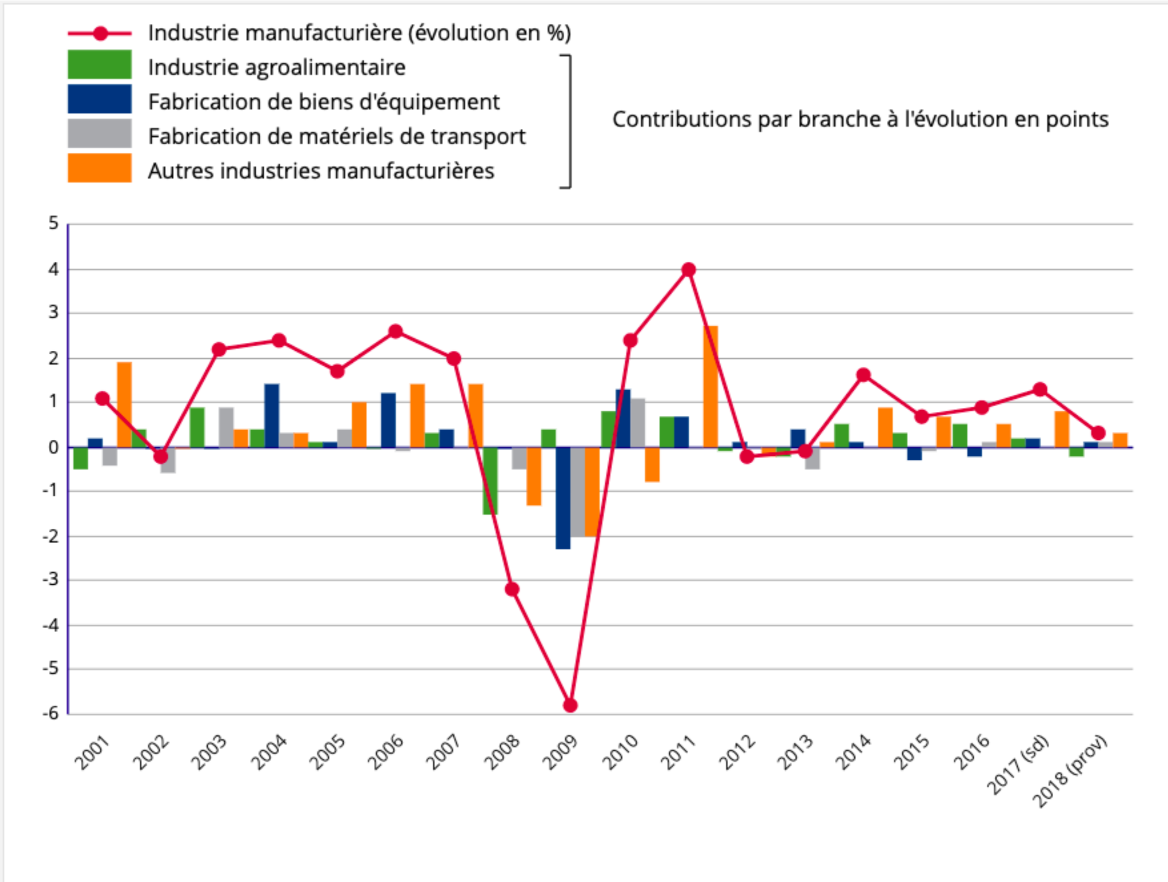



*Chart 7: Evolution of the French value added (in volume). Source: INSEE Première, n°1764, july 2019.*

Accordingly, as a highly value-added asset (OCDE - AEN, 2007), the first benefit of nuclear technology to the French economy is its contribution to mitigation of this industrial decline.

Second, the nuclear-dominated French electricity system has been a net exporter during the last decades (see chart 8). We can say that, when nuclear power plants (and hydraulic dams) are functional, France plays the role of stabilizer on the European grid with the corresponding economic benefit of the sales, i.e., about 2 billion euros every year since the 1990s – except in 2021-2022 when France has had to import electricity due to the maintenance of its nuclear fleet (see chart 9). Lewandowski (2021) stresses that the massive nuclear program reversed a negative electricity trade balance since the 1980s (p.74).

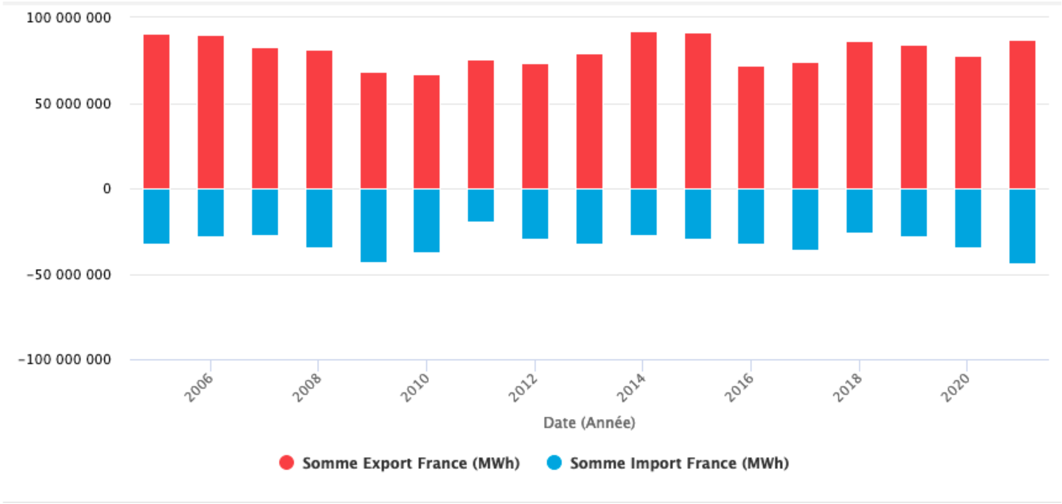



*Chart 8: French electricity exports and imports 2005-2021 (in MWh). Source: ODRÉ opendata reseaux-énergies.*

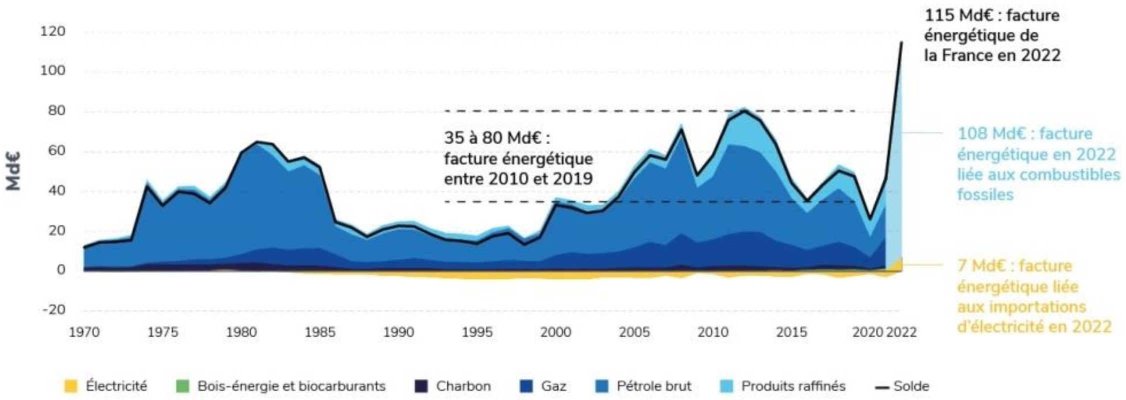



*Chart 9: the French energy bill 1970-2022 (in 2022 constant euros). Source: Bilan électrique RTE 2022 based on RTE and French customs' data.*

Third, the nuclear industry is an important supplier of direct and indirect jobs in France. Lewandowski states that the sector weights for 6.7% of industrial jobs in the country. In the perspective of a sovereignty industry, these jobs cannot be relocated and are higher-skilled than the national industry's average (2021, p.76). According to a 2017 pluralistic estimation, nuclear activities create around 211 000 indirect and direct jobs in France (Beutier, 2017). Some particularly nuclearized regions are proportionally benefiting from more jobs than others. E.g., the Normandie district welcomes more than 6000 direct and indirect jobs (Gosselin, Louza, & Mura, 2022). Moreover, beyond SOEs, the industry has a spiller effect on about 3000 small and medium supplying enterprises (Lewandowski, 2021). In reference to Lovins' soft path (1979), these jobs are at risk in case of radical transition implying a nuclear phase out. We posit that, in the French case, these direct and indirect economic benefits have influenced the energy system's inertia during the last decades.

Eventually, nuclear energy is deemed to be France's energy comparative advantage in Europe. In fact, though financially problematic for EDF and the government (see paragraph I.A.2.), the regulated price ARENH allows French electricity suppliers (and not only the EDF-related ENEDIS) purchasing nuclear electricity at the competitive price of €42 per KWh. Before tax, the French nuclear electricity has been able to supply both industrial customers and households at a competitive, stable and foreseeable price since the 1980s (Lewandowski, 2021, p. 74). However, we shoul qualify the substantial benefit of this price for the French industry, not because of nuclear or the electricity industry, but rather because industrial plants are merely marginally electrified and heavily resort to fossil fuels (see the macro-distribution of the industrial gross energy consumption in chart 10).

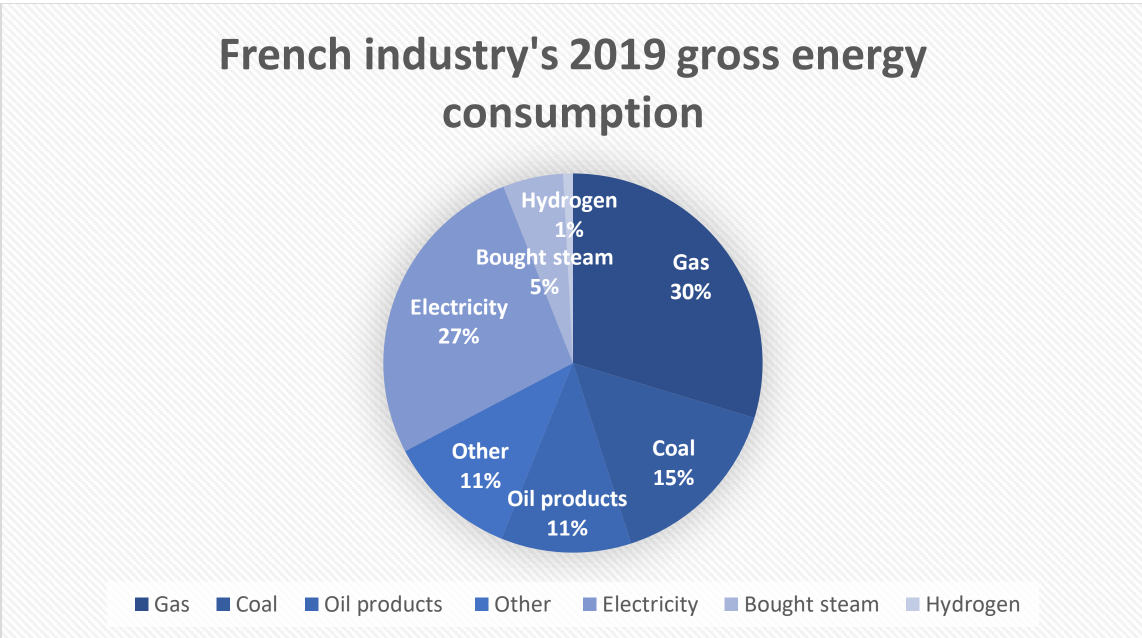



*Chart 10: Elaboration by the author based on INSEE's 2019 data.*

However, bearing in mind the stakes of the ongoing energy transition that supports electrification, we stress that the electricity price in France is among the most competitive in Western Europe, way before Germany. The comparison with the Federal Republic of Germany is particularly relevant because the two countries have fueled an industrial and political rivalry since the early 2000s. And the nuclear industry is their symbolic bone of contention (Turkish, 2004). Yet, the French electricity system has proven to be constantly economically more performant than the German one since the 2000s and by far superior to the Eurozone's electricity price for industrial off-takers and households (see charts 11 and 12).

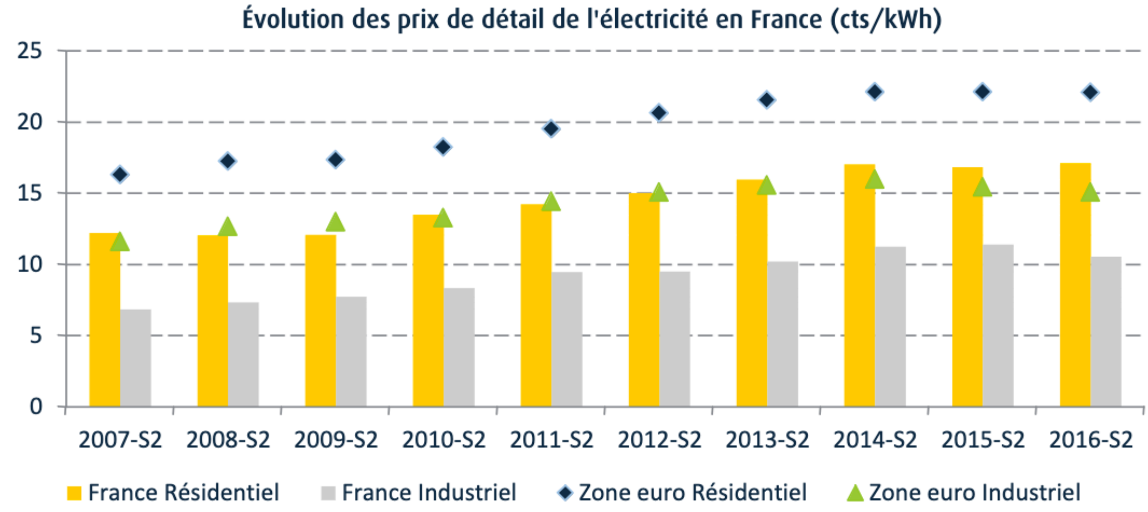



*Chart 11: Evolution of the average electricity price (tax incl.) in the French retail market (in centimes per kWh). Households: from 2500 to 5000 kWh/year. Industrials: from 500 to 2000 MWh/year. Elaboration by OFATE from Eurostat data.*

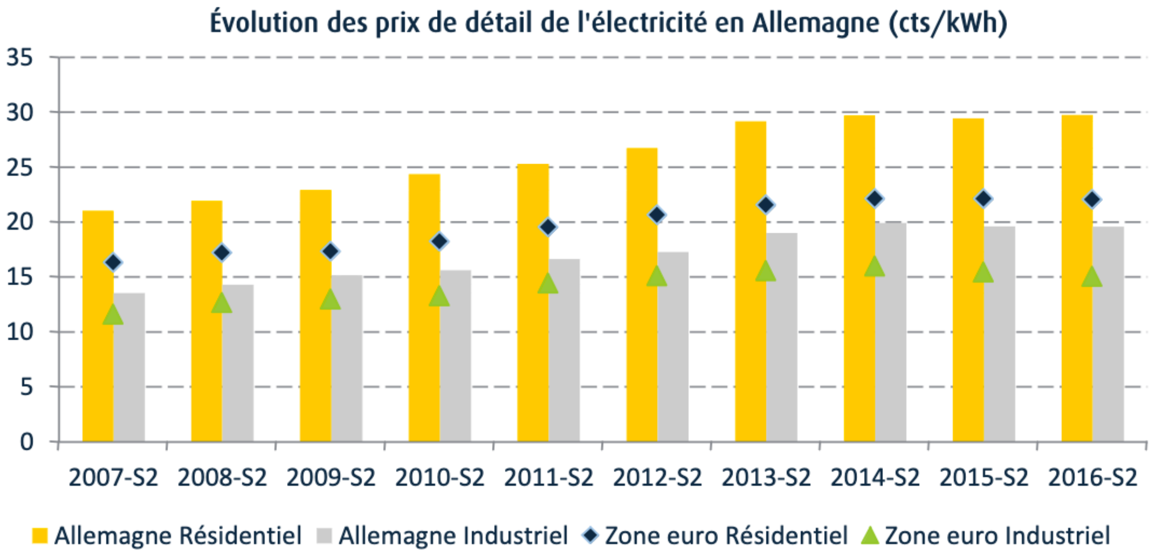



*Chart 12: Evolution of the average electricity price (tac incl.) in the German retail market (in centimes per kWh). Households from 2500 to 5000 kWh/year. Industrials: from 500 to 2000 MWh/year. Elaboration by OFATE from Eurostat data.*

**Conclusion of section I.B.:**

This section has first permitted us to introduce the guarantees and benefits offered by the nuclear industry regarding criticism addressed to the sector. Considering extra-EU issues, we have underlined both the actual security of the supply of uranium to the European industry and the prospective asset of complementing future hybrid energy systems with nuclear power plants in relation to the high demand for specific critical raw materials. Internal EU affairs, especially the outcome of the Austrian anti-nuclear judicial activism show a strong pro-nuclear European jurisprudence that should, notably, minimize the risk inherent to investing in nuclear projects. Finally, the French case shows that, beyond strictly energy and climate considerations, nuclear technologies can bring a country substantial defensive, diplomatic, and economic advantages.

Though chapter one emphasized the optimistic arguments in favor of betting on the nuclear option for the European energy transition, chapter two will address the numerous critical aspects that could restrain the enthusiasm sparked by this technology. In fact, we believe that a 100% nuclear scenario would be as unsound as (if not more than) a 100% renewables one.

## II. A leap in the dark

The present and prospective assets of the nuclear option introduced in the precedent chapter should not obscure a contrasted reality. In fact, the nuclear industry is facing and will face a series of limits and uncertainties. Remember that, though every energy solution will face, to various extent, similar problems, nuclear poses a particularly salient one because of its inherent irreversibility.

Our research has identified two main categories of problems. The first one is multiple key political and social clashes at the national and international levels that, eventually, affect the nuclear industry and undermine its future as we can observe in France (II.A). The second category of limits regards the risks and uncertainties of the future: a fast-changing environment, a risk of raw materials shortage, and international political instability (II.B.). In a discursive way, this second chapter will, first, address the actions already carried out or planned by both the nuclear industry and governments to adapt to foreseeable problems. Second, it will specify uncertainties that would require sound interventions, potentially up to a nuclear exit.

### II.A. Irreconcilable antagonisms: unsolved… and unsolvable political and social conflicts?

Nuclear energy is a fascinating study-case in political science. This section investigates the politicization of this energy source through three lenses. First, nuclear can be a domestic controversy, as observed in France (II.A.1.). It is then interesting to understand how the government and anti-nuclear activist interact both during key steps of the nuclear program and in the long run, once the program is established. The frequent 'non-democratic' feature of nuclear program will be detailed at this occasion. Second, nuclear can be studied in a transnational perspective through the lenses of related health and environmental damages (II.A.2.). In fact, the global nuclear value chain affects several populations and territories around the world. Consequently, anti-nuclear groups can merge beyond borders to elaborate a consistent advocacy and pressure the nuclear industry both in its homeland and from abroad. Thirdly, and still at the international level, the global value chain sometimes implies politically sensitive interdependences (II.A.3.). Part of our argumentation in favor of the theoretical political hedging allowed by the nuclear option should thus be qualified in the light of complex actual situations. Finally, we will investigate the structural issues the nuclear industry is facing (II.A.4).

### *II.A.1. A mainly diffident public opinion toward nuclear?*

We posit that radioactive wastes are the most critical feature of nuclear energy perceived by the large public. This is, at least, what the last opinion surveys about the attitude of European citizens towards radioactive wastes published by the Eurobarometer show, though they are getting old. In fact, they were carried out in the 2000s – 2005 and 2008 – (European Commission, 2008), two decades after Chornobyl and before Fukushima. Moreover, from a methodological perspective, the Eurobarometer is controversial to the extent that its surveys trigger skepticism due to their instrumentalization by the European Commission (which commands them) to support Europeanism and promote EU governance. Additionally, the transnational purpose of these surveys is frequently undermined by different national methodologies in terms of sample and translation errors of the questions in some Member States (Nissen, 2014). Despite these well-known flaws, we deem that these surveys are the most reliable we can find at the EU scale. The result, in 2008, was that a tiny (non-absolute) majority of EU citizens were contrary to nuclear energy production (45% v 44%) and that 11% of EU citizens did not have an opinion on the topic (European Commission, 2008, p. 5). Hence, despite the relative growth of the pro-nuclear population compared to the previous survey (2005), the 2008 one teaches us that the EU public opinion, if it exists, tends to be rather anti-nuclear. Besides, discrepancies are observed among Member States, e.g., a common trend is that populations of nuclearized states tend to feel more informed about radioactive waste management and to be more supportive of nuclear energy production (p.91). However, a January 2022 French survey showed – before the war in Ukraine – a strong penetration of anti-nuclearism in this nuclearized country, with 42% of respondents moderately in favor of a French nuclear exit in addition to 16% of respondents strongly supporting this output. In total, thus, 58% of the respondents adhered to the end of the national nuclear program a few months before the presidential and legislative polls (IFOP - SDN, 2022, p. 8). But the fast-changing international context and energy prices have certainly awoken the volatility of the French public opinion because, merely eight months later, 75% of respondents were favorable to nuclear energy production (IFOP - JDD, 2022, p. 5).

The Eurobarometer and French surveys hence bring two main insights: first, anti-nuclear and pro-nuclear citizens are almost equally numerous at the EU scale; second, the opinion towards nuclear production can be heavily influenced by the economic or political conjuncture. Therefore, to expand our understanding of the decision-making process of energy policy, we need to understand its interaction, first, with international relations, and second, with public opinion.

*Energy policy as a component of States' Grand Strategy.*

The key concept here is energy security and it can be defined in a thin or thick way. Whereas the thin one is satisfied with a situation where a country has "access to sufficient supplies at a reasonable price", the thick one requires having "access to affordable energy without having to contort one's political, security, diplomatic, or military arrangements unduly" (O'Sullivan, 2013, pp. 31-32). In other words, energy policy is intertwined with a State's foreign policy objectives, i.e., its Grand Strategy. Here lies the democratic limit in relation to energy policy. In fact, though some scholars try to challenge the realist assumption according to which foreign policy is not and cannot be democratized (Harriott, 1993), we have enough evidence to believe that – most of the time – foreign policy actually escapes the democratic debate because – in an anarchical world system –leaders handling these topics are incentivized to lie both to other States and to their own people (Mearsheimer, 2013).

By extrapolation, it results that – even in democracies – energy policy is mainly what the executive branch (rather untameably) decides. It is particularly true in France where the political culture is prone to a vertical practice of power. See, e.g., the decision-making process in economic and financial policies such as the pension system (Sirot, 2022). The centralization of power decisions stems from the self-conviction that – because the President of the Republic is directly elected by citizens since 1962 – the executive branch holds the democratic legitimacy to decide the law without substantially negotiating with the legislative branch and trade unions. At most, the government creates the illusion of a collective discussion, but the eventual decision escapes stakeholders. This likely applies to national guidelines, but their local implementation seems, nonetheless, quite negotiable even in energy matters (Chailleux, Smith, & Compagnon, 2022). Yet, a nuclear program like the French one is a matter of national guidelines. Remember that 40 million French people (about 58% of the population) are living at a maximum distance of 100 kilometers from one of the 19 nuclear plants in the country (6Medias, 2017). It consequently turns particularly difficult for anti-nuclear movements to frame nuclear energy production as a problem while the government activates strong communication means to deny, e.g., the importance of a major nuclear accident (Koopmans & Duyvendak, 1995). Clearly, the French executive has chosen massive nuclear energy production as part of the national Grand Strategy since the 1970s and, following the Messmer doctrine, this production is, most of the time, framed as a necessity by the successive French governments. Nonetheless, the story does not stop when the executive branch arbitrates in favor of a national nuclear program.

Before investigating the French government's interaction with anti-nuclear activists (who are, obviously, wronged by this decision), we should introduce the theoretical framework that guides our understanding of the steerability and influential power of public opinions in energy matters. In fact, how could we explain that the French public opinion on nuclear energy production so radically changed in merely eight months in 2022?

*Theoretical framework: the limited say of public opinion in crafting national energy policies.*

Following O'Sullivan (2013), energy policy is integrated into a State's Grand Strategy. It is, consequently, both a question of domestic organization and of foreign policy.

In Western democracies, it could seem misleadingly obvious that citizens have their say in any political matter. Indeed, although the very first point of the famous *President Woodrow Wilson's 14 Points* is that "diplomacy shall proceed always frankly and in the public view", the general public barely access information about its government's foreign policy and the very origin of the decision. Though an institutional perspective would suggest that a system of checks and balances operates between, at least, the Ministry of foreign affairs and a parliamentary committee dedicated to the topic within Parliamentary systems, the literature on International Relations teaches us that there is no iron law about decision-making in foreign policy. The only certitude is that citizens do not decide.

In fact, Graham Alisson (1999) identified three decision models that rely either on the rationality of the decision maker (cost-benefit analysis), or the mechanical routine adopted by the administration and the army (a standardized answer to different situations), or the bargaining between the various state agencies or ministries involved in the case. Moreover, Arthur Schlesinger (2004) demonstrated that "taming the prince" (i.e., limiting the power of the executive branch in foreign policymaking) is not the US priority. Indeed, the "imperial presidency" was not challenged in the early 2000s and is still vigorous today. In France, the equivalent is the President of the Republic's *domaine réservé* (Guisnel, 2007, pp. 297-309). Besides, we acknowledge that it is hard to mobilize public opinion on foreign policy issues if the media do not effectively perform the role of the "fourth estate" in balancing the government's views. Walter Lippman (2010), in fact, developed a realist approach to democracy in the early XX$^{th}$ century[47] and the media failure is particularly outstanding in his description of the instrumentalization of information (i.e., misinformation) in the US to produce efficient propaganda:

> *"Out of the opposition, we make villains and conspiracies. If prices go up unmercifully the profiteers have conspired; if the newspapers misrepresent the news, there is a capitalist plot; if the rich are too rich, they have been stealing; if a closely fought election is lost, the electorate was corrupted; if a statesman does something of which you disapprove, he has been bought or influenced by some discreditable person."* (p.76).

This assumption, recently confirmed by the US democracy under President Trump's mandate (Van Rythoven, 2022, p. 541), applies to the coverage of both foreign policy and domestic issues. In addition, Lippman pessimistically reminds us that the mediatic coverage's quality in democracies is the combined responsibility of mass communication groups (for-profit enterprises), the general public (often seeking distraction rather than enlightenment), and

[47] The first publication of *Public Opinion* was in 1922.

politicians (or activists) keen to use stereotypes and prejudices to gain political support. Eventually, in democracies, public opinion can easily turn into the public's opinion. In this sense, citizens would be mere watchers and commentators of business and political spectacularized performances rather than active stakeholders. In other words, they have no endogenous say in policymaking because they repeat the news contents they consume. As a matter of fact, in a situation of crisis, the well-studied 'Fox Effect' (from the news coverage made by Fox News and CBS channels one month before and during 'Operation Iraqi Freedom' by the US in 2003) shows that the government can succeed in using a rally-around-the-flag strategy to mute opposition and legitimize a serious decision such as going to war although its main argument is a lie. Indeed, Johansen and Joslyn (2008) acknowledge that "in this instance, a misinformed public was the norm" (p. 604). Nevertheless, some studies show that information and political statements do not necessarily affect public opinion as a 'hypodermic needle' would do. On the contrary, it seems that, sometimes, public opinion can influence policymakers' own opinions even in the realm of foreign policy. For instance, the case of the United Kingdom's cooperation with the United States in the South China Sea since 2018, studied by Chu and Recchia (2022), shows a correlation between British public opinion and the shifting opinion of members of the UK Parliament. The authors' conclusions are that public opinion might persuade leaders without a strong opinion and/or legitimate a particular side of the policy debate. The latter effect could, in certain situations, rebalance Lippman's assumption regarding oppositions: they could be initially weak but later empowered by the feeling of being supported by a large share of the public opinion. Yet, the issue related to the UK intervention in the South China Sea is a primarily 'Schmittian' (Cf. Carl Schmitt) problem that offers two simple options: on the one hand, the US is the friend and China is the enemy thus the intervention is legitimate; on the other hand, China is a friend thus the intervention is illegitimate. Non-alignment was, of course, the third option but, since the operation was already launched, non-aligned would have opposed the intervention or changed their mind in favor of the US.

When it comes to defining an energy policy, however, the issue at stake is even more complex. Now, the literature studying processes of lobbying shows that the complexity of a problem dramatically affects its political saliency and consequently limits or favors the role of public opinion (Dür & Mateo Gonzàlez, 2014). It is, indeed, harder to mobilize a large public when a preliminary vulgarization of technical complexities is required. Andreas Dür and Gemma Mateo - in the EU institutions - but also Anne S. Binderkrantz - in Denmark and in the UK -

demonstrated that the political saliency of a policy issue favors diffuse interest groups (NGOs) while a low saliency favors interest groups that hold expertise – which are often the corporate interest groups – (Coban, 2020). In that sense, public opinion is merely instrumental in the policymaking process and influential only if the problem gets sufficient political saliency. Therefore, NGOs will try to influence the media to bring their topic and their view to the top of the mediatic agenda with the hope that this will, later, similarly influence the political agenda. Yet, influence does not necessarily imply that the group will obtain a positive political outcome. In fact, the legislator is, in any case, sovereign.

This brief theoretical overview has shown that, on the one hand, public opinion has very little influence on foreign policy and is, conversely, likely to be influenced by the government and media – especially in times of crisis -; on the other hand, public opinion can play a role in influencing policymaking when a couple of conditions are combined. Now, we can investigate the interaction between public opinion (especially the anti-nuclear one) and the government in France.

*The governing v. the governed: a French insight.*

Sezin Topçu (2013) investigated the technoscientific field.

According to him, what we identified as the three key components of the nuclear industry (the mining industry, nuclear energy, and the arms industry) have a highly centralized, hierarchical, and still very technocratic decisional structure. He mainly refers to Michel Foucault's work as a theoretical framework to understand how the French State and the nuclear industry 'govern' criticism and public space, since the 1970s, through "a set of strategies, tools, and discourses designed to supervise, control, exclude, or, on the contrary, to appropriate, co-opt, institutionalize, and 'scientificate' dissident voices" (p.84). He points out that the election of President Mitterrand in 1981 could have been a source of hope for anti-nuclear activists since the socialist party was close to their movement during the electoral campaign, and yet the result has been a further pro-nuclear government. And this is, indeed, in the 1980s that the French government found a way to domesticate nuclear criticism by promoting critical views in institutionalized forums opened to the scientific component of the anti-nuclear movement to debate with pro-nuclear scientists. The critique was soon tamed, and the nuclear program was able to develop and thrive. On this topic, Sylvie Ollitrault identified two different waves of anti-nuclear contestation in France. The first one, in the 1970s, was grass-root and managed to unify different political claims against the nuclear program, whereas the second, from the late 1980s onward, tended to lose popular support because of the progressive exclusion of non-experts and the consequent lack of contact with citizens' daily preoccupations (Ollitrault & Villalba, 2014). In other words, the government's strategy to weaken the anti-nuclear movement through its institutionalization succeeded. Remember also that, in Europe in the 1980s before Chornobyl, the public and social movements were mainly driven by the military dimension of nuclear – rather than nuclear power plants – because of the Euromissile crisis (Giugni & Kriesi, 1990).

Topçu moreover deems that the institutionalization of anti-nuclear movements and their forced specialization – caused by the government's limited institutional offer – in two topics (radioactivity measurement and nuclear governance) intensified in France to tame the revival of anti-nuclear claims after the Chornobyl accident.

Finally, he observes that acceleration is the key technic adopted by the French government to impose the nuclear option. Indeed, taking the opportunity of crises (e.g., an oil shock, climate change, wars with deep economic impact) successive French governments have always found a way to frame nuclear energy as indispensable and urgent. The trick is, in fact, that the irreversibility of this technology makes the contestation less relevant once the nuclear program is operating. For instance, the imposition of the project of a deep geological repository in Bure (Cigéo) is legitimized by political authorities and the nuclear industry by the urgency to find a long-term solution for storing nuclear wastes… generated by the nuclear program (Julian & Mediavilla, 2022). Not surprisingly, hence, the current French legislative project aimed to favor the launch of the new nuclear program refers to the necessity to accelerate procedures ("*Projet de loi relatif à l'accélération des procédures liées à la construction de nouvelles installations nucléaires à proximité de sites nucléaires existants et au fonctionnement des installations existante*"). We note the permanence of the race-against-the-clock strategy in the nuclearization of the country.

*An impossible compromise?*

The acceptance or rejection of nuclear energy is an essentially polarized question. At the macro-regional level (the European Union), we highlighted the problem of the cohabitation between nuclearized and non-nuclearized member states in paragraph I.B.2. Roughly the same pattern applies at the micro-level, i.e., at the national scale. In fact, as soon as political authorities support the nuclearization of the country, anti-nuclear citizens are wronged because the nuclear plants are built and operate, to various extent, in their 'backyard'. In reference to Lovins (1979), how can anti-nuclear citizens[48] accept that their State promotes the production of nuclear electricity? Beyond the technology used to generate electricity, it is the whole infrastructure and purpose of the national economy that is contested by soft path supporters. While the government and the industry promote a productivist – energy-intensive – system (the hard path), soft path's supporters – especially in the light of climate change – argue in favor of energy sobriety, the consequent economic degrowth, and the decentralization of power generation. In practice, however, soft-path-prone energy communities – a form of local participatory democracy resisting to the hegemonic hard energy path in the national energy system (Debizet & Pappalardo, 2021) – face discouraging legal and financial constraints (Chailleux & Hourcade, 2021). We understand that the current big picture looks like a zero-sum game between the hard path and the soft path. Hence finding a compromise looks impossible.

However, if we precise the energy needs of consumers based on their profile and the kind of technology that would more adequately supply them with low-carbon electricity in the future, we can imagine a form of compromise, though minimal. In fact, the interests of power transporters (e.g., RTE in France) and distributors (e.g., ENEDIS or SER in Strasbourg) do not necessarily converge since the former mainly supplies the big industry and power off-takers (wholesale trade) while the latter deal with retail. Transporters need large power generators (e.g., nuclear and hydropower) while distributors can adapt to a decentralized production by small renewable units (Commission de régulation de l'énergie, 2023). Put differently, power distributors can adapt to the energy soft path while power transporters lie on the hard path. It is consequently not surprising that RTE[49] selected exclusively pro-hard energy path scenarios rather than a deep penetration by renewables combined with energy sobriety (Massemin, 2021). Furthermore, in continuity with productivism, the French government is opting for the hard path to support economic activity and the re-industrialization of the country (Raynal, 2022). These two decisions illustrate the implications of environmental goals from the perspective of sustainable development: on the one hand, promoting the re-industrialization of the country and

[48] Citizens whose opinion can, to our opinion, be associated with the ideology of the soft energy path against the ideology of the energy hard path.

[49] *Réseau de Transport d'Électricité*, the French electricity transporter.

preserving OCDE countries' living standards are possible only through the hard energy path (though largely 'cleaned' from fossil fuels); on the other hand, the energy soft path looks more adequate to adapt to the worst environmental scenarios, i.e., a world that we have never experienced and that we fear (see section II.B.).

Looking at the power supply of "hard to abate" industrial sectors, hydrogen (green and/or pink) seems to be necessary (Ministère de l'économie, 2023). Yet, renewable energy communities will not produce enough power to 'greenly' fuel electrolysis that will likely need centralized power generation from either renewables or nuclear. Moreover, operators specialized in renewables tend to obscure that centralized renewables parks (often funded by 'off-site' power purchase agreements) challenge the theoretical technological dualism between the hard energy path and the soft energy path. Indeed, we can have some doubts regarding, e.g., Engie's promotion of a "short supply chain and local approach" whereas the practical example the company provides is a consumer (Brest Oceanopolis discovery park) more than 700 kilometers distant from the alleged supplying solar park based in Fanjeaux (ENGIE, 2021). Such a distance clearly falls in the realm of power transporters (TSOs)[50].

To a certain extent, based on the problem of centralized power generation, we conclude that radical supporters of the soft path cannot be satisfied with the industry of renewables either. As a matter of fact, this radicality stems from a deep anticapitalism, essentially diffident vis-à-vis the State (François & Lemercier, 2021). We conjecture that this radical wing of anti-nuclearists is marginal and that some (moderate) anti-nuclearists could tolerate the nuclear option while others will still oppose this technology - even if it is not as soft-path radicals - because they deem the sanitary and environmental risk (see paragraph II.A.2.) too high compared to relatively satisfying alternatives. This is, at least, how we interpret opinion surveys alternatively mainly contrary to nuclear energy (IFOP – SDN, 2022) or conciliant (IFOP – JDD, 2022) with an energy policy that – as we have argued – citizens do not substantially decide[51].

---

[50] The example of Brest Oceanopolis is twice interesting because it moreover shows that, beyond the big industry, also some cultural centers aimed to raise awareness about maritime biodiversity and pollution (de Beaulieu & Quéméner , 1996) rely on centralized (though green-labeled) power generation.

[51] Considering the discrepancy between the volatility of the public opinion on the question and the long-time commitment necessary to build and operate a nuclear program, we will stress, in paragraph II.A.3., the relevance of a non-democratic decisional process in energy policy.

Eventually, we deem that – in parallel to the launch of a new nuclear program – the development of energy communities, where they are relevant, should be supported. From an ethical perspective, they allow citizens contrary to the hard path to act as 'produsers' through autonomous and small-scale power generation by renewable technology. Obviously, it cannot be completely satisfying for anti-nuclear citizens since nuclear plants will still be running on their national territory and it is likely that part of their taxes and/or savings (see paragraph I.A.2.) will directly or indirectly finance the nuclear program. Yet, we do not identify alternative forms of compromise.
In this paragraph, it has been explained that the embeddedness of energy policy into a State's grand strategy largely undermines its chances to be democratically elaborated, even in Western democracies. We also specified that the first French nuclear program has been implemented as a race against the clock to impose an irreversible option and anti-nuclear movements have been weakened by their gradual specialization and the level of expertise required to seat at the table with the government. A similar pattern could likely repeat in the future. We will now investigate and discuss the key anti-nuclear framing of nuclear energy, i.e., approaching this technology as a public health and environmental issue.

*II.A.2.* *Health, the environment, and nuclear energy.*

Nuclear energy is far from being a benign technology and consequently requires caution. In France, the concept of nuclear security covers a series of measures that must protect the environment and, incidentally, human health, from ionizing radiation (Lewandowski, 2021, p. 43). The national environmental regulation defines a sub-part of nuclear security that is nuclear safety in art. L.591-11 *Code de l'environnement* as technical and organizational measures applied to the construction, design, operation, stop and decommissioning of nuclear infrastructures plus to the transport of radioactive products with the aim of preventing accidents and limiting their harm if they happen. Lewandowski explains that nuclear security also includes radioprotection, the prevention and repression of malicious actions putting nuclear security at risk and all the evacuation procedures planned in case of nuclear accident. Thus, nuclear energy is not approached as a risk-free technology.
However, a distinction must be drawn between, on the one hand, the government and the nuclear industry which, aware of potential risks, invest in nuclear security, and, on the other

hand, antinuclear movements who use these inherent risks as the main reason for exiting nuclear technology at any cost. There is, on the one hand, a cautious nuclear optimism, against, on the other hand, a radical nuclear pessimism. This mainly explains the polarization of the debate upon this technology we hinted at in the previous paragraph.

Furthermore, this thesis has taken the part of approaching the nuclear industry in its largest definition, i.e., including upstream and downstream operations. We will see that the environmental footprint of, especially, uranium mining operations is critical. Hence, this paragraph will investigate, first, health preoccupations related to the nuclear industry, second, its environmental dimension. Always in a discursive way, we will try to understand to what extent the most dramatic flaws of this technology can be tolerated.

*Nuclear energy likely affects human health… but science cannot prove it.*

In the 1980s, a peak of infantile leukemia observed in Normandie raised concerns about nuclear security in the most nuclearized region of France that, beyond power plants, welcomes a strategical nuclear fuel recycling factory (La Hague) and military nuclear facilities in Cherbourg. Topçu (2013) explains that antinuclear experts made use of this case to conquer public opinion and gain the official labeling of nuclear energy as a threat to public health. Nonetheless, the final scientific assessment, as it often happens, did not find enough evidence to unambiguously attribute the responsibility of these cases of leukemia to potential radioactive leaks nearby – though not either firmly rejecting the hypothesis (pp.252-255). This is one case, among several examples, that illustrates how hard is to assess the actual dangerousness of normal nuclear operations and how frustrating can be the scientific method that does not allow to review (with a satisfactory output) the argument of expertise used by both pro-nuclear and anti-nuclear activists. Basically, this scientific conclusion is mainly frustrating public opinion. Conversely, activists of both sides can use it for their own political purpose since the antinuclear movements, on the one hand, can state that there are enough doubts to believe that corrupted public authorities are hiding the truth and controlling the judicial branch and the media; and the nuclear industry, on the other hand, can satisfy with an official conclusion that does not substantially harm its business. What happened in France is the national symptom of a wider and systematic problem faced by the international institution entitled to assessing the effects of atomic radiation.

*The UNSCEAR: between science and politics.*

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was established by Resolution 913 (X) (untitled "Effects of atomic radiation") taken by the UN General Assembly during its 550th plenary meeting, on 3 December 1955.

According to Article 1, only fifteen States were originally part of this scientific committee, i.e., each of them committed itself to send one scientist, alongside alternates and consultants, to be its representative on the Committee. Today, UNSCEAR is composed of thirty-one states (UNSCEAR, 2022). In a nutshell, the tasks UNSCEAR must carry out are gathering, synthesizing, and communicating - to the UN Secretary-General - radiological data furnished by the UN States Members and the members of the specialized agencies. The Committee aims at contributing to the publication of reports and studies regarding the short and long-term effects of ionizing radiations upon man and his environment (UN, A/RES/913 (X), 1955).

Some may note that States enjoy a wide margin of discretion in the selection of the delegation they send to UNSCEAR. Hence, this Committee has a strong political feature one should not forget when reading its reports and conclusions. Therefore, one might ask, beyond the institutional "façade" (Codaccioni, 2021), to what extent UNSCEAR is stating the latest scientific truth in the realm of ionizing radiation. A piece of the academic literature is, indeed, critical regarding the independence of the scientific sanitary expertise vis-à-vis politics and corporations, especially in front of industrial disasters and scandals affecting military, political, and business actors (see, e.g., Markowitz & Rosner, 2002 and Michaels, 2008).

And, applied to an international environmental and sanitary crisis such as the Chornobyl disaster (1986), this skepticism somehow meets the Marxist school of thought in International Relations. Indeed, in 1864, in his inaugural address to the International Working's Men Association ("First International"), Karl Marx denounced the expansionism of the Russian Empire, "*the immense and unresisted encroachments of that barbarous power, whose head is in Saint Peterburg, and whose hands are in every cabinet of Europe have taught the working classes the duty to master themselves the mysteries of international politics; to watch the diplomatic acts of their respective governments; to counteract them, if necessary, by all means in their power; when unable to prevent, to combine in simultaneous denunciations*". Beyond the historical irony stemming from the Marxist-Leninist doctrine claimed by the USSR, i.e., the State responsible for this nuclear accident, some scholars like Yves Lenoir (2016) deem that the scientific truth has been hidden, scientists muted by political 'hands', and that all the international agencies and scientific committees in charge of assessing Chornobyl's sanitary and environmental situation (including UNSCEAR) deliberately underestimated the consequences of the accident in order to permit the 'nuclear great come back' in the early 2000s and that the same pattern occurred in the aftermath of Fukushima. However, Lenoir mainly denounces the faith in nuclear and the arrivisme of some scientists that, according to him, distort an enlightened choice of the legitimate protocols by UNSCEAR. To him, everything would have been made to publish a final report which would have not endangered the future of nuclear power. But what are the probabilities that all the governments involved in UNSCEAR repeatedly agreed to systematically underestimate the consequences of nuclear accidents?

We can oppose a fact to Yves Lenoir's reasoning: Germany is part of UNSCEAR. Given its political choice, in the aftermath of Fukushima's disaster (2011), to withdraw its civil nuclear program by 2021[52], we could posit that denouncing the absolute environmental and sanitary risk of radiation would have been politically rewarding for the German delegation to UNSCEAR. Conversely, the late Dr. Wolfgang Weiss – a German physician and the Committee's chairperson in 2011 and 2012 - used to consider that the risk of developing cancer due to low radiation exists everywhere, i.e., even by being merely exposed to a natural background radiation. Obviously, he added, additional artificial radiation caused by a nuclear accident increases the probability of developing cancer. But even in this case, the origin of cancer cannot be, for sure, attributed to radiations (Fitze, n.d.).

Furthermore, we believe that skepticism and a critical assessment are understandable to a certain extent that should not be overcome. Yes, the linear no-threshold (LNT) model used by UNSCEAR has certainly some flaws, chiefly systematically minimizing the significance of the time-increasing accumulation of critical knowledge. It is moreover likely that the nuclear industry privileges nuclear workers' health rather than the general population's one (Jobin, 2012). However, accusing the UNSCEAR of betraying science is opening Pandora's box: if UNSCEAR can lie and endanger the world's population, why should we trust the

[52] Though planned by 2021, the actual switch off of the last German nuclear plants took place in April 2023.

Intergovernmental Panel on Climate Change (IPCC)? The tiny gap between critical assessment and conspiracy theory is too easily crossable with these highly political topics.
In this thesis, we take the part of trusting both the UNSCEAR and the IPCC.

*UNSCEAR's sanitary assessment of the two main nuclear accidents in history.*

Among the 600 firemen mobilized to extinguish the fire at Chornobyl's power plant in 1986, 134 have further suffered from an acute syndrome related to a high level of exposure to ionization. Two burnt employees of the plant immediately died and 28 died in the following months. Among the 19 employees who died during the two successive decades, the direct causation is less clear (Cléro & Leuraud, 2021). The general population has likely been affected on the longer run, especially those who were children and teenager at the time of the accident and were exposed to radiation. According to the UNSCEAR, about 25% of thyroid cancer identified in Belarus, Ukraine, and the neighboring Russian regions during the last three decades are due to the nuclear accident of Chornobyl. Yet, as in other regions and periods, sticking exclusively to the trends would be misleading since the increase of identified cancers can also be explained by other parameters like the extension of these populations' life span and the improvement of cancer screening tools (UNSCEAR, 2018). The trauma, chiefly caused by the evacuation (a basic measure of nuclear security) of the region can also facilitate the development of other cancers that are not due to the radioactivity per se: breast cancer, other solid tumors, cardiovascular disease…
In the case of Fukushima Daiichi (2011), UNSCEAR deems that the quantity of radionuclides released by the power plant after the tsunami was substantially lower than the Chornobyl ones. In fact, the sanitary assessment of the accident in the prefecture of Fukushima states that only 16 to 50 cases of thyroid cancers can be attributed to the accident, i.e., at most 0.077% of what a normal cancer screening operation could identify over the lifetime of a generation in this region. Besides, the international committee lacks evidence to draw conclusions about thyroid cancer risk after antenatal exposure (UNSCEAR, 2022). Here again, the local population has been moved and, moreover, traumatized by the tsunami. This has also likely caused a series of sanitary issues.
In conclusion, nuclear energy certainly presents a risk and can harm human health. However, alternative energy sources are also radioactive.

*Beyond nuclear: an assessment of the radioactivity of electricity generation.*

Since generating energy (more precisely, electricity) does not limit itself to these disasters and to nuclear power, we have sought what UNSCEAR could teach us about radiation caused by any kind of energy source. The first remark is: when it comes to generating electricity, nuclear, coal - both in the case of older and modern coal plants-, natural gas, geothermal and even oil (but it is insignificant) fuel expose the population to radionuclides. Obviously, at different levels. Hence, we must acknowledge that electricity, whatever its origin, is never 'clean' or perfectly safe from a sanitary and environmental standpoint (UNSCEAR, 2017, p. 212).

If, following the late Dr. Wolfgang Weiss (see above), we posit that there is no threshold to be at risk of developing cancer or any disease due to low radiation, this is a relevant fact. With no surprise, the coal cycle[53] and the nuclear fuel cycle are the most radioactive sources. They are also, alongside natural gas, the three main existing sources. In normal operations and at the local/regional scale (up to 1.500 km around the power plant or the mine), coal-generated electricity discharges more radionuclides than nuclear electricity. Natural gas produces relatively safer electricity but is still not a perfectly safe one regarding radiation.

[53] The German choice of closing nuclear power plants and to compensate the loss of energy supply with coal and lignite is thus particularly questionable from a sanitary perspective.

Table 46. Collective dose to the worldwide public, and associated normalized collective dose for 2010, integrated to 100 years [a,b]

Except where otherwise specified, the collective doses given are for the local and regional components. Shown also is the percentage of total world electricity generation in 2010 for each electricity-generating technology and the discharges for $^{222}Rn$ normalized to the electricity generation in 2010

| *Electricity-generating technology* | *Collective dose (man Sv)* | *Normalized collective dose (man Sv/(GW a))* | *% of total world electricity generation in 2010* | *Normalized $^{222}Rn$ discharges (TBq/(GW a))* |
|---|---|---|---|---|
| NUCLEAR FUEL CYCLE | | | | |
| Nuclear, total from mining and milling, power plants and reprocessing, excluding global component | 130 | 0.43 | 13 | Uranium mining – 66<br>Milling – 3<br>Operational mill tailings – 3<br>Mill tailings[c] – 10 |
| Adding global component integrated to | | | | |
| 100 years | 910 | 3.0 | | |
| 500 years | 1 700 | 5.5 | | |
| 10,000 years | 7 600 | 25 | | |
| COAL CYCLE | | | | |
| Coal, older coal plants | 1 400 | 1.4 | 40 | Coal mining – 2.8<br>Power plants – 0.07<br>Ash[c] – 1.8 |
| Coal, modern coal plants | 670 | 0.7 | | |
| OTHERS | | | | |
| Natural gas | 55 | 0.10 | 22 | 0.75 |
| Oil | 0.03 | 0.000 3 | 4.6 | 0.002 |
| Geothermal (low-density population – default population) | 5–160 | 1–20 | 0.3 | 150 |

[a] Projections of any health effects using collective doses in the table are not recommended.

[b] All estimates are calculated based on best estimates; site- and location-specific collective doses are not presented.

[c] The values of the normalized $^{222}Rn$ discharges (TBq/(GW a)) shown in table 46 for uranium mine mill tailings (Mill tailings) and for coal ash deposits (Ash) were multiplied by 100 to account for radon emanating for 100 years from these surfaces. The value for coal ash deposits was also multiplied by a factor of 0.6 since only 60% of the ashes produced are deposited.

*Chart 13: Source: United Nations, UNSCEAR 2016 Report to the General Assembly 2017, p.212.*

UNSCEAR also investigated the radioactive toll of the production of wind turbines and solar panels. Once more, the acknowledgment is that no energy source, as long as it requires mining operations either for fueling the power plant or producing the electricity-generating infrastructure, is free of radiation. Indeed, according to the scientific committee, mining operations aimed at extracting the high number of ore needed for the construction of renewable energy facilities – especially solar panels - are the ones that expose the most miners to natural radionuclides. As reminded by the authors in their conclusions, this report only provides a “perspective on the magnitude and differences of radiation exposures” (UNSCEAR, 2017, p. 228). It is then up to policymakers to decide what should be the optimal energy mix and the associated energy generation technologies for their country. An enlightened decision must consider multiple factors, including radiation exposure, but not exclusively.

In conclusion, we would like to point out that, from a nuclear security perspective, the production of an artificial radionuclide such as carbon 14 ($^{14}C$) is not necessarily related to a power industry based on a civilian nuclear program. As a matter of fact, in the late XX$^{th}$ century, *Isotopchim Chimie Fine*, a clandestine chemical laboratory based in Ganagobie (South-East France) used, spread in the surrounding nature (Cognasse, 2021), and traded – notably with Russia but also French pharmaceutical laboratories – carbon 14, tritium and other radionuclides (Leroux, 2013). This case demonstrates that even small forms of organized crime, independent from the power sector can bring radionuclides anywhere and contaminate the place.

Yet, beyond the ‘low-carbon energy’ label, nuclear activities also harm the environment.

*Environmental harms of the nuclear industry*

In the introduction, we, first, pointed out that nuclear midstream operations, when using rivers and seas as coolant, generate thermal pollution than can disrupt the area’s biosystem (Hoerber, 2012). Second, we told that, in the first decades, the European nuclear industry could almost be supplied with uranium extracted in European mines. This is why, for instance, the French region of Limousin has supplied part of the Cogéma’s (today Orano) fresh uranium. Geographical proximity helps our understanding of the environmental stakes surrounding nuclear upstream operations. In fact, in Limousin, millions of tons of ionizing nuclear wastes – stemming from five decades of exploitation – have been left without any protection nearby abandoned former uranium mines. Consequently, soils (especially the mud) and fishes living in the surrounding rivers have been contaminated. Cogéma company has been sued before French tribunals and antinuclear activists were finally given reason in the merits, but the company was eventually not condemned. Indeed, the French justice acknowledged the nuclear pollution caused by Cogéma, but the law has been deemed too imprecise about the threshold of allowed ionizing rejection. In this case, it seemed that what could be identified as a legal threshold had not been reached by Cogéma (Topçu, 2013, pp.259-261). Though this judicial case did not fundamentally disrupt the French nuclear industry, it shows that sparing money in neglecting measures of nuclear security does not frighten some industrials. And being aware that this happened in France is insightful and strengthens the transnational antinuclear criticism that often highlights the mismanagement of uranium mines in Niger by French operators.

Remember that extracting fresh uranium is essentially a highly radioactive thus polluting operation that involves several external tools also exposed to ionizing radiation:

"*Uranium mining and milling (UMM) generates naturally occurring radioactive material (NORM) waste. The waste rock is both the overburden rock, which contains only very low levels of NORM, and the rock from which the uranium bearing material has been separated, which contains residual uranium and other related naturally occurring radionuclides from the uranium decay chain. The mill tailing is the residue after the uranium has been extracted from the uranium bearing material to produce uranium concentrate powder, or so-called 'yellow cake'*." (IAEA, 2022, p. 15).

In reference to sanitary issues, the Areva Company (today Orano) is accused of having neglected miners' protection in Niger, especially in Arlit. The nearby territory is potentially contaminated due to the negligence of Areva (Topçu, 2013, 291-305). It appears that part of the local population was ready to continue mining operations because uranium is anyway a valuable natural resource but in exchange of, at least, a fairer distribution of the value added between mining multinationals and the local population. From a political standpoint, this claim led to the formation of two terrorist groups targeting both the Nigerien government (deemed corrupted) and Areva's assets in Niger between 1992 and 1995 then between 2007 and 2010 (Sadatchy, 2011).

Finally, also downstream operations, even prospective ones like deep geological repository, present a serious risk of large-scale contamination. In fact, the repository will face two highly uncertain risks in the long-run – which is particularly problematic in the case of an irreversible underground asset designed to be closed for centuries. First, the heat generated by the wastes will create hydrogen that will be locked in the repository and there is a risk of explosion and generalized fire that could remind Chornobyl. Second, it is very likely that water will penetrate the repository, be in contact with ionizing material and, eventually, pollute groundwater in the area (Greenpeace France, 2018). Therefore, the nuclear industry is undoubtedly responsible of gross pollutions especially in its upstream and downstream operations. The low-carbon profile of midstream operations should not obscure these facts.

Nevertheless, note that, in parallel, the recent reduction of the cost of solar panels is driven by the Chinese environmental and social dumping. In fact, the People's Republic of China (PRC) represents more than 80% of the manufacturing stages of solar panels' global value chain (IEA, 2022, p. 17). 45% of the available polysilicon (used to build solar panels) in the world was produced in the Chinese region of Xinjiang in 2020 (André, 2022, p. 61). This fact poses the double issue of the carbon footprint of polysilicon production – the industry in Xinjiang is abundantly fueled by local coal – and of the business ethic – since 2017, many Uyghurs slaves have been forcibly moved to work in the solar industry – (Murphy & Elimä, 2021). Downstream operations related to solar panels – that will become increasingly intense with the ageing and gradual decommissioning of oldest solar farms – is also a health and sanitary problem that, alongside old batteries, harm soils and population notably in Eastern African countries like Tanzania (Yee, 2019). It appears that solar panels made of polysilicon (of which market is controlled by China) are the ones that can be recycled without strong chemical operations. Conversely, solar panels made of rare earths require ad hoc chemical products to be decommissioned and recycled (Reno Energy, 2022). In 2017, a European research program was optimistic about the development of solar cells production and recycling method based on fluorine (EU Commission - CORDIS, 2017). Yet, remember that production of fluor gas is a highly toxic process. For instance, the Axens factory of Sud Fluor company in France is regulated by the European Seveso framework[54] (Objectif Gard, 2016).

Besides, the wind industry faces long-term huge environmental problem in its upstream and downstream operations caused, first, by the need for Neodymium used in the turbine rotor and that must be mined (Les Echos Planète, 2020), and, second, by the technical impossibility to recycle the blades if not producing them out of… a chemical solution – the epoxy resin (Mathis, 2023) – also used in the car industry and jewelry industry and that can harm human health and the environment (Government of Canada, 2019). Moreover, wind turbines (onshore and offshore) require a strong base made of concrete. Though this base can be theoretically recycled during the decommissioning of the turbine, if the environmental impact assessment deems that breaking the concrete would create more harm than benefit, the owning company could left the concrete base (of one to two meters deep – depending on the model – per turbine) and thus cause an irreversible harm to the environment (Fortin, 2022). Remember that a single wind turbine requires 157 tones of light-weight concrete or 1.125 tones of heavy-weight concrete. To

[54] 'Seveso factories' refer to the successive European directives 82/501/EC, 96/82/EC and 2012/18/EU taken after the Seveso chemical-industrial disaster that happened in 1976. This regulatory framework reminds us that the nuclear industry is not the unique existing industrial threat.

put this data into perspective, in France, 34 GW of wind power installed capacities represent 14.000 wind turbines. This information tends to comfort us in the view that a 100% renewables scenario would not be a wise energy policy even in strictly environmental terms.
In conclusion, here again, the situation cannot be reduced to a Manichean approach. So that we must bear in mind that every technological choice would have strong both environmental and political ramifications.

This paragraph has thus outlined the scientific limits in assessing the dangerousness of nuclear energy though remembered reliable facts showing the imperative need to take nuclear security seriously. Nonetheless, we have also noted that even operators of the most advanced nuclearized countries (e.g., France), have not taken the adequate measures, especially in Niger. It is exactly because framing nuclear energy as a potential issue for the environment and public health is not exaggerated that the nuclear industry and related governments must be exemplary. Now, we will qualify the geopolitical hedging potential of the nuclear option by highlighting that the global ramifications of national nuclear programs do not always match the official agenda of a nuclearized state's foreign policy.

### *II.A.3. The practical limit of energy independence: hidden interdependences in the nuclear industry.*

In line with the argumentation in favor of the Messmer plan in the 1970s, nuclear energy is often framed by pro-nuclear French politicians as the guaranty of the national energy security. Implicitly, it is even the thick definition of energy security (O'Sullivan, 2013) that is associated with this technology since it is framed as a 'Gaullist' achievement[55] (i.e., part of General de Gaulle's legacy). This is, for instance, how the candidate for President of the Republic Valérie Pécresse rhetorically fostered her nuclear project during the 2022 electoral campaign (Serrajordia & Lasserre, 2022). Nonetheless, though we followed a similar logic in chapter 1 to defend the assets of nuclear energy in terms of strategical hedging (chiefly in opposition to

[55] De Gaulle's political doctrine (*le Gaullisme*) was, not least, made of a strong State interventionism in the French economy to drive the country's companies towards strategical independence, especially vis-à-vis the United States of America (Birnbaum, 1984). Considering the implications in terms of international trade and the subsequent diplomatic effects, le Gaullisme fits what O'Sullivan (2013) thick definition of energy security.

natural gas), we acknowledge that promoting a nuclear program because it makes your country autonomous in terms of energy supply is white a lie because of, at least, two features of the globally integrated nuclear industry.

*The role of Russia in enriching and supplying uranium to European nuclear reactors.*

In the introduction, we hinted at a failed common European project of isotopic plant in the 1950s that was, eventually, made pointless by the US supply of cheap enriched uranium. De facto, importing nuclearized country accepted their dependence on the US and embraced a thin definition of their energy security mainly focused on cutting the cost of energy. Even France, all autonomous the country would like to be, had to find foreign funds to build its own isotopic separation plant in the 1970s. This has been an issue of international relations considering the commitment of Iran since 1975 through the French Iranian consortium Sofidif and two loans. The first one amounted to US $1 billion and was granted to the French Commissariat à l'Énergie Atomique (CEA) while the second amounted to French Francs 943 million and permitted the construction of the Tricastin plant. Of course, the origin of this money turned embarrassing after the 1979 Islamic revolution in Iran (French Court of Cassation, 1984).
What if, seven decades later, the problem was still there in Europe? Indeed, there is still no common European isotopic separation plant and enriching uranium in extra-EU countries seems still attractive. For instance, Hungary's new nuclear power plant in Paks II is built and financed by Russia through Rosatom that is, therefore, the best supplier of nuclear fuel to this plant for the next twenty years, as agreed in 2014. We can observe how cyclical is the recent history of Russia with Eastern European countries and how repetitive is the position taken by the European Union. Indeed, in 2015, the Hungarian People's Republic negotiated with the Euratom Supply Agency (ESA) to be allowed to import nuclear fuel from Russia for its Paks reactors (Reuters, 2015). To put it into context, these talks took place merely one year after the Crimean status referendum (2014) – the European Council and the European Commission officially deemed it to be illegal (Van Rompuy & Barroso, 2014)– and a decade after the Orange Revolution (2004) in Ukraine. Obviously, the EU institutions were contrary to one of their member states getting so close and structurally dependent on the Russian Federation. Accordingly, the most recent war in Ukraine pushed (again) the European Commission to seek alternative financing and fuel supply solutions for the Hungarian nuclear program:

> *Sanctions imposed following Russia's invasion of Ukraine have made it necessary to strenghten the security of supply situation for Russian-designed VVER reactors in the EU and Ukraine. It is necessary to add a new action and budget to carry out necessary safety analyses and tests and establish procedures needed for the licensing of VVER fuel manufactured by suppliers outside Russia*. (European Commission, 2022, p. 2)

Yet, certainly for pragmatic reasons, Hungary's National Atomic Energy Office issued, anyway, a construction license for two VVER-1200 reactors financed by Russia and supplied by Rosatom (World Nuclear News, 2022). Though the type of contract recently offered by Rosatom in Turkey (Build-Own-Operate, BOO) is not used in the EU, we must highlight the risk of complete dependence on a foreign nuclear company that provides all the funds, technology, nuclear workers, and fuel necessary to run the plant in a developing nuclear market. It is deemed that the heavy commitment of the nuclear company Rosatom (chiefly its financial dimension) in Akkuyu plant in Turkey will disincentive the launch of future BOO build-own-operate) contracts that can be politically rewarding but economically dangerous for the Russian company that carries all the risks of the investment (Schepers, 2019).

Parallelly, because the plant in Tricastin does not fully cover domestic needs, France has also outsourced part of its uranium re-enrichment in Russia (Siberia) for economic convenience (Da Sois, 2023). It is not surprising, then, that France and Hungary have been advocating against potential EU sanctions on the Russian nuclear power industry (TASS, 2023). Therefore, we cannot deny that interdependences in the global nuclear industry undermine nuclearized States' strategic autonomy. However, the nuclear industry is dynamic: the thinner the interdependence, the quicker the industry can arrange in a different way. Moreover, contrary to natural gas which pipeline supply can be switched off in a day, the supply of nuclear fuel is made for two years (from 18 to 24 months), hence it is threatened only by long-lasting (and foreseeable) international tensions (Schepers, 2019). Let us point out that the French nuclear industry has gradually stopped its exchanges with Russian subsidiaries (Da Sois, 2023) so to allow the French diplomacy eventually backing a joint European effort aimed at getting independent from the Russian industry (Jack, 2023). Who knows? Maybe will this effort lead to a joint investment in the common European isotopic separation plant fostered by Prime Minister Guy Mollet in the 1950s? At the moment, the immediate reaction comes from Orano which is amending its business plan (notably by switching from French-Russian contracts to French-US contracts) and is investing to upgrade the uranium enrichment capacity of its plant in Tricastin of 30% by 2030 (Godelier, 2023).

Yet, a key component of the French nuclear pride, the mixed oxide fuel (MOX) is also a source of global interdependence.

*The global shipment of plutonium (MOX).*

In chapter 1, we highlighted the benefits of MOX both in reducing the quantity of long-term radioactive wastes (a gain in nuclear safety) and in sparing fresh uranium (an environmental and, to some extent, economic benefit). The MOX is, today, the already mastered solution closer to the ambition to close the nuclear fuel cycle. However, only a couple of nuclear countries use it because most of them prefer an open fuel cycle. Since 1958, France has been able to reprocess spent fuel for light water reactors thanks to its facilities in Marcoule (Melox) plant (Barbe, 1990). Remember that light water reactors (LWRs) include both pressurized water reactors (PWRs) and boiling water reactors (BWRs) notably used in Japan (TEPCO, 2023).

For decades, Japan has been looking for building its own reprocessing plant based on the model used in La Hague in France, but the delivery has been postponed several times and the country is among the most frequent importer of MOX produced in France (World Nuclear News, 2021). Of course, the shipment is not carbon-free. Moreover, it perfectly features the global integration of the nuclear industry, beyond the myth of national energy independence. In fact, the French SOE Orano has sent eight MOX shipments to Japan in 2022 and it is interesting to note that Orano and its Japanese customer (Kepco) jointly own the shipping company based in the UK – Pacific Nuclear Transport Ltd. (Orano, 2022). This kind of shipping operation requires, of course, a stringent security apparatus (a dedicated transport ship, no scheduled port of call during the journey, an armed escort vessel to accompany the transport ship) and is exposed to international controversies due to the inherent risk of the cargo. In fact, it happens that individual failures can lead to embarrassing cases of data falsification regarding the cargo (about nuclear safety measures), as observed between the British Nuclear Fuels plc and Mitsubishi Heavy Industries in 1999 (UK Parliament, 2000).

We can posit if French nuclear reactors were able to absorb all the MOX produced by the French nuclear industry, no MOX would be shipped (and this applies to all MOX exporters). For instance, the development of fast-neutron reactors (FNRs) could burn all the MOX produced (World Nuclear News, 2022). Yet, since emerging MOX-consuming nuclear markets (China) have been spotted by the French nuclear industry, we doubt that MOX shipment is likely to end in the future (Orano, 2023).

This paragraph pointed out the limits of the alleged strategic benefits of the nuclear option. Though the supply of nuclear fuel cannot be stopped overnight like natural gas, it exists relatively binding interdependences between nuclearized countries that can limit their respective strategic autonomy. Moreover, the production of MOX currently drives further global interdependence in the nuclear sector. Therefore, even beyond the well-known dependence on extra-EU suppliers of fresh uranium, the nuclear option is not an absolute guarantee in terms of geopolitical hedging.
Let us now move to our final current critical issue faced by the nuclear industry, i.e., its own structural flaws that are affecting its ability to deliver operational reactors with due cost and diligence.

### *II.A.4. A French nuclear industry in crisis and trying to survive.*

During President Macron's first term, in August 2019, Mrs. Borne, then French Minister of Ecological and Inclusive Transition announced the stop of an ambitious project aimed to build a prototype of fourth-generation nuclear reactor called 'ASTRID' (Chodorge, 2019). In this occasion, the then rising political star of the French Green party (*Europe Écologie Les Verts*, EELV) stressed the cost of this failure associated to "billions of euros atomized" by the French nuclear program and drew a comparison with the investments that, instead, should have been made in renewables according to his party (@yjadot, 2019). Remember that the economic relevance of the nuclear program had become the main frame to evoke nuclear energy in public affairs. In fact, when running for President in 2017, Macron himself pointed out the huge cost (and safety risk) of the program and the necessity to cut the nuclear share to 50% (25 points lower than the current 75%-share of nuclear electricity) and improve the renewables' one in the French electricity mix in the coming years (Le Monde, 2022), as planned by the law on energy transition adopted in 2015 during President Hollande's term (Le Hir, 2015). Symbolically, President Macron has also been, in 2018, the first President of the Fifth Republic to actually close a nuclear power plant (Fessenheim) and announcing the phase out of the whole program with 14 reactors supposed to stop by 2035. His main argument was 'listening to the social alarm' (Le Parisien, 2018) – that we understand as arbitrating in favor of the anti-nuclear movement in a German fashion. Though President apparently changed his mind in 2022, as we hinted at in the introduction, the obvious lack of public support to the nuclear industry in the last years has definitely undermined a sector that was already suffering from its own (internal) structural problems. As we will see, the capacity of the French nuclear industry to be reborn and effectively drive the ongoing energy transition is legitimately questionable. In this paragraph, we will try to spot and synthesize the key problems affecting the sector.

*The turmoil of European Pressurized Reactors (EPRs).*

In the introduction, we mentioned the promotion of EPR technology (III+ generation) in the 1990s as the future of nuclear energy generation. It is supposed to be safer and cheaper than the reactors of the third generation built during the first French large-scale nuclear program.
European Pressurized Reactors are called hybrid minsters by their detractors (especially pro-nuclear ones). Who knows whether it is a purely technical assessment or rather a parochial reaction to a design that mixed French (a pressurized water reactor) and German (a Konvoi reactor) technologies…? It is however certain that building EPRs last and cost much more than expected (see, Flamanville 3, Sizewell C, and Olkiluoto 3). Besides, the US nuclear industry has also proven that opting for a simple improvement of past technologies (III generation) to match higher requirements in terms of nuclear safety (III+ generation) while starting from an already mastered model is not necessarily more successful since the AP1200 reactors built by the US Westinghouse are suffering from similar time and cost overruns (Fluchère, 2019).
On this occasion, the French nuclear industry has been restructured with Framatome (originally an EDF subsidiary) absorbed by Areva (expert in nuclear fuel, today Orano). Moreover, the French-German cooperation led to the creation, in 2001, of Framatome ANP owned at 66% by the French Framatome and 33% by the German Siemens (Fluchère, 2019, p. 8). The first problem is certainly the sudden influence taken by antinuclear movements in Germany in the early 2000s (even before Fukushima) that gradually led to the actual disappearance of Siemens' nuclear branch. De facto, the joint work under Framatome ANP in Finland (Olkiluoto) has been undermined by this sudden loss and this paved the way to a succession of problems in further projects in France and in the United Kingdom.

In addition, the French nuclear industry had started to lose skills due to years of inactivity after its last achievement… in 1995. Therefore, young and unexperienced engineers have supervised the realization of the unprecedented nuclear creature that is the European Pressurized Reactor. Besides, the historical French steel supplier, the Creusot smithy factory has also experienced internal troubles that result in production mishap affecting the quality of the steel used by the works for Flamanville 3 (Reporterre, 2017). Fluchère (2019) also spots the institutional instability on the top of EDF and the paradoxical stability of failing managers on the top of Areva as a source of conflict. These intestine wars have certainly undermined the influence of the French traditional 'nuclearocracy': a godsend for the French antinuclear movement and a possible explanation to the gradual distance taken by Hollande and Macron's administration with the nuclear industry. Reading Fluchère, it seems the pro-nuclear international activism carried out by President Sarkozy in the early 2010s[56] can be seen as an illusion of expansion aimed to hide the implosion of the French nuclear industry.

In a nutshell, there is a long list of faults at the various levels of the French nuclear industry that can explain why building an EPR takes so long. Yet it is even more worrying to note that the problem is structural and goes way beyond this specific technology. Such a turmoil makes more understandable the political decision to stop an ambitious project of fourth generation like ASTRID.

*The case: stopping ASTRID project.*

ASTRID was the name of the project aiming at developing a prototype of sodium-cooled fast neutron reactor (SFR), a type of reactor that matches the standards of the expected fourth generation of nuclear reactor. Among its assets, the SFR is supposed to burn spent nuclear fuel hence substantially close the nuclear fuel cycle. As put by the former High Commissioner for Atomic Energy and Alternative Energies Yves Bréchet before some members of the French Parliament in 2022, investing and achieving SFRs in France would have been the consecration (and retrospective legitimation) of seven decades of public investment in the nuclear program (Revue politique et parlementaire, 2022). In fact, in reference to paragraph I.A.II., the economic and safety benefits of the fourth generation of nuclear reactor could enable nuclear energy to

[56] Cf. paragraph I.B.3.

stand among the most appealing sources of the future. France had a comparative advantage that has been, to Bréchet, spoiled by a short-sighted political (mainly accounting) decision. Yet Yves Bréchet was optimistic about the close readiness of the SFR developed by the CEA in collaboration with Japanese partners. It could have been a serious tool of thick energy security since notably the need for fresh uranium would have been drastically cut. As a matter of fact, when reasoning upon the stakes inherent to the energy transition, Bréchet referred to the end of this project as the evidence that the French State, once a 'strategist', has turned to be exclusively 'talkative'.

Ending ASTRID in 2019 has thus been a dramatic decision that certainly worsened the malaise in relation to nuclear energy in the engineering community: does France really want to close its nuclear fuel cycle? (Gassilloud & Piednoir, 2021, p. 13). By extension, has nuclear energy any future in France? Before President Macron's 2022 pro-nuclear speech in Belfort, the technology tended to appear as abandoned by the State, without any perspective. For a few years, nuclear energy has lost its appeal in France, and it is likely a further explanation to the growing anti-nuclear opinion showed by the survey carried out in early 2022[57]. Let us now investigate the two big structural issue of the French nuclear industry: the inter-generational loss of skills and its lack of attractivity.

*The nuclear industry's scourges:*
*the inter-generational loss of skills and its lack of attractivity.*

In waiting for Flamanville 3 (an EPR) to be delivered and operational, the French industry has not built any new reactor for the last two decades in France. The recent history of nuclear energy shows more failures and disillusions than achievements and shared promises. As a fatality, young engineers are not attracted anymore by the nuclear sector and France is therefore losing its know-how. Since the late 2000s, a huge gap was identified between the number of yearly graduate nuclear engineers (300) and the yearly need expressed by the sector (1200). In other words, merely 25% of the open positions could be filled by French engineers. Professors have empirically observed a shift in the career chosen by their engineering students across generations. Once, working for EDF and the CEA was perceived as a successful career whereas,

[57] Cf. paragraph II.A.1.

in the ultimate years, young engineers left apart the nuclear option to start a career in renewables, energy efficiency or finance. Mechanically, France is experiencing a generational void at the conceptual level of the nuclear industry and will likely have to bet on foreign nuclear engineers to fill the positions (Gassilloud & Piednoir, 2021, pp. 24-25).
The "stop and go" policy is certainly a cause of this loss of appeal.

*The harmful discrepancy between planification and volatility.*

We argued in favor of a centralized decision-making in energy policy in paragraph II.A.1. Yet, ending ASTRID project has been an extremely centralized decision taken even without consulting the Parliament (Gassilloud & Piednoir, 2021). Hence, in front of this dramatic acknowledgment let us be versatile and qualify our initial argument: a centralized decision-making is necessary if it is the better way to secure consistent and forward-looking decisions in energy policy. If, on the contrary, these decisions are as volatile as public opinion is, investing in a nuclear program and withdraw it in a couple of year or even months is more harmful than beneficial. To this regard, remember the Italian case that have already hinted at in paragraph I.A.2. During their 2022 parliamentary hearings, both Yves Bréchet and Henri Proglio[58] have made particularly clear that a nuclear program requires a massive and long-term commitment of the State otherwise it fails. Proglio emphasized that the liberalization of the electricity market (EU level) combined with growing influence of the green-socialist coalition in France since the late 1990s has led to the gradual dismantlement[59] of the French civilian nuclear apparatus as it had existed since the 1950s with a well-structured and functional distribution of competencies. In fact, the traditional trinity made of the CEA (for the research & development), Framatome (for the construction) and Cogema (for supplying nuclear fuel) constituted the backbone of the French nuclear industry. RTE was the transporter and EDF the

[58] Henri Proglio has a long experience in the French electricity industry for having been the chairman and CEO of EDF between 2009 and 2014. He is particularly interested in nuclear generation and hydroelectricity, i.e., the traditional French combination for electricity generation since the second half of the XX$^{th}$ century.

[59] Before the end of ASTRID project, the socialist government led by Lionel Jospin had created a precedent by ending, in 1998, an ambitious project of fast breader reactor called Super-Phénix. At that time, the justification was already short-sighted: the immediate cost of R&D was not justified since the price of fresh uranium was relatively low.

generator and off-taker (Proglio, 2022). This has guaranteed, according to Proglio, the stability of electricity prices in France for decades and served the country's industrial competitiveness. As explained in the introduction, this structure does not fit the framework required by EU law. We already explained that the ARENH price is the solution imagined so to comply with EU law though trying to protect the French electricity industry's architecture. It resulted, to the former CEO of EDF, in the downsizing of investment in nuclear R&D in France and in the loss of osmosis between the CEA and EDF.

Therefore, the 'stop and go' policy is the consequence of external (EU) and internal (the green-socialist agreement) pressures put on nuclear projects. Yet, the very recent history proves that an influential EU member can free itself from external pressures in energy matters if it acknowledges that the energy transition urges to think out of the box. To borrow Bréchet's expression, the French state must return to be a strategist.

*Fatalism?*

It appears that both the government and the French industry have understood the stakes and are preparing to tackle the obvious decline.

The electricity lobby *Union Française de l'Électricité* (UFE) has screened between 2021 and 2022 the needs of the French nuclear industry to face the works by 2030, namely: building 6 EPR2, extending the technical lifespan of existing reactors (*grand carénage*), decommissioning some plants (e.g., Fessenheim), developing small modular reactors and building the deep geological repository (CIGÉO). Sometime beyond the focus we made on nuclear engineers, UFE highlighted six essential jobs that will require qualified workers (and are struggling with recruiting them) in the very short term: radioprotection, piping and welding, system engineering, civil engineering, boilermaking and project management (UFE, 2022). The lobby recommends promoting careers in the nuclear industry through the creation of an educational label 'formation du nucléaire' but also improving the multiscale (regional and national) identification of the needs and the consequent distribution of workers in the relevant places. In terms of welding skills, the Normandie will be, once more, active in providing solutions since the *haute école de formation en soudage* (called *Héfaïs*). This university of applied science is sponsored by public authorities and industrial players like EDF, Naval Group and Orano (Gasly, 2021). Furthermore, Framatome has decided to re-invest *100 million euros* in the historical smithy factory of Le Creusot to bring back to France the construction of nuclear reactor vessels that had been relocated in Eastern Europe in the last years (Bembaron, 2023).

Besides, we have observed that the EU framework tends to be more and more eager to grant nuclear energy a chance in the energy transition. Making it compatible with low-carbon sources and storage methods (e.g., pink hydrogen) seems to be the way to secure the future of the nuclear industry and to favor a consistent and long-lasting public support to a nuclear program. Eventually, since the Gaullist illusion is dramatically undermined by the reality of global interdependences in the nuclear ecosystem, it could be wise to seriously consider transnational multilateral cooperation (rather than mere bilateral cooperation that can easily fail as observed with Germany and the EPR) in the development of the nuclear technologies of the future. Of course, a sound selection of topics that can be shared should be done since we bear in mind the civilian-military nexus in the French nuclear industry.

This paragraph has shown the various problems the French nuclear industry is experiencing, from the turmoil of the EPR technology to its structural decline. It is clear that the industry has struggled with a completely new context in the very early 21st century and is now trying to (hardly) be reborn with the current government's support. We, eventually posit that a further internationalization of the nuclear industry, which would consequently have to admit its global ramifications, could be an interesting perspective.

**Conclusion of section II.A.:**

In this section, political, sanitary, and environmental issues related to nuclear energy have been addressed in a discursive way. We have, first of all, noted that public opinion in Europe seems mainly skeptical towards the nuclear option if not genuinely antinuclear. Yet the last official EU surveys are about fifteen years old. More recent ones carried out in France have shown how volatile this opinion can be. We have posited that major international events and subsequent macroeconomic effects can easily affect the assessment of most respondents to the point of making them change their minds about nuclear energy in merely a couple of months. Yet, considering the current difficulties the French nuclear industry is facing, we have identified that a ‘stop and go policy’ in nuclear matters causes harmful structural problems. Hence, we have argued in favor of a non-democratic, but rather technocratic, decision-making of the energy policy, even in democratic countries.

Furthermore, sanitary and environmental harm cannot be denied. Nuclear security must thus be taken extremely seriously, and both the nuclear industry and the State of nuclearized countries must be exemplary. Therefore, we recommend not using BOO (build-own-operate) contracts like the one recently offered by Rosatom in Turkey.
Eventually, in light of all these issues, opting for the nuclear option is a choice that must balance the drawbacks and assets of nuclear energy generation. We firmly believe that, despite the risk, operating a large-scale nuclear program is manageable, as proven by France throughout the last decades. Yet, the French case also shows that a country cannot limit its commitment in a nuclear program to past investments and successes and eternally enjoying a privileged position.
The final question now is whether the nuclear industry can adapt to prospective problems mostly caused by climate change.

## II.B. Nuclear facing the risks of the future: climate change, shortage, and international wars.

The intergovernmental panel on climate change (IPCC) is highly confident that the global temperature increase will affect the use of water to energy and industrial purposes by 2050 (Caretta, Mukherji, & Arfanuzzaman, 2022, pp. 614-616). Of course, hydropower will be the first technology affected but, parallelly, the global demand for freshwater destined to cool energy facilities is expected to rise by 24% globally by 2050 under the scenario of global temperature increase by 2°C. Both power plants and upstream water-intensive mining operations will be affected worldwide. Every country could have to deal with a growing competition between economic sectors for water use.
Two main threats arise from this scenario. First, in terms of nuclear safety, the nuclear industry must be able to build reactors of which cooling system is (as much as possible) independent from rivers that are destined to suffer from water scarcity. Once more, the concept of ‘open cycle’ and ‘closed cycle’ (applied, in this case, to water use) will be useful to understand the technical stakes. Moreover, since nuclear electricity generation lies on heating water, the generation of nuclear electricity itself will be a sector subject to the growing competition for water use. Today, most of the French nuclear power plants are settled close to a river and use this resource to cool their reactors. This paragraph will hence try to understand the exact stakes posed by climate change to the nuclear industry and envisage the scenario of an industrial collapse (II.B.1.). Second, if water scarcity affects mining operations worldwide, the

phenomenon could interfere with the supply of uranium. We will wonder to what extent this, combined with other parameters (chiefly the growing global demand for uranium), could lead to a shortage of uranium and how the nuclear industry could adapt to this calamity (II.B.2).
Finally, the IPCC often points out the growing prospective risk of war caused by the competition related to natural resources. In addition, the war in Ukraine has shown that even the European continent is not immune from the risk of high intensity wars on its own territory. We will thus end this thesis by discursively addressing the issue of nuclear security in case of international war (II.B.3.).

*II.B.1. A changing environment.*

The world is expected to evolve hotter and dryer (in continental areas), especially during summer periods. Moreover, several littorals will face the rise of sea levels. The US National Aeronautics and Space Administration (NASA) has observed a + 0.97 millimeters rise in two decades (since 1993) at the global level. This phenomenon is attributed to the combined effect of melting ice sheets and glaciers, and the expansion of seawater due to its warm (NASA, 2022). It should not stop in the future.
The nuclear industry is directly concerned with this evolution. In fact, the role of water in nuclear electricity generation is twofold. First, an initial share of water is destined to be heated by the energy released during the nuclear fission process. Once heated, this water turns into steam that has the driving power to activate the radioisotope thermoelectric generator. Nevertheless, the steam must lately be liquified to keep the thermal balance within the reactor. Therefore, steam is subsequently cooled by an additional share of fresh water (between 0 and 30°C) to dissipate the energy that has not been transformed into electricity (Sfen, 2022). The fifty-six French nuclear reactors annually consume 26 billion $m^3$ of water which represents half of the total French industrial takings of this resource. As we have already hinted at, Hoerber (2012) points out that this overall process causes thermal pollution that affects biodiversity[60]. One could also wonder to what extent this thermal effect could accelerate the rise of sea levels in areas nearby nuclear power plants.
We believe that the rise of sea level, on the one hand, and episodes of water scarcity in rivers, on the other hand, put nuclear safety at risk in the long run.

[60] Note that the wind and solar industries also face problems with environmental impact assessment.

Indeed, building nuclear power plants on litoral could be a convenient solution to secure an abundant source of fresh water (open water cooling cycle). Yet, we have to be certain that these littorals do not present other risks to nuclear safety, for instance, the seismic potential of the region in the coming decades. Everyone bears in mind that the nuclear accident in Fukushima, contrary to Chornobyl, stems from a tsunami more than genuine nuclear malfunctioning.

It must be remembered that Fukushima Dai-ichi is not the norm but a dramatic exception. During the same earthquake, the second nuclear power plant of Fukushima (Dai-ni, which welcomes four nuclear reactors) automatically shut down without incident. Moreover, still during the same earthquake, some inhabitants of Miyagi (the city most affected by this natural catastrophe: even shelters were destroyed by the tsunami), paradoxically found protection in the neighboring nuclear power plant of Onagawa (built in the early 1980s) that resisted to both earthquake and tsunami (Burbi, 2023). However, the subsequent ionizing pollution of the territory is undeniable even though this fact can be qualified by the existence of naturally ionizing regions.

Moreover, an unmanageable situation of water scarcity affecting rivers nearby nuclear power plants would force them to stop. In fact, in continental territories, the cooling solution for nuclear reactors is the ‘closed’ one, i.e., combining a limited source of water and the refreshing capacity of a cooling tower. Yet, remember the relatively minor nuclear accident that happened in Three Mile Islands (the US) in 1979 was caused by a malfunction and an operator error that undermined the cooling water circulation (US Office of nuclear energy, 2022). For now, it is deemed that the steaming process is much more water-consuming than the cooling process. Thus the issue would first concern the actual capacity of the plant to generate electricity before putting its cooling functioning at risk (Laconde, 2023). The French nuclear industry is confident that deep cooperation between hydroelectric dams and nuclear power plants present on the same rivers (facilitated by the fact that they are both operated by EDF) will guarantee the necessary supply of water for nuclear electricity generation and that merely an occasional stop will occur for extreme climatic reasons (Sfen, 2022). *Nonetheless, if major attention is put on biodiversity and more demanding environmental impact assessments are imposed, the problem of thermal pollution by nuclear reactors will escalate and potentially fuel tensions with foreign (non-nuclearized) stakeholders in the use of transnational rivers (e.g., Switzerland for the Rhône River, and Germany for the Rhine River). In this case, if a technological (“high tech”) solution cannot be found, a nuclear exit could be considered. Yet, since also renewables are bound by* *environmental impact assessments and that they require, overall, wider areas than nuclear power plants, the nuclear industry will not be the only one affected by major protection of biodiversity. This question is likely a lose-lose game for nuclear and renewables.*

Hence, though we have framed nuclear energy as a baseload dispatchable source, it could happen that – if they cannot be cooled – nuclear power plants will face periods of intermittency less for safety reasons than for the simple availability of water to be heated. Even the nuclear industry acknowledges this trend, higlighting that the French nuclear fleet has already been, on average, unable to generate 1.4 TWh per year during the period 2015-2020 because of climate constraints (Sfen, 2022). This last point is the umpteenth evidence that diversifying the electricity mix, i.e. making energy sources hedging will be necessary. Both a 100% nuclear and a 100% renewables scenario would be unsound. We also would like to point out that, based on its time-storage capacity, pink hydrogen can be an interesting complement that could compensate for the seasonal stop of nuclear power plants. In fact, if they can run as a baseload source for months and fuel electrolysis during this 'fast' period, and hydrogen can then be used during the hottest and driest period when nuclear reactors are switched off, the combined use of the overall electricity generation assets could be optimal.

Nonetheless, there is still uncertainty about the multiple transformations that climate change can bring to Earth. For instance, the melting ice cap could provoke geological chain reactions including unexpected tsunamis (Steffen, 2022). The hypothesis is serious enough to interest insurance companies. Besides, it is increasingly taken for granted that Southern France will be increasingly dry by 2050 (Feitz, 2023). The low-water flow of the Rhône River, for instance, has decreased by 13% since 1960 and could continue decreasing by a further 20% by 2050. Six nuclear reactors are currently running nearby this river, including the strategic plant of Tricastin. We have doubts regarding the soundness of building future nuclear reactors in regions with such a scenario (that increasingly seems to be a proper forecast). In the short term, the trend seems to build new reactors (Flamanville 3, and two EPR2s) along the sea, in Normandie. In fact, EDF relies on this region as the safest one in terms of maritime access and seismic potential (Loubet, 2018).

Finally, a current of thought has thrived in the academic literature throughout the last years: the collapsology, i.e. prospective studies focused on a speculative global collapse of the industrial civilization. This topic is entangled with climate change since, according to Will Stefen, the planet has nine limits that should not be overcome if humankind wants to preserve a favorable living system on Earth (Stefen, 2015). To Stefen, humankind has already overcome five of the nine limits, namely: climate change, biodiversity erosion, phosphorus, and nitrogen biogeochemical cycles, and soil use change. These overcome limits are deemed irreversible and thus condemn humankind to the continuous degradation of its living habitat. Note that the various parameters studied by the IPCC echo the alleged planetary limits.

The industrial collapse is not the end of the world but the end of our thermo-industrial world (Salerno, 2018). One could wonder to what extent such a teleological approach is reliable, but, parallelly, we cannot deny that human civilizations have disappeared in the past. Eventually, some optimistic collapsologists assert that the industrial collapse will lead to a more equal and ecological global society whereas others write 'survivalist' manuals in a quite Hobbesian fashion (where the Leviathan could not exist anymore). We do not have a strong opinion on how seriously the collapsological perspective should be taken. But we will try to discursively address its stakes applied to the nuclear industry.

Let us posit a future where the energy system – especially the nuclear industry –, and the economy as a whole, produce only diminishing returns (Tainter, 1988). The nuclear cycle's TOTEX[61] cannot be covered anymore and drained public finances are unable to support it as they used to perform. Breaches to nuclear safety rules that used to be exceptional and the fact of a minority of unscrupulous entrepreneurs have become the new normal due to economic constraints and the erosion of the State's authority growingly incapable of enforcing laws and regulations. Nuclear waste storage is increasingly unsafe and the irreversibility feature of nuclear energy proves the nuclear program to be among the worst decision of the past. What should we answer to one who apprehends the future of the nuclear option in these terms? Under this frame, the management of long-lived nuclear waste is, in fact, a dramatic problem.

Yet, if the prevention of such a situation should stop nuclear activities today, this would include nuclear medicine. Especially, linear particle accelerators used to cure… cancers (through x-rays or electrons). Indeed, these devices and the R&D in this field generate long-lived wastes too. For instance, though Italy officially stopped its nuclear program after a referendum in 1987, the Sogin company (the state-owned enterprise dealing with nuclear decommissioning) signed an agreement with Areva in April 2007 (Senato della Repubblica, 2007) to process nuclear wastes. The Italian need for decommissioning includes wastes generated at 40% by nuclear

61 See paragraph I.A.2.

medicine, the (non-energetic) industry, and research (Sogin, 2014, p. 28). Logically, as long as Italy does not launch a new nuclear program, only this non-energetic share of long-lived nuclear wastes is going to increase.
Hence, the industrial collapse issue can be reframed this way: is this hypothesis worth stopping nuclear medicine? Once again, it is a matter of perspective. In our opinion, opting for a nuclear exit based on this speculation would be unsound.

In this paragraph, we have discussed the adaptability of the nuclear industry to climate change, especially in relation to the availability of water used both as an essential means of electricity generation and as a coolant material. Though we cannot be absolutely certain that future nuclear power plants will fit the fast-changing climatic conjuncture of tomorrow, measures taken in France based on today's knowledge seem sound to us. Furthermore, we have discursively rejected the nuclear exit suggested by collapsology in front of the lack of reliability of its predictions. Indeed, we think that the aim of stopping the production of nuclear wastes through the complete withdrawal of all nuclear activities (with a subsequent loss of modern comfort) does not deserve such a sacrifice. Yet, if the nuclear industry should not shy away in front of external pressures, is it able to adapt to internal ones like a uranium shortage or a relatively similar calamity?

### *II.B.2. <u>A potential uranium shortage.</u>*

Climate change – by worsening the extractive conditions –, and the growing demand for uranium due to the proliferation of large nuclear program in Asia, are expected to become two important game changers on the uranium market. Yet, the current third (or third +) generation of nuclear reactors is completely dependent on enriched uranium. In this paragraph, we will try to understand how the uranium has worked until today and to what extent the European nuclear industry can be affected by this new situation.

#### General trends on the uranium market.

The uranium market behaves as a typical market of energy commodities, i.e., the spot price can rise dramatically when a shortage is feared. In case of low prices, suppliers are incentivized to cut their production and, conversely, high prices incentivize investment to increase the production on supplying capacities (OCDE AEN, 2007).

Nonetheless, the uranium market can easily be disrupted by, first, the civilian-military nexus in the nuclear industry, and second, the effect of nuclear accidents on national nuclear programs worldwide. In fact, the famous MOX (mixed oxide fuel) enables the partial recycling of atomic weapons, i.e., the plutonium they contain, into nuclear fuel (Birraux, 1994). Hence, nuclear (in the sense of military) powers enjoy benefit from the saving realized out of the fresh uranium they do not have to buy because they can use ‘home-made’ MOX to fuel their nuclear reactors. This first phenomenon tends to decrease the demand on the spot market. Furthermore, strong variations correlated to prominent nuclear accidents have historically been observed on the uranium spot market. In fact, whereas the spot price rocketed threefold between 1973 and 1975 due to a peak of demand driven by a western enthusiasm for waging nuclear programs and the military demand for the needs of the Cold War, the accident of Three Miles Island made the spot price drop between 1979 and 1981 (OCDE AEN, 2007, p. 31). Chornobyl had a similar effect on the spot market (see chart 14).

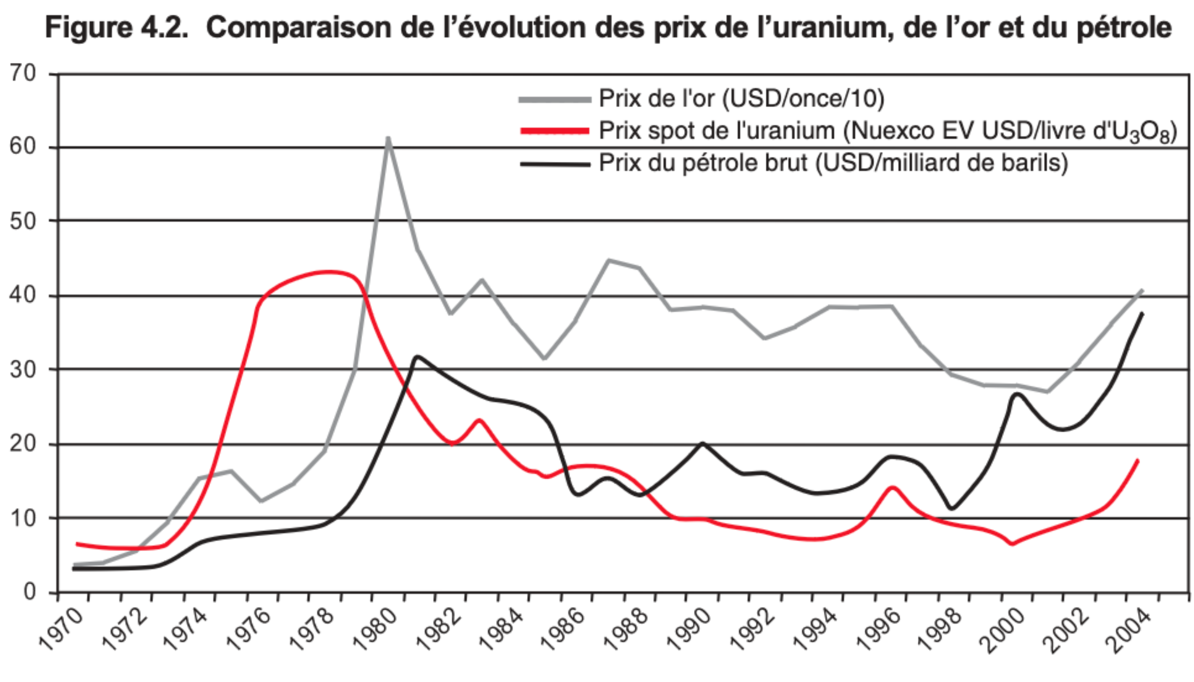



*Chart 14: Comparison of the spot prices of uranium, gold and oil (1970-2004). Source: OECD, Ressources, production et demande de l’uranium : Un bulan de quarante ans., AEN Infos 2006, n°24.1, p.30.*

*The international trade of uranium in the post-colonial era.*

Beyond the MOX, post-colonial international relations can also drive the price actually paid by uranium importers. For instance, the French Areva has been able, in 2007 to renew its preferential forward contract (five to ten years) with the State of Niger to purchase every year 3.000 tons of uranium for €62/kilogram, i.e., merely about 32% of the spot price at that moment (Labertit, 2007). Remember that, the 24th April 1961, the French Republic signed a series of bilateral agreements with the Republic of Ivory Coast, the Republic of Dahomey (Benin), and the Republic of Niger including a preferential commercial partnership on commodities such as uranium and thorium that the countries should trade in priority to France "once the domestic needs [for these commodities] of these countries are satisfied" (Debré & Foyer, 1961). Without a doubt, hence, France has enjoyed – for decades – preferential prices for its supply of uranium destined for both its military and civilian nuclear needs. It is likely the reason why funding the huge CAPEX to develop a fast-neutron reactor of the IVth generation (Superphénix) seemed extravagant to Prime Minister Jospin's government in 1997 (Gracieux, 2005). Indeed, why spend billions to prepare for the end of uranium abundance if current prices are so low? Yet, the context is changing with the rise of the Chinese nuclear industry (which could drive the global demand for uranium in the future) and the economic effects of sanctions (or the absence of sanctions) on Russian-enriched uranium during the war in Ukraine (Bouckaert, 2022). It is likely that the uranium market is entering a new era where Western countries will find less convenient trade conditions.

The most reliable hedging solution in this new paradigm is known: the European nuclear industry should develop and build fast-neutron reactors (Bouttes, 2022). In fact, with FNRs, France could rely almost exclusively on its impoverished uranium (already stored in the country, hence not having to purchase further fresh uranium).

We believe that, far from being lethal for the nuclear industry, high uranium prices and the risk of shortage of both uranium and fissile materials will be a clear incentive to deploy alternative reactor technologies (fast-neutron reactors, fast-breeder reactors, molten salt fast reactors) of which CAPEX is currently a deterrent in front of low uranium prices (Pitois et al, 2022). Euratom has, indeed, carried out a research project (Kloosterman, 2020) to allow molten salt fast reactors in the future, i.e., likely at horizon 2050 to deploy them in France.

In this paragraph, we have introduced the main market mechanism driving uranium's spot price that reacts to demand variations as many energy-commodity markets and is consequently highly sensitive to major nuclear accidents. Yet, we have also explained that ex-colonial powers (e.g., France) have enjoyed preferential prices that deterred their consistent investment in technologies preparing for the end of uranium abundance. We eventually conjectured that fast-changing rules on the global uranium market will turn less convenient to Western countries than they used to be and that they will consequently be incentivized to finally develop the fourth generation of nuclear reactors.
Let us now address our final issue which is the risk to nuclear security in a world that could know high-intensity international conflicts again.

II.B.3. <u>The nuclear option facing the return of international wars.</u>

Realism in International Relations could suggest that, since the end of the Cold War, the western has experienced a peaceful parenthesis in which the liberal paradigm has thrived. We are tempted to compare the intellectual period between the late 1980s and today to the inter-war period of the early XX$^{th}$ century (1919-1939) that Edward Hallett Carr labeled 'the twenty years' crisis' (Carr, 2016 [1939]).
Indeed, in 1987 was published a milestone report that enshrined sustainable development as the horizon that the whole world (from international organizations to the industry and non-governmental organizations) should target (World Commission on Environement and Development, 1987). In 1989, the Berlin wall – key symbol of the Cold War on the European continent – fell. The Soviet Union (USSR) was dissolved in 1991 and, in 1992, a milestone essay on the end of major conflicts, deemed as 'the end of history' (Fukuyama, 1992), was published. Moreover, the European Union was established with the entry into force of the Maastricht Treaty in 1993. From a trade perspective, the so-called Uruguay Round conducted between 1987 and 1994 permitted the establishment of the World Trade Organization, and the Energy Charter Treaty was established in 1991. These are only a sample of successive events that tended to confirm that the liberal paradigm was accurate and that major conflicts would not occur anymore due, notably to the growing interdependence permitted by globalization. To some extent, from Kantian (Kant, 2007 [1795]) and Wilsonian (Wilson, 2023 [1917]) perspectives, sovereign States were expected to disappear under internal pressures – the revival

of regions and local governments, e.g., devolution in the UK) –, and external ones – supranational organizations.
We have pointed out, in paragraph II.A.4., that the French and US nuclear programs have been less vigorous since the mid-1990s and, based on the various features of the nuclear industry we have introduced in this thesis, we are tempted to conjecture that a correlation can exist between the erosion of the States and this (civilian) nuclear anemia. And what could such a correlation tell us about the revival of nuclear programs worldwide in the post-Covid era? We believe that the psychological revolution brought by the necessary state intervention in the economy during the last pandemic has triggered the return of an international world (rather than a global world) where States return to be key players and where tensions can escalate into international wars implicating at least one nuclear power, even at the EU borders (e.g., the war in Ukraine).
In this paragraph, bridging this evolving international landscape with our research question, we will wonder to what extent a revolution is occurring in the framework of nuclear security and to what extent this could aggravate the risks taken by any State choosing to launch a nuclear program.

*Energy infrastructures are at risk in Europe and in the world.*

The recent connection of the Ukrainian operator Ukrenergo to the European power grid through ENTSO-E[62] falls into the continuity of the liberal-inspired European expansionism[63] towards Eastern European countries observed since the 1990s. Yet, happening in the mid of a war with the Russian Federation, this connection reminds us that the EU neighbors the Ukrainian People's Republic for the best and the worst. In fact, Ukraine stands among the most nuclearized countries in the world with fifteen running nuclear reactors generating half of its electricity (World Nuclear Association, 2023). Chornobyl plant has, of course, been stopped after the 1986 accident. Eventually, as reminded by the ongoing war, Ukraine geopolitically stands in the 'buffer zone' between the European Union and the Russian Federation that has been targeted by multiple EU sanctions throughout the last decades. And, in 2022 – after the explosion that targeted the two Nordstream (1 and 2) natural gas pipelines in the Baltic Sea –,

[62] See paragraph I.A.1.

[63] From a Russian and Belorussian perspective, it is rather a realist act of war since this new connection followed a disconnection of Ukraine from its grid with Russia and Belorussia.

President Putin stated that “any energy infrastructure in the world is at risk” (The Economist, 2022). As we will see with the study case of Zaporizhzhia plant, the question of nuclear security is extremely worrying under these conditions.
Besides, Stuxnet malware used – likely by the US and Israel – against the Iranian nuclear plant of Natanz shows that Russia is neither the first nor necessarily the most determined State to threaten the nuclear security of nuclear power plants as a hard means of foreign policy.
We believe that, in the current century, weaponizing nuclear power plants to terrorize civilians and governments could become a widespread technic of hybrid war.

*Zaporizhzhia: new symptom of the Ukrainian nuclear curse.*

The Ukrainian reputation in terms of nuclear security is marked by Chornobyl accident. Today, it is feared that a spectacularly dramatic new nuclear catastrophe will happen in the country because of the Russian invasion. As a matter of fact, a nuclear power plant based in Zaporizhzhia region – that the Russian Federation claims as its own oblast after the illegal referendum it has organized in September 2022 (Knott, 2022) – could be the future Chornobyl. It is, indeed, reported that the region has been the theater of tens of military attacks (artillery, drones, airplanes, rocket systems) in only a couple of days in April 2023 (Voitovych, 2023). The presence of such critical infrastructure is obviously not a deterrent to the deployment and use of heavy military means nearby. Yet, Russian authorities are aware of nuclear security stakes since they are taking care of the external power line that makes the cooling of the plant’s six reactors possible[64]. Though they are switched off, they need to be cooled to avoid their spontaneous meltdown as highlighted by the IEAE experts (Reuters, 2023).
Eventually, the most worrying fact is that the Russian military is using the plant as a fortress in its campaign. In fact, after having damaged the infrastructure to conquer it in 2022, Russian forces later established firing facilities within the plant that they are using to bomb Ukrainian targets nearby (Valova, 2023). Hence, if Ukrainian forces actually wage a counteroffensive to reconquer the lost Crimean territories, it is likely that a battle will concern Zaporizhzhia nuclear power plant with its inherent risk to regional and maybe global nuclear security.

[64] Note that the situation in the plant is peculiar since it is operated by captive Energoatom (Ukrainian) employees under the orders of Russian soldiers and Rosatom.

*Natanz: when Western nuclearized States attack nuclear infrastructure.*

In 2010, Stuxnet, a computer worm was identified in the computer system of Natanz uranium enriching facility in Iran. For about one year, the plant's centrifuge spinning had been abnormally high, and no mechanical failure seemed to be the cause (Van Dine, 2017).

It is believed that the worm has been introduced into the plant by physical support (a USB key) used by a computer engineer working for a subsidiary company (the German Siemens). The engineer himself did not even have to be aware of the worm he was carrying since infected USB keys had likely been gifted in series, by US secret services, during various international events with a bespoke code aimed at taking control of the Iranian plant computer system (BBC, 2012). Natanz plant was, in fact, identified as the backbone of the Iranian military nuclear program with a uranium-enriching potential to overcome mere civilian needs. The discovery contributed to raising awareness globally about the cyber vulnerability of such dangerous infrastructures (CCIS, 2016). Moreover, it showed that the US would not hesitate to disrupt a nuclear power plant to achieve its objectives of foreign policy.

*Discussion of the what-if scenario.*

No major cyber-attack nor physical territorial aggression affecting nuclear power plants has, for now, been registered in EU member states. This is the first empirical curb on the extrapolation of these extra-EU nuclear security threats. Yet, we can wonder to what extent the French nuclear security measures, for instance, can prevent the occurrence of such events.

Let us start with cybersecurity. Firstly, the digitalization and automation of nuclear plants are not new. Since, at least, 1955 the French CEA has worked on the full automation of nuclear reactors' pipes (Weill, 1955). Furthermore, it appears in the images of President De Gaulle's visit to the power plant of Marcoule in 1958 that the commanding room is full of computers (INA, 1958). Of course, one can object that it does not prove anything about the actual cybersecurity of the plant. Hence, secondly, let us investigate more recent evolutions. On 30 March 2015, the French Defense Code has been reformed with the creation of some articles, e.g., art. R1332-41-2. It stipulates that any operator of "vital importance" (nuclear plants, hospitals, telecommunications...) and their subsidiaries and partners must implement the rules established by the Agence nationale pour la sécurité des systèmes d'information (ANSSI). We know from ANSSI's 2020 guide that all installations hosting nuclear materials cannot be connected to the public network. It notably applies to video protection systems within power plants (ANSSI, 2020, p. 107). In addition, a physical control at the entrance of the plant is performed by Commandement Spécialisé pour la Sécurité Nucléaire (CoSSeN) that is co-managed by the French ministries of the interior and of the energy. The CoSSeN is allowed to investigate any individual or object entering the nuclear plant's area (Ministère de l'intérieur, 2023). Hence a Natanz scenario should not occur or, at least, not as it likely happened. Nonetheless, we acknowledge that it is not an absolute guarantee against any cyberattack a French nuclear power plant could face.

Then, the question of the physical aggression to the French territory is more theoretical in the sense that the country has not experienced any invasion since World War II like all Western EU member states… Remember that the European Coal and Steel Community has been established to this end in 1952! Moreover, in reference to the mechanism of nuclear deterrence we have hinted at in this thesis, France is a prominent nuclear power since the 1960s. It makes a preliminary fundamental difference with Ukraine, for instance. And, in fact, we will base our reasoning on the risk of a war affecting the French territory and its nuclear power plants on the existence of French nuclear deterrence.

It is admitted in International Relations that the principle of nuclear deterrence has proven to be efficient even during the apex of the Cold War, i.e. the Cuba crisis of 1962. Furthermore, we believe that, beyond military nuclear proliferation, the proliferation of nuclear power plants in the world is an indirect (i.e. civilian) way to comply with Kenneth Waltz's theory – "more may be better" – of the sobering effect of a widespread nuclear weapon (Waltz, 1981). Still based on International Relations theories, if nuclear energy is chosen by States to secure relatively high-life standards for their population/industry, by extrapolating John Mueller's concept of hollandization (i.e., the non-willingness of economically and technologically interdependent States to go to war) we can posit that nuclearized countries will not go to war (Mueller, 1990). As a matter of fact, Chornobyl's accident highlighted the USSR's industrial failure and its incapacity to achieve its successive five years plan target of 1981-1985 and then 1986-1990 (Potter, 1990). This could explain why Russian forces are currently taking care of the cooling system of the Zaporizhzhia nuclear power plant in stark contrast with the violence of surrounding battles. A nuclear catastrophe is, in fact, absolutely contrary to the industrial logic of building nuclear power plants to secure a certain life standard and shows that USSR was not completely “hollandized”. Conversely, hollandized nuclearized countries pay extreme attention to nuclear safety (e.g., the successive postponements of the delivery of Flamanville 3’s EPR in France and Vogtle’s AP1000 in the US). Hence based on the literature on International Relations, war is, first, unlikely to break out between nuclearized countries. Second, if it happens anyway, nuclear power plants should be substantially spared even though they could be instrumentalized to make the conflict escalate (as observed in Ukraine).

As far as EU member states are concerned, we are confident that the combination of art.42.7 TEU and art.5 North Atlantic Treaty on mutual/collective defence is as serious deterrent for military invasion. The Ukrainian case, as a non-EU State and non-NATO member, and part of the buffer zone between the EU and the blatantly hostile Russian Federation, is more sensitive and its evolution must be monitored. But any nuclear catastrophe happening in Ukraine could not seriously be imputed to the revival of the nuclear option in the EU.

In our view, international wars are not the main risk, but asymmetric conflicts (e.g., terrorism) will continue to be a major threat to nuclear power plants. Consequently, the current mediatic focus on high-intensity conflict should not distract the intelligence and other relevant services from the control of domestic and transnational subversive groups that could target the power plants.

In this final paragraph, we have discussed the scope and the implications of the growing cyber and military threats on civilian nuclear plants. In terms of cybersecurity, we have argued that the malware Stuxnet has been as worrying as insightful for security experts and that the French authorities have subsequently improved their physical and remote measures in nuclear areas to prevent this kind of attack. Then, we discussed the hypothesis of an invasion of French territory in relation to its nuclear power plants. It results that, for a series of military (nuclear deterrence) and politico-economic (the so-called hollandization) considerations, such an event is, first, very unlikely to happen, second, even more unlikely to lead to a nuclear catastrophe on the French territory.

**Conclusion of section II.B.:**

In this final section, prospective issues affecting the nuclear industry have been addressed in a discursive way. We have acknowledged that environmental, economic and political, and security conditions will certainly change in the coming years. Basically, the beginnings of these changes are already observable and have helped our reflection. Such a preliminary acknowledgment is fundamental in relation to an energy choice that requires a strong planification and that is largely irreversible.

It exists relevant antinuclear arguments inspired by the three categories referred to above. We have provided counterarguments comforting the nuclear option, but we reckon that there is still a wide margin of uncertainty. However, we have concluded that prospective threats urge a nuclear exit or the withdrawal of new nuclear programs. Indeed, we are confident that technological, political, and economic solutions will always find a way to maintain a high level of nuclear security.

## Conclusion

Answering the question "To what extent can nuclear energy help achieve the EU's decarbonation and energy independence goals?", this thesis has supported the insertion of nuclear energy in future hybrid energy systems and its consequent labeling as an 'energy of the future' in Europe.

We acknowledged that the issue is more a matter of persuasion than a technical assessment. Indeed, several times in this thesis, we have concluded that politics must decide to choose or reject a specific option in a complex political, environmental, and economic situation. Overall, the debate systematically stands between nuclear optimism and nuclear pessimism.

We have, moreover, identified two crucial comparative assets of nuclear energy to support the nuclear option: on the one hand, nuclear has a great potential to cut the European power generation mix's $CO_2$ emissions; on the other hand, adding nuclear power generation to the European mix will have hedging benefits in terms of energy security in a highly competitive world.

*Low-carbon electricity for the energy transition.*

First, nuclear energy can favor the low-carbon electrification required by the energy transition and maintain high living standards. Our preliminary assumption is that both populations and governments will seek to preserve a relatively high living standard and, thus, maintain a growth-oriented economic system. If, conversely, populations were ready to accept the implications of economic degrowth – that allows strong energy sobriety – the reasoning we have developed in this thesis would be irrelevant.

Hence, we have built a pro-nuclear argumentation positing that citizens' and governments' preferences impose a dominant centralized, technocratic, and growth-oriented energy system. In this system, nuclear fission[65] – as a low-carbon baseload dispatchable source of energy – will complement the deep penetration of renewables in the European power grid and lighten the need for battery energy storage systems. In fact, taking into consideration the whole cycle and value chain of both nuclear energy and renewable energies, no energy source is essentially

[65] *And maybe nuclear fusion in an uncertain future.*

‘clean’. But complementing renewables with nuclear energy could avoid the resort to more polluting baseload dispatchable solutions (natural gas or even coal) as well as reducing the demand for raw materials present in batteries.

Moreover, bearing in mind that the overall energy transition requires unprecedented investments, we have identified sustainable financial solutions for funding incoming nuclear programs. We have, furthermore, introduced a series of technological improvements that could be achieved in the short or medium term by the nuclear industry and improve its resilience, notably in front of the risk of fuel shortage, and reduce the quantity of ionizing nuclear wastes (and inherent downstream problems).

Nonetheless, it has been made clear that the nuclear option has environmental and sanitary drawbacks that require exemplarity from both governments and nuclear companies. In addition, the exact mid-long-term implications of climate change on the physical environment that will welcome the nuclear reactors of tomorrow are uncertain. Therefore, the nuclear industry must propose solutions for operating these reactors in a flexible way. In other words, the nuclear reactors of the future should be operated not as a baseload source anymore but in a load-following manner. And this could increase the cost and the frequency of their maintenance. Yet, it is the sine qua non condition for them to be part of future hybrid energy systems. We posit that pink hydrogen could facilitate this flexibility, but this topic should be further investigated.

The virtues of complementing future hybrid energy systems are not only environmental. In fact, the second key comparative advantage of the nuclear option is its current and prospective benefits to energy security.

*Diversifying the power generation mix to strengthen energy security.*

Among the insights of this thesis, we note that the energy world is getting less Western-centric and that, subsequently, the competition for essential resources is increasing. In this new context, energy hedging is not an option anymore, but a proper necessity.

It is consequently counter-productive to reason in terms of the ‘100% renewables’ or ‘100% nuclear’ scenario. The more low-carbon energy sources the better. Furthermore, climatic pressures and the economic development of new giant markets like India and China will make a race out of any energy commodity or relevant ore. Recycling more is, of course, part of the solution. Yet, through the example of the renewables industry, we have shown that it is, for now, rather a non-performative slogan and that the practical recycling solutions will have their own health and environmental drawbacks.

Thus, energy hedging will be the key, and – as proven by the European jurisprudence – it cannot afford parochial judicial battles between EU member states to prevent the neighbor from developing a low-carbon source of energy. Accordingly, it will tighten the nexus between foreign policy and energy policy – two sectors that escape democratic decision-making. We have, in this sense, defended the technocratic feature of energy policymaking.

However, we have also pointed out that the nuclear industry is more integrated into the global value chain than many pro-nuclear politicians assert. It is thus doubtful to frame nuclear electricity as the absolute guarantee of national energy security. On the contrary, like all other technology, nuclear fission requires international trade of raw materials, technological transfers, and – growingly in the declining Western nuclear industry – the resort to foreign skilled nuclear workers. Yet, the fundamental civilian-military nexus in several nuclearized countries make curb transnational nuclear cooperation and strengthen the nationalist rhetoric. But the nuclear industry's history teaches that the economic imperative can moderate even the most determined nationalists.

This thesis brings a multidisciplinary insight into the multidimensional stakes related to the European energy transition. We have explained that local issues have global resonance and vice-versa. Furthermore, beyond the well-known 'not in my backyard' issue of public opinion, this work highlighted that the nuclear energy is at the crossroad of long-term environmental, techno-industrial, financial, judicial, and diplomatic stakes often ignored by citizens.

Eventually, we have identified a couple of research questions that could inspire further complementing works.

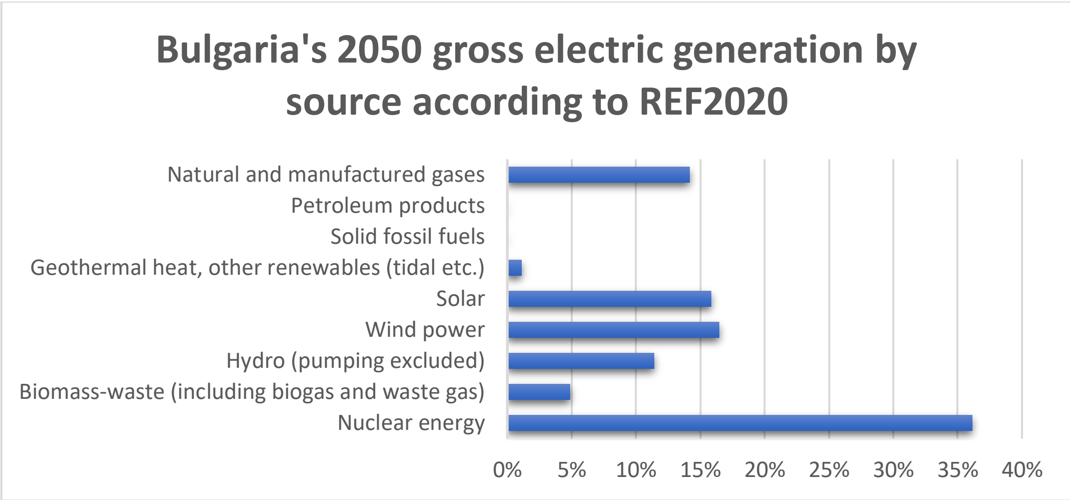
First, investigating the alternative assumption to the growthist paradigm we have used could be extremely relevant to compare the reformulation of Lovins' soft and hard energy paths in the 21$^{st}$ century:
- understanding what could make populations ready to radically change their lifestyle and provide a grass-root support to degrowth.
- solutions to build an energy system fitting degrowth and socially acceptable.

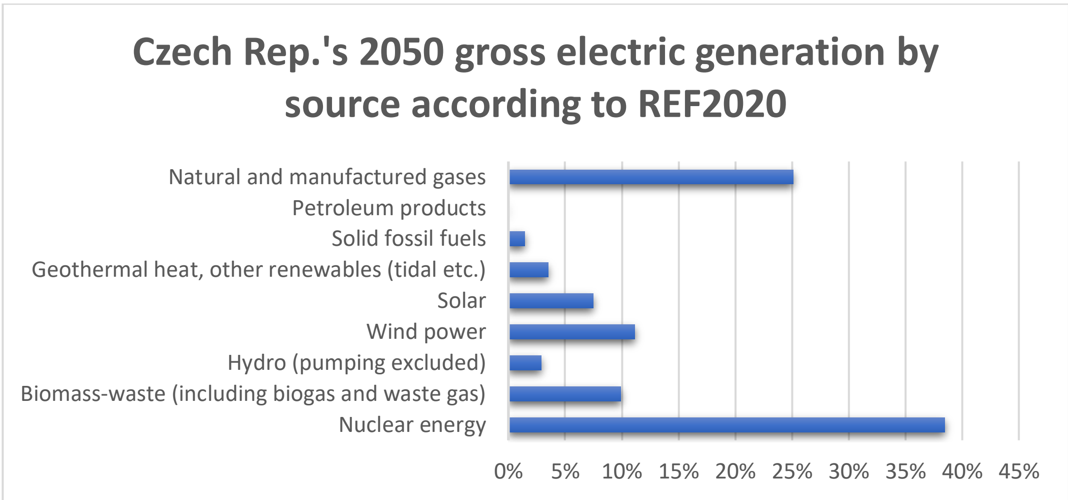
Second, sticking to our growthist paradigm, there are key issues that must be further explored, among which:
- the exact limits and potential of pink hydrogen.
- potential solutions to make uranium mining less polluting though keeping the low price of the commodity.
- the possibility to master and commercially deploy nuclear fusion in the foreseeable future.

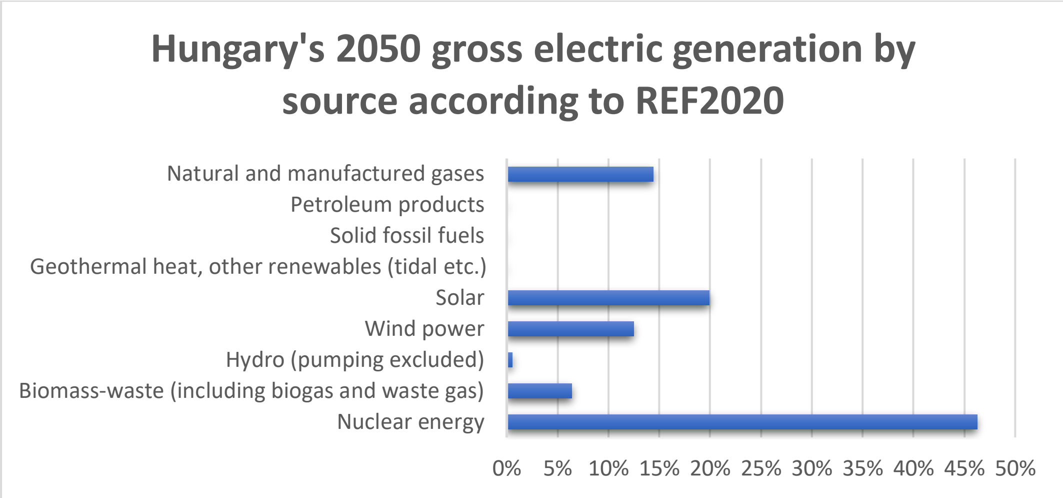
We firmly believe that investigating the implications and practical implementations of the energy transition will still be a thrilling matter of academic research in the coming years and warmly encourage both scholars and student to enrich this field!

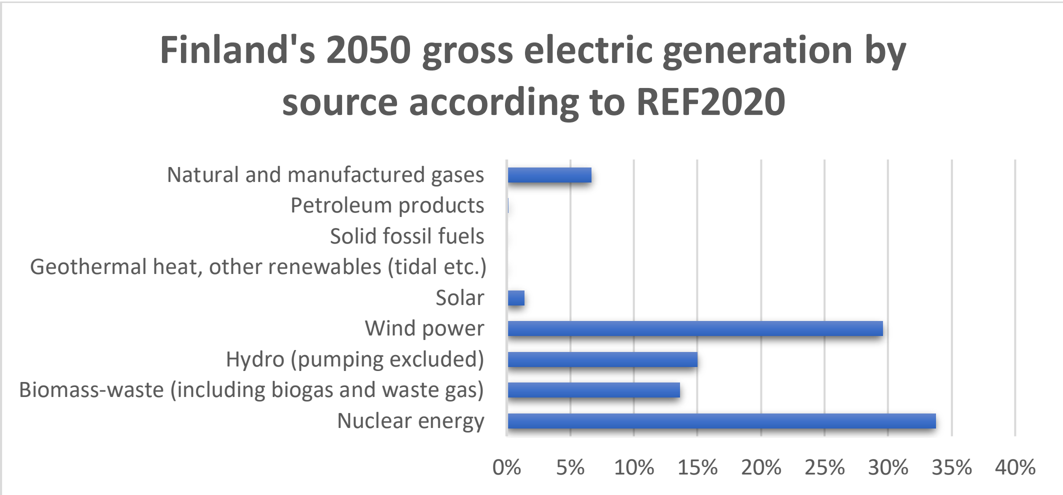
# Annex

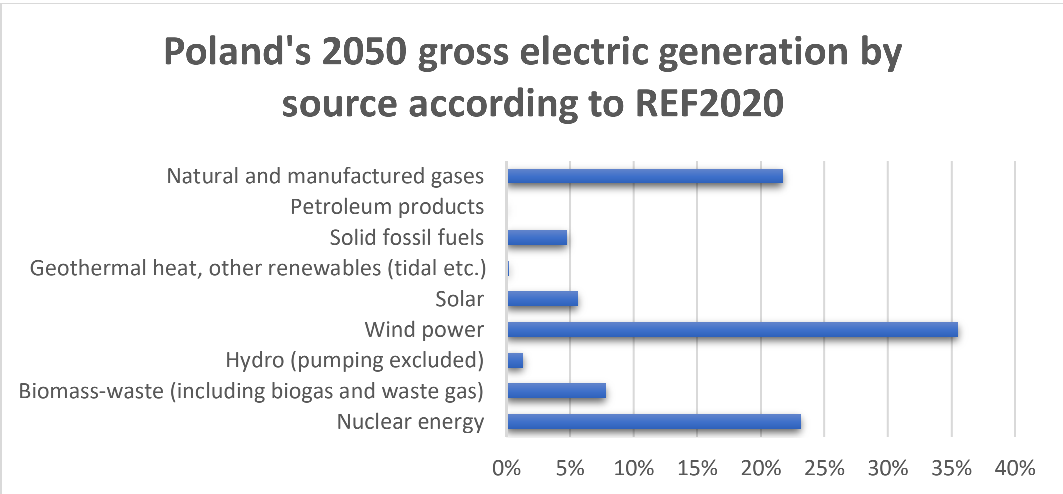
*Nota bene*: all the following graphs have been elaborated by the authr based on the REF2020 scenario.

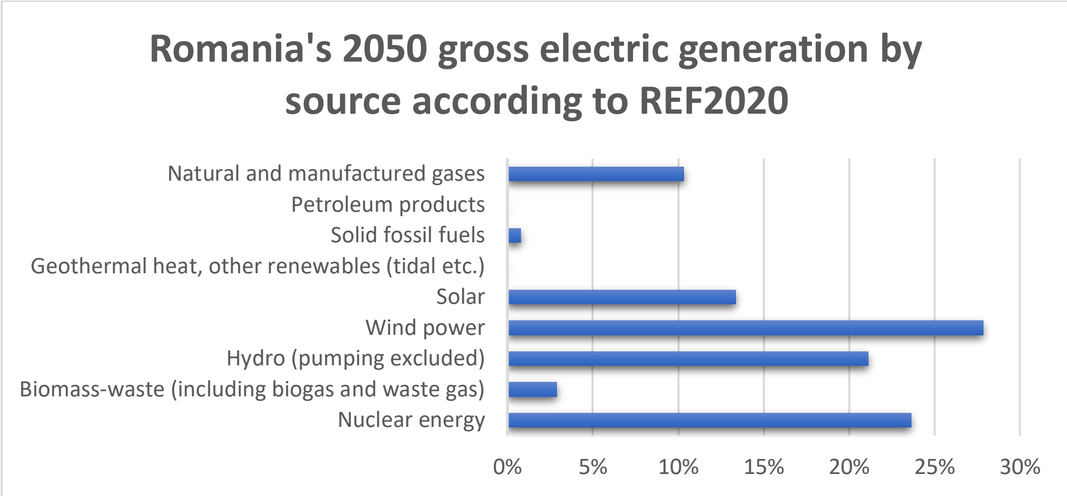


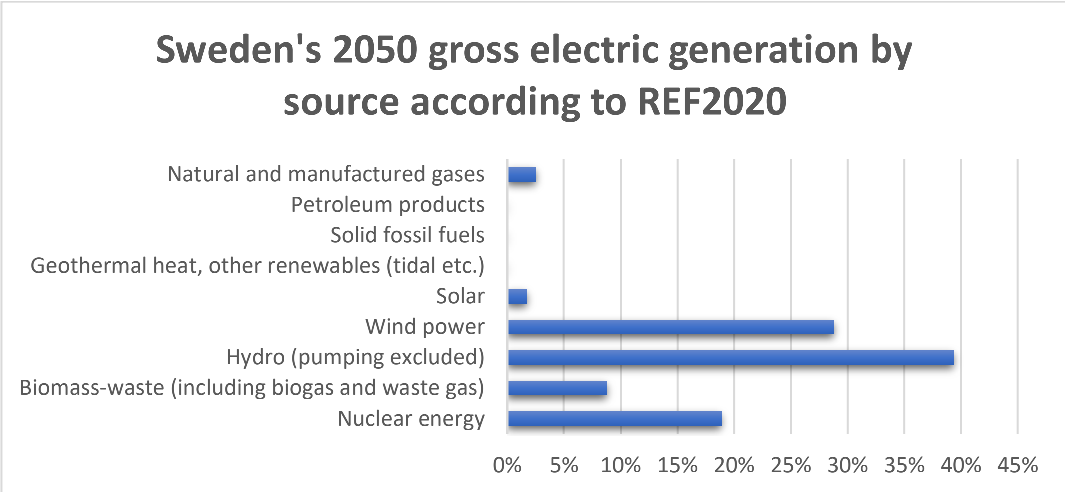



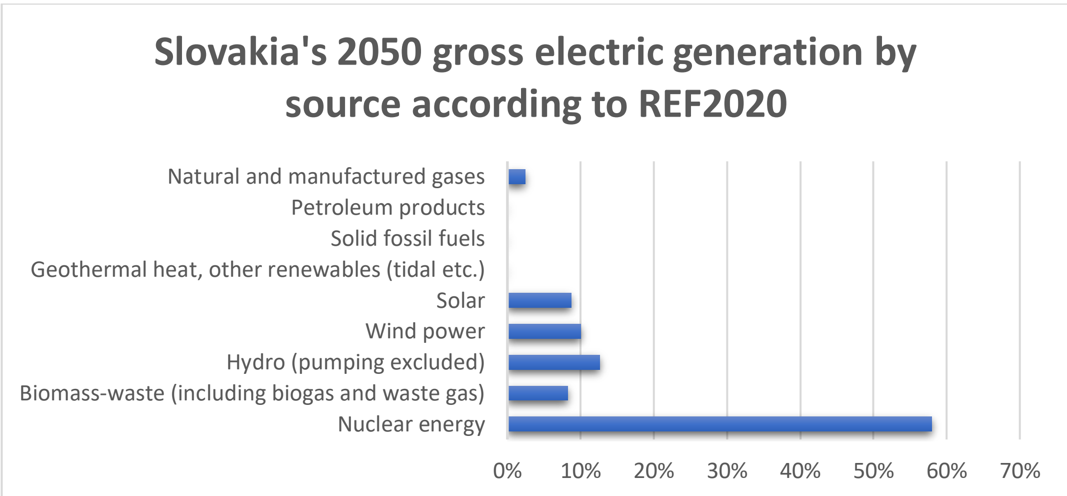

Hungary's 2050 gross electric generation by source according to REF2020
Natural and manufactured gases
Petroleum products
Solid fossil fuels
Geothermal heat, other renewables (tidal etc.)
Solar
Wind power
Hydro (pumping excluded)
Biomass-waste (including biogas and waste gas)
Nuclear energy
0% 5% 10% 15% 20% 25% 30% 35% 40% 45% 50%


Finland's 2050 gross electric generation by source according to REF2020
Natural and manufactured gases
Petroleum products
Solid fossil fuels
Geothermal heat, other renewables (tidal etc.)
Solar
Wind power
Hydro (pumping excluded)
Biomass-waste (including biogas and waste gas)
Nuclear energy
0% 5% 10% 15% 20% 25% 30% 35% 40%


Poland's 2050 gross electric generation by source according to REF2020
Natural and manufactured gases
Petroleum products
Solid fossil fuels
Geothermal heat, other renewables (tidal etc.)
Solar
Wind power
Hydro (pumping excluded)
Biomass-waste (including biogas and waste gas)
Nuclear energy
0% 5% 10% 15% 20% 25% 30% 35% 40%


Romania's 2050 gross electric generation by source according to REF2020
Natural and manufactured gases
Petroleum products
Solid fossil fuels
Geothermal heat, other renewables (tidal etc.)
Solar
Wind power
Hydro (pumping excluded)
Biomass-waste (including biogas and waste gas)
Nuclear energy
0% 5% 10% 15% 20% 25% 30%


Sweden's 2050 gross electric generation by source according to REF2020
Natural and manufactured gases
Petroleum products
Solid fossil fuels
Geothermal heat, other renewables (tidal etc.)
Solar
Wind power
Hydro (pumping excluded)
Biomass-waste (including biogas and waste gas)
Nuclear energy
0% 5% 10% 15% 20% 25% 30% 35% 40% 45%


Slovakia's 2050 gross electric generation by source according to REF2020
Natural and manufactured gases
Petroleum products
Solid fossil fuels
Geothermal heat, other renewables (tidal etc.)
Solar
Wind power
Hydro (pumping excluded)
Biomass-waste (including biogas and waste gas)
Nuclear energy
0% 10% 20% 30% 40% 50% 60% 70%

# Summary




This thesis addresses the sensitive question of inserting, or not, nuclear energy in the energy mix of interested member states of the European Union from political (high and low politics), financial and legal perspectives.

A priori, all low-carbon sources of electricity generation can help the European energy transition towards its 2050 net-zero-emissions goal. Nevertheless, nuclear electricity – though mastered since the half of the XX$^{th}$ century – is controversial both within nuclearized countries and at the international level. Its future in a low-carbon energy mix cannot be taken for granted.

Discursively, this thesis tries to provide a balanced argumentation in favor of the inclusion of nuclear electricity in future energy mixes in relation to two main goals. The first one is the drastic reduction of the greenhouse gas emissions of the European Union. The second one is the strategic opportunity offered by a specific energy source, or combination of energy sources, to favor the qualified European energy independence towards (unreliable) extra-EU suppliers.
In fact, the EU energy plan 'REPowerEU', launched in late 2022, has highlighted the international competition inherent to the energy transition which is not exclusively a question of physics, chemistry, and biology – dimensions that are well studied by the Intergovernmental Panel on Climate Change (IPCC) – but also of politics, law, and finance.
Pervasive energy matters affect the economy and any individual life. Therefore, when investigating a potential energy policy choice, we must adopt a perspective that encompasses its finality, and this is already a first political choice. In this thesis, we posit that the European energy transition is aimed at preserving the high living standard of EU citizens while cutting its carbon footprint. Our pro-nuclear argumentation stems from this premise. Consequently, most of the counterarguments we raise to discuss the future of nuclear energy implicitly or explicitly conjecture an alternative finality to the European energy transition, namely, economic degrowth and the relative political and social impacts. In comparison, the perspective we adopt is conservative.

*Nuclear (low carbon) electricity to secure high living standards*.

Hence, as explained in paragraph II.A.1., the hegemonic energy system of the future will be growth-oriented, centralized, and technocratic. We explain that the nuclear industry's feature fit such an energy system. Moreover, as pointed out in paragraph I.A.1. when assessing the German energy mix throughout the last few years, nuclear electricity is likely the least bad baseload dispatchable source of energy in terms of greenhouse gas emissions. However, this does not exempt the nuclear industry from the imperative of environmental exemplarity since the overall nuclear chain (especially upstream and downstream operations) harms the environment and human health (II.A.2.). Investments in nuclear security and the enforcement of relative measures are thus paramount and cannot be derogated. Yet, in comparison, also renewables can be framed as an environmental and sanitary threat, though to a lesser extent.

Indeed, a key tenet of this thesis is that no energy source is essentially virtuous. And, considering the respective drawbacks of the main low-carbon options (chiefly renewables, nuclear, and natural gas with carbon capture and storage technology) we argue in favor of a diversified energy mix rather than ideological '100%' renewables or nuclear scenarios.

It must also be said that – largely because of the growthist perspective we adopt – this thesis does not investigate in depth the potential of energy savings and fields where energy sobriety could become the norm. Of course, they are part of the energy transition, but our focus is the electricity generation abundantly required by energy-intensive sectors like industry and transport (II.A.1.). At smaller scales and for more modest energy needs, we support the establishment of energy communities fueled by renewables where it is suitable.

On the one hand, we acknowledge that nuclear electricity is not necessary everywhere. On the other hand, we have serious doubts regarding the capacity of renewables to efficiently supply the growing European demand for electricity, even with the support of battery-based storage systems – BSS – (I.B.1).

In fact, it appears, out of the German experience, that the leading European country in developing renewables has not decreased its consumption of fossil fuels. On the contrary, it is obvious that closing nuclear reactors and delegating the function of baseload dispatchable sources to thermoelectric plants (fueled either by natural gas or by coal and lignite) is not helping Germany in getting rid of fossil fuels (I.A.1.). Then, the high-tech alternative to thermo-electricity is storing electricity generated by renewables either in batteries or in green hydrogen (with a loss of energy). Yet, in this thesis, we point out that the alleged green feature of renewables turns grey when they are combined with lithium-ion batteries and alternative technologies that always require upstream mining and downstream partial recycling operations… as nuclear energy does (I.B.1). Opposing renewables to nuclear when considering the overall nuclear chain is misleading since, paradoxically, mining uranium (used to produce the nuclear fuel) often allows the parallel extraction of vanadium used in batteries aimed at storing the electricity generated by renewables. We, moreover, highlight that energy-supplying solutions offered by nuclear electricity (especially the Small Modular Reactors, SMRs) to the industry will also benefit the industries of solar panels, wind turbines, batteries, and their recycling factories (I.A.3.).

It is consequently the acknowledgment of nuclear and renewables' interdependence – on the one hand – and differences in terms of specific ores their respective industries require – on the other hand – that brings us to argue in favor of the combination of renewables and nuclear energy in hybrid energy systems. In fact, both are and will be highly ores-consuming, and – beyond the problem of the pollution inherent to their extraction – ores are available only in limited quantities in the world. Yet the energy transition is expected to be global and not merely European. It means that big traditional competitors (e.g., the United States of America) and emerging ones (e.g., the People's Republic of China and the Republic of India) will contribute to increasing the global demand and correlated competition for these resources. Recycling existing energy facilities is certainly a way to lighten the demand for fresh ores and must be supported. But we are skeptical regarding the actual capacity of covering the industrial demand through mere recycling (I.B.1.). Therefore, we stress the hedging potential of hybrid energy mixes including nuclear energy compared to alternative schemes.

*The more low-carbon energy sources, the better.*

Global competition for strategic ores and energy commodities is increasing and the trend will last. Natural gas, renewables, and nuclear are affected. Consequently, basing an energy system on a single source or even only two would be unsound. We believe that diversification is the future of energy systems. It certainly has a cost, but the cost of foreign energy dependence (e.g., on natural gas in the mid of the gas market's turmoil) has proven to be higher and a long-term cause of economic inflation. A country eager to develop a robust apparatus that provides a fair level of energy security should thus diversify enough its sources of energy supply not to be too affected in case of shortage (I.A.1. and I.B.1.). As highlighted in this thesis, the commodity shortage can have political causes, but, in the future, its origin could increasingly be environmental (II.B.)

It is therefore important to invest in long-term alternative technological solutions. We believe that the nuclear industry can provide satisfying empowered nuclear reactors, which technology could limit (ideally make irrelevant) the recourse to fresh uranium which is a finite resource increasingly targeted at the global scale because of the launch of ambitious nuclear programs worldwide. In fact, the fourth generation of nuclear reactors, for instance, fast-neutron reactors (FNRs) could be able to reuse already burnt nuclear fuel as well as mixed oxide fuel that allows the partial recycling of nuclear weapons (I.A.3). Their deployment, by 2050, could prevent the actual risk of uranium shortage and help the nuclear industry find internal means of diversification and thus efficiently hedge itself. Furthermore, the research and development of the 'perpetual dream' that is nuclear fusion – though uncertain and unlikely to be achieved during this century – must be financed to keep the hope of safely generating almost illimited energy.

Yet, always from the perspective of energy security and the ambition of developing qualified energy independence, we note that – beyond the myth cultivated by some politicians – the nuclear industry is well integrated within the global value chain (II.A.3.). Not least, we posit that the French and Hungarian connection with the Russian nuclear industry brought this two EU member states to obstruct potential EU sanctions against Russian nuclear actors. Consequently, the nuclear option is not the guarantee of national energy independence though it is also true that the dual use of nuclear energy (the military-civilian nexus) prohibits the transnational disclosure of some information and that nuclear is purchased way in advance (up to two years before its consumption) hence is less sensitive to the volatility of its spot price (II.B.2.). In this thesis, we suggest that acknowledging these global interdependencies and supporting transnational cooperation could help the development of the nuclear industry worldwide in terms of safety, and research and development of the fourth generation of nuclear reactors. The question of nuclear security is, in fact, both a domestic and international source of political tensions.

*Nuclear will always be controversial.*

In terms of political economy, nuclear energy technologically embodies a technocratic growthism. Citizens contrary to the centralization and elitization (because of the high level of expertise required to understand nuclear stakes) of their country's energy policy are likely to be anti-nuclear. In fact, waging a nuclear program is an irreversible choice because of the production of long-lived ionizing wastes. In addition, the continuous public commitment required by the good endeavor of the program cannot afford the discussions imposed by a democratic debate. As observed in France, the debate between anti and pro-nuclear is essentially polarized because the one who supports the national nuclear program knows that a 'stop and go' policy undermines the whole nuclear infrastructure and spoils already-made investments in this program whereas the anti-nuclear one deems that it has caused enough irreversible environmental harm, that it undermines investments in alternative energy sources (chiefly renewables) and that the opposition to the program is muted by a pro-nuclear State apparatus. And, indeed, the symbolic antinuclear political moves of closing ambitious research programs of fourth-generation reactors (Superphénix and Astrid) and closing an aging plant (Fessenheim) have satisfied none. As a matter of fact, anti-nuclear did not obtain the actual closing of the remaining 56 reactors and the end of the project of the deep geological repository while pro-nuclear observe that the symbolic decision has weakened the French nuclear industry by contributing to desperate nuclear workers and disincentivized young engineers to start a career in the nuclear industry. Hence, the long-term effect is that, though the French state did not withdraw its nuclear program as Germany did, the French nuclear industry has dramatically suffered from the loss of public support and investments – in addition to internal management failures – throughout the last two decades (II.A.4.). It is consequently uncertain – considering the time and cost overrun experienced in ongoing nuclear works (e.g., Flamanville 3 and Sizewell C) – whether the French industry will be able or not to be part of the energy transition. Our thesis, moreover, points out the volatility of public opinion toward the nuclear option and consequently supports the technocratic decision-making process rather than a more democratic procedure, even in Western democracies. Furthermore, in the case of France, the dual use of nuclear energy makes the energy policy tightly intertwined with the State's foreign policy and we acknowledge that these two realms largely escape a democratic decision-making process (II.A.1.).

The international dimension of nuclear security is the second crucial bone of contention related to nuclear energy. Indeed, beyond the military debate on the risk related to nuclear proliferation, even the civilian use of nuclear energy fuels geopolitical tensions in the post-Chornobyl era. In the European Union, the Austrian anti-nuclear judicial activism is the perfect illustration of this phenomenon. Yet, so far, Austrian claims against the European Commission (in cases involving Rosatom in Hungary and Électricité de France in the United Kingdom) have always failed to weaken the pro-nuclear European jurisprudence that enjoys the legal support of the Euratom Treaty (I.B.2.). The Republic of Austria is certainly the most extreme example of State anti-nuclearism in the European Union, but softer forms of this doctrine appear at the political level. In fact, it is a hard task for France to build a pro-nuclear coalition to lobby in favor of the nuclear option before EU institutions while Western EU member states are all phasing out their nuclear program. The cross-border risk of ionizing contamination explains non-nuclearized states' reluctance to let their neighbor build and operate nuclear power plants.

*The French self-interest in promoting nuclear energy.*

The French Republic is the leading EU member state in backing pro-nuclear European policies and regulations. Statistically, it is and is expected to remain the most nuclearized State of the European Union. Politically, it is also the State that has initiated a coalition building, first in early the 2000s and, ultimately, at the occasion of the talks upon the EU green taxonomy to promote the inclusion of nuclear energy in key supranational energy strategies.

France, because of the Gaullist legacy, historically fosters energy independence through nuclear energy. The national doctrine promotes its dual use – France is, with the UK, the only European country able to resort to nuclear deterrence in its international relations – and is favorable to a wide civilian proliferation since France has, for long, been an exporter of nuclear technologies that constitute a strong trade landmark when opening a commercial relationship with a new partner country. The country has moreover built a strong commercial relationship with Japan in trading and shipping mixed oxide fuel (II.A.3.). In this thesis, we notably point out the institutionalization of this commercial strategy in the 2010s through the establishment of the *Agence France Nucléaire International* (AFNI) and the trading role played successively by the *Commissariat à l'Énergie Atomique* (CEA) and Areva (I.B.3.).

The very specific French relation to nuclear energy and nuclear technologies can explain the public scheme envisaged to finance the next French nuclear program.

*Financing a huge CAPEX.*

The capital expenditure of nuclear power plants is high, and time and cost overruns in the delivery of AP-100 (in the US) and European Pressurized Reactors (in Europe) worsen this financial feature. Nuclear supporters object that such overruns are normal for first-of-a-kind (FOAK) reactors and that the investment and insights learned from the ongoing works will facilitate the building of the reactors of the same series. In this thesis, we introduce the various costs inherent to a nuclear program (capital expenditure, operating and maintenance, and external costs) and discuss the potential financial schemes that could support the investment required (I.A.2.). Before anything else, we highlight that the energy transition could revolutionize the investment framework established by the Energy Charter Treaty (ECT) in the

1990s and explain that the European green taxonomy is not substituting ECT. Hence, States that are a member of ECT will either have to comply with the conditions enshrined in this treaty or find a multilateral agreement to amend it. We, furthermore, qualify the supranational power that could enjoy the European Union in determining the kind of investment framework that a pro-nuclear EU member state could choose to finance its national nuclear program.

In Europe, France, and the United Kingdom – though not an EU member state anymore – represents two ideal types. France, on the one hand, will not hesitate to mobilize public funds and savings of French bank accounts (*Livret A*); whereas the United Kingdom, on the other hand, could privilege softer forms of public intervention like the Regulatory Asset Base (RAB) or Contracts for Difference (CFD). We notably explain why the French strategy to comply with EU law on the liberalization of the electricity market, though protecting the quasi-monopoly of its State-owned enterprise EDF, limits its capacity to recourse to CFD.

We, moreover, remember that, in case of a nuclear accident, the State must pay. Hence, from financing the CAPEX of nuclear plants to insuring the nuclear program against calamity, the environmental and sanitary threat posed by nuclear fission must be comprehended.

*Nuclear fission's environmental and sanitary drawbacks.*

Chornobyl is the most prominent nuclear accident and precedent frequently used to advocate against nuclear programs. Far from denying the environmental and sanitary harms caused by nuclear programs, from their upstream (mining) to downstream (managing nuclear wastes) operations, this thesis reminds us that the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is unable to determine a threshold of exposure to ionizing radiation from which you can be certain that cancer (often thyroidal cancers) is due to artificial nuclear activity. Moreover, nuclear security measures in case of an accident such as the evacuation of the population nearby is a traumatizing event that can have heavy psychosomatic effects (II.A.2.).

This risk strengthens the doubts regarding the capacity of the nuclear industry to adapt to climate change.

*The nuclear industry facing climate change.*

Climate change is a multicausal and multidimensional phenomenon that will put essential resources (e.g., water) at risk in regions of the world while increasing the occurrence of environmental disasters in unexpected areas. It is expected that by overcoming certain physical limits of Earth, climate change will completely escape any form of control and human life on Earth will turn harder if not impossible. All speculative such an output can be, it is likely to weaken our growthist perspective. Indeed, how could we maintain the current high living standard without the essential environmental conditions and resources to achieve it? The asset of the nuclear option is, in this context, that it is truly a low-carbon source of energy, and it consequently only marginally contributes to the accumulation of carbon dioxide and methane that could cause the extinction of humankind after large shares of known biodiversity. Its main drawback, however, is the fear that, in five decades (the lifespan of a nuclear program), the environment where nuclear power plants would have been built will not be stable enough to guarantee the safe use of nuclear power plants. Water is already identified as a key parameter since water scarcity will affect the availability of this resource to be heated hence permitting nuclear electricity generation and cooling future nuclear reactors. More uncertain worries concern, for instance, the potential seismicity of certain areas. Building nuclear power plants along the seas and oceans to avoid water scarcity would, then, turn risky if a tsunami occurs where it was not expected or with an unforeseen intensity (II.B.1.).

Besides, in a growingly competitive world (II.B.2.), the return of international (high-intensity) wars raises concerns about the security of nuclear power plants. Reasoning on the recent examples of Zaporizhzhia in Ukraine and Natanz in Iran, this thesis discusses the risk of a civilian nuclear power plant being targeted during a war based on combined theories of International Relations. Our conclusion is that the risk inherent to international wars is low but that infra-state actors like terrorist groups should be carefully monitored (II.B.3).

**Conclusion**

Answering the question "To what extent can nuclear energy help achieve the EU's decarbonation and energy independence goals?**"**, this thesis supports the insertion of nuclear energy in future hybrid energy systems and its consequent labeling as an 'energy of the future' in Europe.

We acknowledge that the issue is more a matter of persuasion than a technical assessment. Indeed, several times in this thesis, we conclude that politics must decide to choose or reject a specific option in a complex political, environmental, and economic situation. Overall, the debate systematically stands between nuclear optimism and nuclear pessimism.

We, moreover, identify two crucial comparative assets of nuclear energy to support the nuclear option: on the one hand, nuclear has a great potential to cut the European power generation mix's $CO_2$ emissions; on the other hand, adding nuclear power generation to the European mix will have hedging benefits in terms of energy security in a highly competitive world.

*Low-carbon electricity for the energy transition.*

First, nuclear energy can favor the low-carbon electrification required by the energy transition and maintain high living standards. Our preliminary assumption is that both populations and governments will seek to preserve a relatively high living standard and, thus, maintain a growth-oriented economic system. If, conversely, populations were ready to accept the implications of economic degrowth – that allows strong energy sobriety – the reasoning we develop in this thesis would be irrelevant.

Hence, we build a pro-nuclear argumentation positing that citizens' and governments' preferences impose a dominant centralized, technocratic, and growth-oriented energy system. In this system, nuclear fission[66] – as a low-carbon baseload dispatchable source of energy – will complement the deep penetration of renewables in the European power grid and lighten the need for battery energy storage systems. In fact, taking into consideration the whole cycle and value chain of both nuclear energy and renewable energies, no energy source is essentially 'clean'. But complementing renewables with nuclear energy could avoid the resort to more polluting baseload dispatchable solutions (natural gas or even coal) as well as reducing the demand for raw materials present in batteries.

Moreover, bearing in mind that the overall energy transition requires unprecedented investments, we identify sustainable financial solutions for funding incoming nuclear programs. We, furthermore, introduce a series of technological improvements that could be achieved in the short or medium term by the nuclear industry and improve its resilience, notably in front of the risk of fuel shortage, and reduce the quantity of ionizing nuclear wastes (and inherent downstream problems).

[66] *And maybe nuclear fusion in an uncertain future.*

Nonetheless, we make clear that the nuclear option has environmental and sanitary drawbacks that require exemplarity from both governments and nuclear companies. In addition, the exact mid-long-term implications of climate change on the physical environment that will welcome the nuclear reactors of tomorrow are uncertain. Therefore, the nuclear industry must propose solutions for operating these reactors in a flexible way. In other words, the nuclear reactors of the future should be operated not as a baseload source anymore but in a load-following manner. And this could increase the cost and the frequency of their maintenance. Yet, it is the *sine qua non* condition for them to be part of future hybrid energy systems. We posit that pink hydrogen could facilitate this flexibility, but this topic should be further investigated.

The virtues of complementing future hybrid energy systems are not only environmental. In fact, the second key comparative advantage of the nuclear option is its current and prospective benefits to energy security.

*Diversifying the power generation mix to strengthen energy security.*

Among the insights of this thesis, we note that the energy world is getting less Western-centric and that, subsequently, the competition for essential resources is increasing. In this new context, energy hedging is not an option anymore, but a proper necessity.

It is consequently counter-productive to reason in terms of the '100% renewables' or '100% nuclear' scenario. The more low-carbon energy sources the better. Furthermore, climatic pressures and the economic development of new giant markets like India and China will make a race out of any energy commodity or relevant ore. Recycling more is, of course, part of the solution. Yet, through the example of the renewables industry, we have shown that it is, for now, rather a non-performative slogan and that the practical recycling solutions will have their own health and environmental drawbacks.

Thus, energy hedging will be the key, and – as proven by the European jurisprudence – it cannot afford parochial judicial battles between EU member states to prevent the neighbor from developing a low-carbon source of energy. Accordingly, it will tighten the nexus between foreign policy and energy policy – two sectors that escape democratic decision-making. We defend, in this sense, the technocratic feature of energy policymaking.

However, we also point out that the nuclear industry is more integrated into the global value chain than many pro-nuclear politicians assert. It is thus doubtful to frame nuclear electricity as the absolute guarantee of national energy security. On the contrary, like all other technology, nuclear fission requires international trade of raw materials, technological transfers, and – growingly in the declining Western nuclear industry – the resort to foreign skilled nuclear workers. Yet, the fundamental civilian-military nexus in several nuclearized countries make curb transnational nuclear cooperation and strengthen the nationalist rhetoric. But the nuclear industry's history teaches that the economic imperative can moderate even the most determined nationalists.

This thesis brings a multidisciplinary insight into the multidimensional stakes related to the European energy transition. We point out that local issues have global resonance and vice-versa. Furthermore, beyond the well-known 'not in my backyard' issue of public opinion, this work highlights that nuclear energy is at the crossroad of long-term environmental, techno-industrial, financial, judicial, and diplomatic stakes often ignored by citizens.

Eventually, we identify a couple of research questions that could inspire further complementing works.

First, investigating the alternative assumption to the growthist paradigm we use could be extremely relevant to compare the reformulation of Lovins' soft and hard energy paths in the 21st century:
- understanding what could make populations ready to radically change their lifestyle and provide grass-root support to degrowth.
- solutions to build an energy system fitting degrowth and socially acceptable.

Second, sticking to our growthist paradigm, there are key issues that must be further explored, among which:
- the exact limits and potential of pink hydrogen.
- potential solutions to make uranium mining less polluting though keeping the low price of the commodity.
- the possibility to master and commercially deploy nuclear fusion in the foreseeable future.

We firmly believe that investigating the implications and practical implementations of the energy transition will still be a thrilling matter of academic research in the coming years and warmly encourage both scholars and students to enrich this field!

# Sources


Épaulard, A., & Gallon, S. (2001). La valorisation du projet nucléaire EPR par la méthode des options réelles. *Économie & prévision*(149), 29-50.

AFIS. (2021, March 22). *Le nuage de Tchernobyl qui s'arrête à la frontière : une fable sans cesse réitérée*. Retrieved April 2023, from afis.org: https://www.afis.org/Le-nuage-de-Tchernobyl-qui-s-arrete-a-la-frontiere-une-fable-sans-cesse

AFP. (2022, November 2022). *Projet nucléaire: la Roumanie obtient un financement de Washington*. Retrieved from energynews.pro: https://energynews.pro/projet-nucleaire-la-roumanie-obtient-un-financement-de-washington/

Alexandrowicz, L. (2022, August 27). *La Hongrie va ajouter deux nouveaux réacteurs à sa centrale nucléaire, avec l'aide de la Russie*. Retrieved from euronews.com: https://fr.euronews.com/2022/08/27/la-hongrie-va-ajouter-deux-nouveaux-reacteurs-a-sa-centrale-nucleaire-avec-laide-de-la-rus

Alisson, G. (1999). *Essence of Decision: Explaining the Cuban Missile Crisis.* London: Longman.

Alunaimi, R., & Khuwaileh, B. (2022). Nuclear design of an integrated small modular reactor based on the APR-1400 for RO desalination purposes. *Nuclear Science and Techniques, 33*.
André, J. (2022, December). Travaux forcés sous le solaire chinois. *Le Point - Hors-Série*(7), pp. 59-62.
ANSSI. (2020). *Recommendations sur la sécurisation des systèmes de contrôle d'accès physique et de vidéoprotection.* ANSSI.
Appelqvist, Ö. (2008). Deux voies politiques vers le plein-emploi et deux modèles sociaux : France - Suède (1944-1948). *La Revue de l'IRES, I*(56), 61-93.
Arndt, A., & Horovitz, L. (2022). *Nuclear rhetoric and escalation management in Russia's war against Ukraine: A Chronology.* German Institute for international and Security Affairs, Research division International Security . Berlin: German Institute for international and Security Affairs.
Arte. (2022). *L'énergie nucléaire, civile et militaire, au cœur du conflit russo-ukrainien*. Retrieved December 2022, from arte.tv: https://www.arte.tv/fr/videos/107710-262-A/l-energie-nucleaire-civile-et-militaire-au-coeur-du-conflit-russo-ukrainien/
Aykut, S. C., & Dahan, A. (2022). Boomerang géopolitique : peut-on encore relever le défi climatique global ? *GREEN*, 34-42.
Baillot, L. (1973, January 24). Séance du Vendredi 23 Novembre 1973. *JO de la République française - débats parlementaires*(97), 6340-6341.
Banque de France. (2022, October 28). *The three faces of France's international trade*. Retrieved April 2023, from blocnotesdeleco.banque-france.fr: https://blocnotesdeleco.banque-france.fr/en/blog-entry/three-faces-frances-international-trade
Barbarino, M. (2020). A brief history of nuclear fusion. *Nature Physics*(16), 890-893.
Barbe, A. (1990). LWR fuel reprocessing in France. *Atomwirtschaft, Atomtechnik, XXXV*(8/9), 433-435. Retrieved from iaea.org: https://inis.iaea.org/search/searchsinglerecord.aspx?recordsFor=SingleRecord&RN=21090717
BBC. (2012, July 24). *Stuxnet thwarted by control code update*. Retrieved April 2023, from bbc.com: https://www.bbc.com/news/technology-18968233
BBC. (2017, April 28). Niger 'cleared' over Areva uranium deal. *BBC* .
Béhar, C. (2014). *Les réacteurs nucléaires à caloporteur sodium* . Le Moniteur.
Belyi, A. (2009). *Russia-Ukraine Gas Dispute: Soft and Hard Security Issues - A View from Russia.* Retrieved March 2023, from ogel.org: https://www.ogel.org/article.asp?key=2877
Bembaron, E. (2023, March 3). Relance du nucléaire: Framatome mise sur Le Creusot. *Le Figaro*.
Beutier, D. (2017). *Calcul des emplois de la filière nucléaire par région.* Société Française d'Enegie Nucléaire (SFEN).
Bianchi, A. (2021, May 6). Nucleare, l'Austria spinge per la riforma dell'Euratom. *Euractiv*.
BMKW. (2023, February 1). *Sichere Versorgung mit Strom bis Ende des Jahrzehnts gewährleistet* . Retrieved from bmwk.de:
Birnbaum, P. (1984). *Dimensions du pouvoir.* Paris: Presses Universitaires de France.
Birraux, C. (1994). *Rapport sur le contrôle et la sûreté des installations nucléaires.* Paris: Assemblée nationale.

Bloomberg Finance LP. (2016, February). *The rise of electric cars*. Retrieved February 2023, from bloomberg.com: https://www.bloomberg.com/features/2016-ev-oil-crisis/img/ev-sales.jpg

https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2023/02/20230201-sichere-versorgung-mit-strom-bis-ende-des-jahrzehnts-gewahrleistet.html?view=renderNewsletterHtml

Bocquet, M. (2022, December 30). *Nucléaire: la Bulgarie signe un accord inédit avec Framatome pour s'affranchir du combustible russe*. Retrieved from bfmtv.com: https://www.bfmtv.com/economie/entreprises/energie/nucleaire-la-bulgarie-signe-un-accord-inedit-avec-framatome-pour-s-affranchir-du-combustible-russe_AV-202212300282.html

Borunda, A. (2020, February 19). Natural gas is a much 'dirtier' energy source than we thought. *National Geographic*.

Bouchet, C. (2014, April). Traitement des lixiviats: des affluents complexes qui nécessitent un traitement poussé. *L'eau, l'industrie, les nuisances*(Editions Johanet).

Bouckaert, L. (2022, April 13). *Les prix de l'uranium ont déjà augmenté de 50% cette année: « Ils vont continuer à augmenter »*. Retrieved from fr.businessam.be: https://fr.businessam.be/les-prix-de-luranium-ont-deja-augmente-de-50-cette-annee-ils-vont-continuer-a-augmenter/

Bougherara, N. (2006). *Les rapports franco-allemands à l'épreuve de la question algérienne (1955-1963).* Peter Lang.

Bourgeois, I. (2012, April 17). Énergie : la bronca des milieux économiques. *Regards sur l'économie allemande*(104), pp. 31-32.

Bourgery-Gonse, T. (2023, March 9). Germany 'not opposed' to nuclear-made hydrogen, says will import from France. *Euractiv*.

Bouttes, J.-P. (2022). Les déchets nucléaires, talon d'Achille ou atout du nucléaire civil ? *Revue Progressistes*(36).

Breteau, P. (2022, January 24). L'indépendance énergétique de la France grâce au nucléaire : un tour de passe-passe statistique. *Le Monde*.

Bretesché, S., & Ponnet, M. (2013). 2013/1 Le risque environnemental entre oubli et gestion du passé : le cas d'une ancienne mine d'uranium française. *Annales des Mines - Gérer et comprendre*(111), 15-24.

Britz, C. (2022, April 28). Ulstein veut réintroduire le nucléaire dans la construction navale civile. *Mer et Marine*.

Brugère, D. (2014). Industrie de souveraineté et diplomatie d'entreprise. *Géoéconomie, V*(72), 197-205.

Buccholz, S., Ricotti, M., & Martin, O. (2020). *Improved safety features of LW-SMR, WP 1: Identification of improved safety features of LW-SMRs.* Euratom.

Bueno de Mesquita, B. (1980, December). An Expected Utility Theory of international Conflict. *The American Political Science Review*(74), 917-931.

Bulkeley, H., & Kern, K. (2006, November). Local Government and the Governing of Climate Change in Germany and the UK. *Urban Studies, 43*(12), pp. 2237– 2259.

Buongiorno, J. (2018). *The Future of Nuclear Energy in a Carbon-Constrained World.* Massachusetts Institute of Technology.

Bunn, M., Fetter, S., Holdren, J. P., & van der Zwaan, B. (2003). *The Economics of Reprocessing Vs. Direct Disposal of Spent Nuclear Fuel.* Cambridge: Harvard University.

Burbi, M. (2023). *Nucleare in zona sismica? La lezione di Fukushima*. Retrieved March 2023, from nucleareeragione.org: https://nucleareeragione.org/2023/02/20/nucleare-in-zona-sismica-la-lezione-di-fukushima/

Campbell, M. (2022, November 21). *In pictures: South America's 'lithium fields' reveal the dark side of our electric future*. Retrieved March 2023, from euronews.com: https://www.euronews.com/green/2022/02/01/south-america-s-lithium-fields-reveal-the-dark-side-of-our-electric-future

Caretta, M., Mukherji, A., & Arfanuzzaman, M. (2022). Water. In H.-O. Pörtner, & D. Roberts, *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 551-712). Cambridge University Press.

Carr, E. (2016 [1939]). *The Twenty Years' Crisis: 1919–1939: An Introduction to the Study of International Relations.* Palgrave Macmillan.

Caurant, D., & Majérus, O. (2021). Glasses and Glass-Ceramics for Nuclear Waste Immobilization. *Encyclopedia of Materials: Technical Ceramics and Glasses, II*, 762-66.

Catino, F. (2013). L'illusione del nucleare. *Contributo italiano alla storia del pensiero , Tecnologia e industria*.

CCIS. (2016, May 17). *The Cyber Threat to Nuclear Facilities*. Retrieved April 2023, from csis.org: https://www.csis.org/analysis/cyber-threat-nuclear-facilities

CEA. (2021, January 6). *Réacteurs de quatrième génération*. Retrieved March 2023, from cea.fr: https://www.cea.fr/Pages/domaines-recherche/energies/energie-nucleaire/reacteurs-nucleaires-futur.aspx?Type=Chapitre&numero=2

Chailleux, S., & Hourcade, R. (2021). Introduction. Politiques locales de l'énergie : un renouveau sous contraintes. *Natures Sciences Sociétés, XXIX*, 3-12.

Chailleux, S., Smith, A., & Compagnon, D. (2022, April 11). *Projets d'énergies renouvelables : à quoi servent vraiment les débats publics ?* Retrieved from theconversation.com: https://theconversation.com/projets-denergies-renouvelables-a-quoi-servent-vraiment-les-debats-publics-179213

Chateauraynaud, F. (2011). Sociologie argumentative et dynamique des controverses : l'exemple de l'argument climatique dans la relance de l'énergie nucléaire en Europe. *A contrario*(16), pp. 131-150.

Chenoweth, W. (1981). The uranium-vanadium deposits of the Uravan Mineral Belt and adjacent areas, Colorado and Utah. In R. Epis, & J. Callender, *New Mexico Geological Society Fall Field Conference Guidebook - 32 Western Slope (Western Colorado an Eastern Utah)* (pp. 165-170). Rudy C. Epis & Jonathan F. Callender, eds.

Chodorge, S. (2019, September 2). Comment le gouvernement justifie l'arrêt du projet nucléaire Astrid. *L'Usine Nouvelle*.

Chu, J., & Recchia, S. (2022). Does Public Opinion Affect the Preferences of Foreign Policy Leaders? Experimental Evidence from the UK Parliament. *Journal of Politics, LXXXIV*(3).

Clavier, H. (2023, February 17). *Pourquoi EDF continue de s'endetter ?* Retrieved March 2023, from publicsenat.fr: https://www.publicsenat.fr/article/politique/pourquoi-edf-continue-a-s-endetter-236789

Cléro, E., & Leuraud, K. (2021). Conséquences sanitaires 35 ans et 10 ans après les accidents nucléaires de Tchernobyl et de Fukushima. *Environnement, Risques & Santé, XX*(6), 525-534.

Coban, M. (2020). Diffuse interest groups and the regulatory policy change: financial consumer protection in Turkey. *Interest Groups & Advocacy, IX*, 220-243.
Codaccioni, V. (2021). Les façades institutionnelles : ce que montrent les apparences des institutions. *Sociétés contemporaines, IV*(88), 5-15.
Cognasse, O. (2021, December 28). La 'villa radioactive' de Ganagobie, un chantier de vingt ans pour décontaminer un laboratoire travaillant dans l'illégalité la plus complète. *L'Usine Nouvelle*.
Coldefy, A. (2015). Le nucléaire militaire : hier, aujourd'hui, demain. *Revue Défense Nationale*(782), 9-11.
Commission nationale du débat public. (2020). *Compte rendu et bilan du débat sur le PNGMDR -Synthèse 1 - Monorecyclage*. Retrieved March 2023, from pngmdr.debatpublic.fr: https://pngmdr.debatpublic.fr/17-synthese/7-synthese-1-monorecyclage
Commission de régulation de l'énergie. (2023, January 26). *Présentation des réseaux d'éléctricité*. Retrieved February 2023, from cre.fr: https://www.cre.fr/Electricite/Reseaux-d-electricite/presentation-des-reseaux-d-electricite
Cornell Law School. (2021, August). *Shall*. Retrieved April 2023, from Legal Information Institute: https://www.law.cornell.edu/wex/shall
Council of the European Union. (2014). *Council Directive 2014/87/Euratom of 8 July 2014 amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations.* Brussels: Council of the European Union.
Cour des comptes. (2019). *L'aval du cycle du combustible nucléaire - Les matières et les déchets radioactifs, de la sortie du réacteur au stockage* . Paris: Cour des comptes.
Cour des comptes. (2021). *L'analyse des coûts du sytème de production électrique en France.* Paris: Cour des comptes.
Crampes, C., & Léautier, T.-O. (2016, July 29). *Financing French nuclear power in France and overseas*. Retrieved January 2023, from eui.eu: https://fsr.eui.eu/nuclear-power-france-overseas/
CURIA. (2020). *Judgment of the Court (Grand Chamber) In Case C-594/18P*. Luxembourg: Cour of Justice of the European Union .
CURIA. (2022, November 30). *Press release No 192/22*. Retrieved January 2023, from curia.europa.eu: https://curia.europa.eu/jcms/upload/docs/application/pdf/2022-11/cp220192en.pdf
Davasse, G. (2022, August 5). *Nuclear and gas inclusion in the taxonomy creates a "between in and out"*. Retrieved from natixis.com: https://gsh.cib.natixis.com/our-center-of-expertise/articles/nuclear-and-gas-inclusion-in-the-taxonomy-creates-a-between-in-and-out
Davydova, A. (2021, November 24). Will Russia ever leave fossil fuels behind? *BBC*.
de Montesquiou, A. (2000). *L'énergie nucléaire en Europe : union ou confusion ?* Sénat. Paris: Sénat.
Da Sois, J. (2023, March 12). Le nucléaire français est-il vraiement "sous emprise" de la Russie, comme l'affirme Greenpeace ? *Le Figaro*.
de la Esperanza Mata Pérez, M., & al., e. (2019, November). The multi-speed energy transition in Europe: Opportunities and challenges for EU energy security. *Energy Strategy Reviews, XXVI*.
De Monicault, F. (2016, December 23). Nucléaire: les clés du redémarrage d'une centrale. *Le Figaro* .

de Montesquiou, A. (2000). *L'énergie nucléaire en Europe : union ou confusion ?* Sénat. Paris: Sénat.
De Vita, A., Capros, P., & Paroussos, L. (2021). *EU reference scenario 2020 : energy, transport and GHG emissions : trends to 2050.* European Commission, Directorate-General for Climate Action, Directorate-General for Energy, Directorate-General for Mobility and Transport. Publications Office.
Debizet, G., & Pappalardo, M. (2021). Communautés énergétiques locales, coopératives citoyennes et autoconsommation collective : formes et trajectoires en France. *Flux*(126), 1-13.
Debré, M., & Foyer, J. (1961). *Projet de loi n°226.* Paris: Sénat de la République française.
Debré, M. (1974, January 24). Energie nucléaire (fabrication des cuves nucléaires). *JO République française - Débats parlementaires* (5), p. 389.
Delanglade, S. (1997, January 30). Fissure au corps des Mines. *L'Express*.
DG Trade - EU Commission. (2022, June 24). *Agreement in principle reached on Modernised Energy Charter Treaty*. Retrieved from policy.trade.ec.europa.eu: https://policy.trade.ec.europa.eu/news/agreement-principle-reached-modernised-energy-charter-treaty-2022-06-24_en
Dimistrina, R. (2022, June 6). *The weaponisation of energy and Europe's way out*. Consulté le December 2022, sur ips-journal.eu: https://www.ips-journal.eu/topics/economy-and-ecology/the-weaponization-of-energy-and-europes-way-out-5979/
Dür, A., & Mateo Gonzàlez, G. (2014, May). Public Opinion and Interest Group Influence: How Citizen Groups Derailed the Anti-Counterfeiting Trade Agreement. *Journal of European Public Policy*, 1-27.
E3-Modelling. (2021). Technology assumptions - Power & Heat. *REF2020 scenario*.
EDF. (2020, October 29). *EDF réajuste le coût du programme Grand Carénage.* Retrieved November 2022, from edf.fr: https://www.edf.fr/sites/groupe/files/contrib/groupe-edf/espaces-dedies/espace-medias/cp/2020/2020-10-29-cp-certifie_edf-reajuste-le-cout-du-programme-grand-carenage.pdf
EDF. (2021, December 9). *Jaitapur Nuclear Power Plant*. Retrieved December 2022, from india.edf.com: https://india.edf.com/en/jaitapur-nuclear-power-plant
EDF. (2023). *Le MOX*. Retrieved Februrary 2023, from edf.fr: https://www.edf.fr/groupe-edf/espaces-dedies/l-energie-de-a-a-z/tout-sur-l-energie/produire-de-l-electricite/le-mox
EDF. (2023). *Le nucléaire en chiffres*. Retrieved February 2023, from edf.fr: https://www.edf.fr/groupe-edf/espaces-dedies/l-energie-de-a-a-z/tout-sur-l-energie/produire-de-l-electricite/le-nucleaire-en-chiffres
EDF. (2023, January 13). *EDF reinforces its nuclear offer to Poland and signs with Respect Energy a specific Exclusive Cooperation Agreement for the development of nuclear power projects in Poland based on NUWARD™ SMR technology*. Retrieved March 2023, from edf.fr: https://www.edf.fr/sites/groupe/files/epresspack/4541/PR_EDF-signs-with-Respect-Energy-an-Exclusive-Cooperation-Agreement_.pdf
EDF. (2023, February 28). *Structure du capital*. Retrieved March 2023, from edf.fr: https://www.edf.fr/groupe-edf/espaces-dedies/investisseurs-actionnaires/l-action-edf/structure-du-capital
Edison. (2023, March 6). *EDF, Edison, Ansaldo Energia e Ansaldo Nucleare annunciano di aver firmato una Lettera di Intenti (LOI) per lo sviluppo del nuovo nucleare*. Retrieved March 2023, from edison.it:

https://www.edison.it/sites/default/files/documents/CS_LOI%20EdF%20Edison%20Ansaldo_6%20marzo23%20ITA%20def_0.pdf
Enault, M. (2022, September 17). Sondage. 75% des Français se disent favorables au nucléaire. *Le Journal du Dimanche*.
ENEL. (2022). *Electricity's strategic role in leading Europe's decarbonization - An Enel Position Paper*. Consulté le February 2023, sur enel.com: https://www.enel.com/company/our-commitment/electricity-role-europe-decarbonization/electrification
Enerdata. (2022). Simple energy balance France 2021.
ENTSO-E. (2017, July 7). *Electricity transmission system operators of the ENTSO-E Continental Europe Region sign agreements on the Conditions for Future Interconnections with Ukraine and Moldova*. Retrieved November 2022, from entsoe.eu: https://www.entsoe.eu/news/2017/07/07/entsoe-ce-agreement-conditions-future-grid-connections-with-ukraine-moldova/
ENTSO-E. (2022, April 26). *ENTSO-E welcomes Ukrenergo as Observer Member*. Retrieved from entsoe.eu: https://www.entsoe.eu/news/2022/04/26/entso-e-welcomes-ukrenergo-as-observer-member/
Erdyn. (2022, November 25). *Les batteries lithium-ion : un recyclage en devenir*. Retrieved from erdyn.com: https://www.erdyn.com/recyclage-batterie-li-ion/
ESA. (2022). *Euratom Supply Agency Annual Report 2021.* European Union .
EU Commission. (2016, April 4). *Commission presents Nuclear Illustrative Programme (PINC)*. Retrieved 2023 March, from ec.europa.eu: https://ec.europa.eu/commission/presscorner/detail/en/IP_16_1202
EU Commission - CORDIS. (2017, March 7). *New process for manufacturing PV cells means cheaper solar power*. Retrieved March 2023, from cordis.europa.eu: https://cordis.europa.eu/article/id/121679-new-process-for-manufacturing-pv-cells-means-cheaper-solar-power
EU Commission JRC. (2021). *Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation').* EU Commission.
*Europe*. Consulté le February 2023, sur commission.europa.eu: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en
EUnews. (2014, October 8). *Via libera Commissione Ue ad aiuti di Stato al nucleare in GB*. Retrieved March 2023, from eunews.it: https://www.eunews.it/2014/10/08/via-libera-commissione-ue-ad-aiuti-di-stato-al-nucleare-in-gb/
Eurelectric. (2022, March 25). *Ukraine, one month on*. Retrieved from eurelectric.org: https://www.eurelectric.org/news/ukraineupdate1/
EUROfusion. (2023). *History of fusion*. Retrieved March 2023, from euro-fusion.org: https://euro-fusion.org/fusion/history-of-fusion/
European Commission . (2010). International climate policy post-Copenhagen: acting now to reinvigorate global action on climate change. *COM(2010) 86 final*. European Commission .
European Commission. (2008). *Attitudes towards radioactive waste - Special Eurobarometer 297.* European Commission.
European Commission. (2017). *C(2017) 1486 final.* Brussels: EU Commission.
European Commission. (2020). *COM(2020) 63 final.* Brussels: European Commission.
European Commission. (2022). *C(2022) 4240 final.* Brussels: European Commission.

European Commission Finance. (2022, August). *EU taxonomy for sustainable activities*. Retrieved February 2023, from finance.ec.europa.eu: https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en

European Commission Law. (2023). *Electricity market – reform of the EU's electricity market design*. Consulté le February 2023, sur ec.europa.eu: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13668-Electricity-market-reform-of-the-EUs-electricity-market-design_en

European Council. (2022, December 19). *Member States agree on new rules to slash methane emissions.* Consulté le March 2023, sur consilium.europa.eu: https://www.consilium.europa.eu/en/press/press-releases/2022/12/19/member-states-agree-on-new-rules-to-slash-methane-emissions/

Eurostat. (2023, March 8). *GDP and main components (output, expenditure and income).* Retrieved from ec.europa.eu: https://ec.europa.eu/eurostat/databrowser/view/nama_10_gdp/default/table

Eurostat. (2022, December). *Nuclear energy statistics*. Consulté le February 2023, sur ec.europa.eu/eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Nuclear_energy_statistics

Evrard, A. (2013). *Contre vents et marées, Politique des énergies renouvelables en Europe.* Presses de Sciences Po .

Faudon, V. (2022). Power Generation from Nuclear Energy. In M. Hafner, & G. Luciani, *The Palgrave Handbook of International Energy Economics* (pp. 131-143). Palgrave Macmillan .

Feitz, A. (2023, March 30). Climat : le sud de la France va encore s'assécher. *Les Echos*.

Fitze, U. (n.d.). *Atomic bomb victims as a reference*. Retrieved October 2022, from mensch-und-atom.org: https://www.mensch-und-atom.org/index.php/en/focus2/radiation/item/138-atomic-bomb-victims-as-a-reference

Fluchère, J. (2019). *Les 5 maux de l'EPR. Synthèse. Point de vue de Jean Fluchère.* Union d'associations de retraités et d'anciens du nucléaire.

Forsberg, C., & Omoto, A. (2017). *Future of Nuclear Power in a Low-Carbon World: The Need for Dispatchable Energy.* Cambridge: MIT - Advanced Nuclear Power Program.

Fortin, P. (2022, February 21). Le recyclage des éoliennes en France: mythe ou réalité? *Les Echos*.

Forum nucléaire Suisse. (2023, February 1). *Slovaquie: Mochovce 3 connectée au réseau*. Retrieved from nuklearforum.ch: https://www.nuklearforum.ch/fr/nouvelles/slovaquie-mochovce-3-connectee-au-reseau

Framatome. (2022, February 24). *Propulsion nucléaire : signature d'une convention de recherche et de développement entre le CEA, Framatome et Naval Group*. Retrieved January 2023, from framatome.com: https://www.framatome.com/medias/propulsion-nucleaire-signature-dune-convention-de-recherche-et-de-developpement-entre-le-cea-framatome-et-naval-group/

Framatome. (2023). *High and low temperature electrolysis for H2 production with advanced reactors*. Retrieved April 2023, from framatome.com: https://www.framatome.com/solutions-portfolio/portfolio/product?product=A1914&sol=secondary-energy-generation

France Info. (2022, September 5). *Un nouveau convoi de MOX prévu le 7 septembre au départ de Cherbourg selon Greenpeace*. Retrieved February 2023, from francetvinfo.fr: https://france3-regions.francetvinfo.fr/normandie/manche/cherbourg-

cotentin/un-nouveau-convoi-de-mox-prevu-le-7-septembre-au-depart-de-cherbourg-selon-greenpeace-2606648.html
French Court of Cassation. (1984, September). France: COurt of Cassation Decision in EURODIF Corporation et al. v Islamic Republic of Iran et al. *International Legal Materials, XXIII*(5), 1062-1070.
Friends of the Earth Europe. (2013). *Lithium.* Wien: GLOBAL 2000 Verlags-Ges.m.b.H.
Gaddis, J. (1986, Spring ). The Long Peace: Elements of Stability in the Postwar International System. *International Security, X*(4), 99-142.
Fukuyama, F. (1992). *The End of History and the Last Man.* Free Press.
Galindo, A. (2022). *What is Nuclear Energy? The Science of Nuclear Power*. Retrieved January 19, 2023, from International Atomic Energy Agency: https://www.iaea.org/newscenter/news/what-is-nuclear-energy-the-science-of-nuclear-power
Gasly, J.-O. (2021, October 4). *HEFAÏS : Haute école de formation Soudage en Cotentin*. Retrieved January 2023, from normandinamik.cci.fr: https://www.normandinamik.cci.fr/hefais-haute-ecole-de-formation-soudage-en-cotentin/
Gassilloud, T., & Piednoir, S. (2021). *L'énergie nucléaire du futur et les conséquences de l'abandon du projet de réacteur nucléaire de 4e génération « Astrid ».* Assemblée nationale & Sénat, Office parlementaire d'évaluation des choix scientifiques et technlogiques. Paris: Assemblée nationale.
Geldron, A. (2017). *L'épuisement des métaux et minéraux : faut-il s'inquiéter ?* . Angers: ADEME.
Giugni, M., & Kriesi, H. (1990). Nouveaux mouvements sociaux dans les années '80 : évolution et perspectives. *Schweizerische Zeitschrift für Politikwissenschaft, XXX*, 79-100.
Godelier, M. (2023, January 27). Nucléaire : le sprint d'Orano pour remplacer l'uranium enrichi russe, notamment aux Etats-Unis. *La Tribune*.
Gosselin, S., Louza, T., & Mura, B. (2022, July 7). *Plus de 6 000 emplois générés par l'activité des centrales nucléaires normandes*. Retrieved April 2023, from insee.fr: https://www.insee.fr/fr/statistiques/6471675
Gouvernement. (2022, February 10). *FRANCE 2030 : le Président de la République annonce 2 Md€ pour le soutien à l'innovation de rupture et son industrialisation dans le domaine des énergies renouvelables et du nouveau nucléaire en France*. Retrieved December 2022, from gouvernement.fr: https://www.gouvernement.fr/france-2030-le-president-de-la-republique-annonce-2-mdeu-pour-le-soutien-a-l-innovation-de-rupture
Government of Canada. (2019, March 25). *Epoxy Resins Group - information sheet*. Retrieved March 2023, from canada.ca: https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/chemicals-glance/epoxy-resins-group.html
Gracieux, C. (2005, September 19). *L'abandon du surgénérateur Superphénix*. Retrieved March 2023, from enseignants.lumni.fr: https://enseignants.lumni.fr/fiche-media/00000000439/l-abandon-du-surgenerateur-superphenix.html
Greenpeace France. (2018). *Déchets nucléaires : pourquoi le projet Cigéo à Bure doit être stoppé*. Retrieved January 2023, from greenpeace.fr: https://www.greenpeace.fr/dechets-nucleaires-projet-cigeo-a-bure-etre-stoppe/#failles
Greenpeace. (2022, December 7). *[Nucléaire] L'État français, via EDF, verse des centaines de millions d'euros à l'entreprise russe Rosatom*. Retrieved February 2023, from

greenpeace.fr: https://www.greenpeace.fr/espace-presse/nucleaire-letat-francais-via-edf-verse-des-centaines-de-millions-deuros-a-lentreprise-russe-rosatom/
Grubler, A. (2012). Energy transitions research: Insights and cautionary tales. In R. Fouquet, *Energy Policy - Special Section: Past and Prospective Energy Transitions - Insights from History* (Vol. 50, pp. 8-16). Elsevier .
Guisnel, J. (2007). *Histoire secrète de la Ve République* . Paris: La Découverte.
Guterres, A. (2020). The State of the Planet. New-York: United Nations .
Hancock, A. (2023, March 13). EU liberals battle big state role in plans for green economy. *Financial Times*.
Hanus, E. (2022). *NUWARD.* EDF - ELSMOR summer school.
Harriott, H. (1993, May). Review: The Dilemmas of Democracy and Foreign Policy. *Journal of Peace Research, XXX*(2), 219-226.
Hecht, G., Müller, B., & Naepels, M. (2020). Toxicité et invisibilisation. Nucléaire, rapports postcoloniaux et justice environnementale. *Monde Commun*(5), pp. 10-28.
Hoerber, T. (2012). Energy and environment: atom section. Dans T. Hoerber, *The Origins of Energy and Environmental Policy in Europe The Beginnings of a European Environmental Conscience.* Routledge.
Hollinger, P. (2022, October 19). Will the energy crisis crush European industry? *Financial Times*.
House, K. (2008, July 29). *In praise and fear of France's energy policy*. Retrieved October 2022, from thebulletin.org: https://thebulletin.org/2008/07/in-praise-and-fear-of-frances-energy-policy/
Hudec, M. (2023, February 28). Slovakia may build new nuclear power plant as electricity consumption rises. *Euractiv*.
IAEA. (2021). *Nuclear Power Reactors in the World.* International Atomic Energy Agency. Vienna: IAEA.
IAEA. (2022, June). *France*. Retrieved March 2023, from iaea.org: https://cnpp.iaea.org/countryprofiles/France/France.htm
IAEA. (2022). *Status and trends in spent fuel and radioactive waste management / International Atomic Energy Agency.* Vienna: International Atomic Energy Agency.
IEA. (2021). *The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions.* International Energy Agency .
IEA. (2022). *Gas Market Report, Q3-2022.* International Energy Agency. International Energy Agency.
IEA. (2022). *Nuclear Power and Secure Energy Transitions: From Today's Challenges to Tomorrow's Clean Energy Systems.* International Energy Agency .
IEA. (2022). *Special Report on Solar PV Global Supply Chains.* Paris: IEA.
IEA. (2022). *World Energy Outlook.* International Energy Agency.
IEC. (2022, November 22). *The 33rd Meeting of the Energy Charter Conference held under the Chairmanship of Mongolia*. Retrieved from energycharter.org: https://www.energycharter.org/media/news/article/the-33rd-meeting-of-the-energy-charter-conference-held-under-the-chairmanship-of-mongolia/
IFOP - JDD. (2022). *Les Français et le nucléaire : adhésion et traits d'image.* IFOP.
IFOP - SDN. (2022). *Les Français et l'énergie nucléaire.* IFOP & Sortir du Nucléaire .
INA. (1958, August 6). *Visite du général de Gaulle au centre nucléaire de Marcoule*. Retrieved November 2022, from ina.fr: https://www.ina.fr/ina-eclaire-actu/video/afe85007946/visite-du-general-de-gaulle-au-centre-nucleaire-de-marcoule

INA. (2022, February 10 ). *1974 : Pierre Messmer lance le premier grand plan nucléaire civil français* . Récupéré sur ina.fr: https://www.ina.fr/ina-eclaire-actu/1974-pierre-messmer-lance-le-premier-grand-plan-nucleaire-civil-francais

International Monetary Fund. (2023). *Reinventing the System (1972-1981)*. Consulté le January 2023, sur imf.org: https://www.imf.org/external/np/exr/center/mm/eng/mm_rs_02.htm

Jack, V. (2023, April 20). French-Russian nuclear relations turn radioactive . *Politico*.

Jervis, R. (1976). *Perception and Misperception in International Politics: New Edition.* Princeton University Press .

Jobin, P. (2012). Qui est protégé par la radioprotection ? *Ebisu*(47), 121-131.

Johansen, M., & Joslyn, M. (2008). Political Persuasion During Times of Crisis: The Effect of Education and News Media on Citizen's Factual information About Iraq. *J&MC Quarterly, LXXXV*(3), 591-608.

Jong, S., Boardman, R., & Bragg-Sitton, S. (2018, October 14). Dynamic performance analysis of a high-temperature steam electrolysis plant integrated within nuclear-renewable hybrid energy systems. *Applied Energy, 228*, 2090-2110.

Julian, S., & Mediavilla, L. (2022, August 1). Piscine saturée à la Hague, polémiques autour de Bure... Déchets nucléaires, l'heure des choix. *L'Express*.

Jungblut, S.-I. (2019, December 12). *Our Digital Carbon Footprint: What's the Environmental Impact of the Online World?* Retrieved April 2023, from reset.org: https://en.reset.org/our-digital-carbon-footprint-environmental-impact-living-life-online-12272019/

Kanellos, M. (2011, January 20). *Nuclear Startup NuScale Suspends Operation*. Retrieved March 2023, from greentechmedia.com: https://www.greentechmedia.com/articles/read/nuclear-startup-nuscale-suspends-operation

Kant, I. (2007 [1795]). *Perpetual Peace.* FQ Classics.

Kissane, C. (2021). The Upending of the Geopolitics of Energy: Disruption Is the New Normal. In C. Ankersen, *The Future of Global Affairs* (pp. 247-69). Palgrave Macmillan Cham.

Kloosterman, J. (2020). *Activities in Euratom projects SAMOFAR and SAMOSAFER.* Retrieved March 2023, from msrworkshop.ornl.gov: https://msrworkshop.ornl.gov/wp-content/uploads/2020/11/27_Kloosterman_MSR_workshop_20201.pdf

Knoche, P. (2020). Approvisionnement en uranium et métaux stratégiques pour le nucléaire : dépendance ou faux problème ? *Annales des mines - Responsabilité et Environnement*(97), 136-39.

Knott, E. (2022, October 14). *Russia's attempt to annex Kherson, Zaporizhzhia, Donetsk, and Luhansk has undermined its claim on Crimea*. Retrieved April 2023, from blogs.lse.ac.uk: https://blogs.lse.ac.uk/europpblog/2022/10/14/russias-attempt-to-annex-kherson-zaporizhzhia-donetsk-and-luhansk-has-undermined-its-claim-on-crimea/

Koopmans, R., & Duyvendak, J. (1995, May). The Political Construction of the Nuclear Energy Issue and Its Impact on the Mobilization of Anti-Nuclear Movements in Western Europe. *Social Problems, XLII*(2), 235-251.

Kraev, K. (2021, June 14). *Ukraine / Westinghouse And Energoatom Sign Contract For Fuel Assembly Documentation* . Retrieved from nucnet.org: https://www.nucnet.org/news/westinghouse-and-energoatom-sign-contract-for-fuel-assembly-documentation-6-1-2021

Krige, J. (2006). Atoms for Peace, Scientific Internationalism, and Scientific Intelligence. *Osiris, XXI*(1), 173.
Labertit, G. (2007, August 18). À qui profite l'uranium nigérien ? *Le Monde*.
Laconde, T. (2023, March 16). Sécheresse : « On ne peut pas soutenir un projet nucléaire sans vouloir qu'il soit en mesure de fonctionner normalement ». *Le Monde*.
Lagendijk, V. (2008). *Electrifying Europe: The power of Europe in the construction of electricity networks.* Amsterdam: Asmterdam university Press.
Lalive, P. (1986). Ordre Public Transnational (ou Réellement International) Et Arbitrage International. *Revue de l'arbitrage*, 329-373.
Lauer, H. (2023, February 2). *La sortie du charbon nécessite la construction préalable de nouvelles centrales à gaz.* Retrieved March 2023, from allemagne-energies.com: https://allemagne-energies.com/2023/01/05/la-sortie-du-charbon-necessite-la-construction-prealable-de-nouvelles-centrales-a-gaz/
Lazard, O. (2022, June 14). *Russia's Lesser-Known Intentions in Ukraine*. Retrieved April 2023, from carnegieeurope.eu: https://carnegieeurope.eu/strategiceurope/87319
Le Hir, P. (2015, July 22). La loi sur la transition énergétique définitivement adoptée au Parlement. *Le Monde*.
Le Monde. (2022, February 10). *lemonde.fr*. Retrieved March 2023, from De 2017 à 2022, comment Emmanuel Macron a changé de position sur le nucléaire: https://www.lemonde.fr/planete/video/2022/02/10/de-2017-a-2022-comment-emmanuel-macron-a-change-de-position-sur-le-nucleaire_6113173_3244.html
Le Parisien. (2018, November 27). Emmanuel Macron annonce la fermeture de 14 réacteurs nucléaires d'ici 2035. *Le Parisien*.
Le Point. (2023, March 13). L'avenir du nucléaire en France se joue à l'Assemblée. *Le Point*.
Les Echos. (2022, November 30). Nucléaire : EDF en lice pour un réacteur en République tchèque. *Les Echos*.
Lenoir, Y. (2016). *La comédie atomique : l'histoire occultée des dangers des radiations.* Paris: La Découverte: Cahiers libres.
Le Renard, C. (2017). Les débuts du programme électronucléaire français (1945-1974) : de l'exploratoire à l'industriel. *Hérodote*(2), pp. 53-66.
Leroux, O. (2013, March 28). Père et fille condamnés pour un négoce nucléaire illégal. *La Provence* .
Lewandowski, C. (2021). *Le nucléaire.* Paris: Presses Universitaires de France.
Lippmann, W. (2010). *Public Opinion.* Middletown: Feather Trail Press.
Ljunggren, D. (2022, March 22). *Putin held phone call with Macron, discussed Russia-Ukraine talks - Interfax*. Retrieved April 2023, from reuters.com: https://www.reuters.com/world/europe/putin-held-phone-call-with-macron-discussed-russia-ukraine-talks-interfax-2022-03-22/
Locatelli, G., Boarin, S., & Fiordaliso, A. (2018, April 1). Load following of Small Modular Reactors (SMR) by cogeneration of hydrogen: a techno-economic analysis. *Energy, 148*, 494-505.
Loftus, S. (2022, March 11). *Putin's Risk Calculus in Ukraine: Realism and Identity in Great Power Competition*. Retrieved April 2023, from e-ir.info: https://www.e-ir.info/2022/03/11/putins-risk-calculus-in-ukraine-realism-and-identity-in-great-power-competition/
Lohez, L. (2023, March 1). Qu'est-ce que l'"alliance du nucléaire", ce cercle qui veut défendre l'atome en Europe ? *L'Express*.

Lokhov, A. (2011). *Technical and Economic Aspects of Load Following with Nuclear Power Plants.* NEA, OECD.

Lovins, A. (1979). *Soft Energy Paths.* Cover.

Lovins, A. (1980, February 28). Nuclear weapons and power-reactor plutonium. *Nature, 283*(5750), 817-23.

Loubet, M. (2018, November 18). *La question pas si bête : pourquoi la Normandie est l'une des régions les plus nucléaires du monde ?* Retrieved March 2023, from actu.fr: https://actu.fr/societe/question-pas-bete-pourquoi-normandie-regions-plus-nucleaires-monde_19552158.html

Madelin, T. (2011, January 20). DCNS veut développer un réacteur nucléaire sous-marin de petite puissance. *Les Echos*.

Mann, N. (2022, March 18). Trois questions sur le raccordement du réseau électrique ukrainien à la plaque européenne. *L'usine nouvelle*.

Marsh, S., & Chambers, M. (2022, February 22). *Germany freezes Nord Stream 2 gas project as Ukraine crisis deepens*. Retrieved April 2023, from reuters.com: https://www.reuters.com/business/energy/germanys-scholz-halts-nord-stream-2-certification-2022-02-22/

Markowitz, G., & Rosner, D. (2002). *Deceit and Denial: The Deadly Politics of Industrial Pollution.* Berkely: University of California Press.

Massemin, É. (2021, November 22). *L'air de rien, RTE défend une France nucléaire*. Retrieved February 2023, from reporterre.net: https://reporterre.net/L-air-de-rien-RTE-defend-une-France-nucleaire

Mathis, W. (2023, February 8). *Wind Turbine Giant Says It Has a Solution That Will Keep Blades Out of Landfills*. Retrieved March 2023, from bloomberg.com: https://www.bloomberg.com/news/articles/2023-02-08/vestas-says-wind-turbine-recycling-solution-to-keep-blades-out-of-landfills?leadSource=uverify%20wall

McDonald, J. (2021, September 20). *Smart grids could soften the blow of cyberattacks, but make them more common*. Retrieved April 2023, from emergingtechbrew.com: https://www.emergingtechbrew.com/stories/2021/09/20/smart-grids-soften-blow-cyberattacks-make-common

McMahon, L. (2018). *Is staying online costing the Earth?* Policy Connect.

Mearsheimer, J. (2013). *Why Leaders Lie: The Truth About Lying in International Politics.* Oxford Univeristy Press .

Mejía-Montero, A. (2020). Chapter 17 - The role of social resistance in shaping energy transition policy in Mexico: the case of wind power in Oaxaca. In L. N. Guimarães, *The Regulation and Policy of Latin American Energy Transitions* (pp. 303-318). Elsevier.

Merlin, C. (2020, September). *Le renouveau du secteur nucléaire aux États-Unis. De Make America Great Again à l'Energy Dominance.* Ifri , Centre Énergie . Études Ifri .

Meyer, T. (2023, February 23). Imaginaires du nucléaire : le mythe d'un monde affranchi de toutes contraintes naturelles. *The Conversation*.

Michaels, D. (2008). *Doubts Is Their Product: How Industry's Assault on Science Threatens Your Health.* New York: Oxford University Press.

Michel, C. (2021, September 8). Elements For A Doctrine: In Conversation With Charles Michel. (L. G. Continent, Interviewer)

Ministère de l'économie. (2023, February 6). *Industrie : vers une nouvelle stratégie hydrogène pour la France*. Retrieved April 2023, from economie.gouv.fr: https://www.economie.gouv.fr/industrie-nouvelle-strategie-hydrogene-pour-la-france#

Ministère de l'intérieur. (2023, February 2023). *Le CoSSeN fête ses deux ans : le point sur un service à compétence nationale*. Retrieved 2023 March, from gendarmerie.interieur.gouv.fr: https://www.gendarmerie.interieur.gouv.fr/gendinfo/l-info-en-continu/le-cossen-fete-ses-deux-ans-le-point-sur-un-service-a-competence-nationale

Ministère de la Transition Écologique. (2023). *Comment Cigéo est-il financé ?* . Retrieved from cigeo.gouv.fr: https://www.cigeo.gouv.fr/comment-cigeo-est-il-finance-137

Ministère de la transition écologique et solidaire. (2020). *Stratégie française pour l'énergie et le climat - Programmation pluriannuelle de l'énergie.* Gouvernement .

Ministère de la Transition énergétique. (2021, July 5). *Acteurs et gouvernance du nucléaire*. Consulté le January 2023, sur ecologie.gouv.fr: https://www.ecologie.gouv.fr/acteurs-et-gouvernance-du-nucleaire#scroll-nav__1

Ministère des armées. (2023). *Les Sous-marins Nucléaires Lanceurs d'Engins (SNLE)*. Retrieved April 2023, from defense.gouv.fr: https://www.defense.gouv.fr/marine/nos-equipements/marins-nucleaires-lanceurs-dengins-snle

Ministerial Conference on the International Energy Charter. (2015). *International Energy Charter.* The Hague: Ministry of Economic Affairs of the Netherlands.

Molnar, G. (2022). Economics of gas transportation by pipeline and LNG. In M. Hafner, & G. Luciani, *The Palgrave handbook of international energy* (pp. 23-57). Palgrave Macmillan .

Mueller, J. (1990, September). The Obsolescence of Major War. *Bulletin of Peace Proposals, XXI*(3), 321-328.

Müller, P. (2016). EU foreign policy: no major breakthrough despite multiple crises. *Journal of European Integration*(38), 359-374.

Munchmeyer, M. (2023, January 10). *Overview of Recent Energy Case Law from the CJEU: highlights from the event*. Retrieved February 2023, from Florence School of Regulation: https://fsr.eui.eu/overview-of-recent-energy-case-law-from-the-cjeu-highlights-from-the-event/

Murphy, L., & Elimä, N. (2021). *In borad daylight. Uyghur Forced Labour and Global Solar Supply Chains.* Sheffield : Helena Kennedy Centre for International Justice.

MYRRAH. (2023). *About MYRRHA.* Retrieved March 2023, from myrrha.be: https://myrrha.be/about-myrrha

Nakagaki, T. (2021). Issues in power generation and future prospects. Dans Y. Koizumi, *Fundamentals of Thermal and Nuclear Power Generation* (Vol. I, pp. 275-288). Elsevier .

NASA. (2022, November). *Sea Level*. Retrieved April 2023, from nasa.gov: https://climate.nasa.gov/vital-signs/sea-level/

Nieuviaert, J.-J. (2023, March 1). Relance du nucléaire : la France doit miser sur des petits réacteurs pour atteindre ses objectifs. *Capital* .

Nissen, S. (2014). The Eurobarometer and the process of European integration. *Quality & Quantity*(48), 713-727.

Norton Rose Fulbright. (2022, June). *Regulatory Trends: New nuclear RAB funding model*. Retrieved March 2023, from nortonrosefulbright.com: https://www.nortonrosefulbright.com/en/knowledge/publications/55726950/nuclear-energy---briefing-8-july-2022

Norwegian Maritime Authority. (2023, January 09). *Zero emissions in the world heritage fjords by 2026*. Retrieved March 2023, from sdir.no:

https://www.sdir.no/en/shipping/vessels/environment/prevention-of-pollution-from-ships/zero-emissions-in-the-world-heritage-fjords-by-2026/
Nuclear Europe. (2022). *New nuclear solutions: small modular reactors.* Nuclear Europe.
Objectif Gard. (2016, September 8). *objectifgard.com*. Retrieved March 2023, from Fait du jour Alès, le virage audacieux d'une start-up montpelliéraine: https://www.objectifgard.com/a-la-une/fait-du-jour-ales-le-virage-audacieux-dune-start-up-montpellieraine-60300.php
OCDE - AEN. (2007). *Innovation dans la technologie nucléaire.* Paris: OCDE.
OCDE AEN. (2007). *Ressources, production et demande de l'uranium : Un bilan de quarante ans. "Rétrospective du Livre rouge".* Agence de l'OCDE pour l'énergie nucléaire . Paris: OCDE AEN.
OECD. (2011). *Technical and Economic Aspects of Load Following with Nuclear Power Plants.* OECD - Nuclear Energy Agency .
Okumu, S. (2022, June 16). *7 ways Gen-Z (and you) can get involved in climate action now*. Retrieved from greenpeace.org: https://www.greenpeace.org/international/story/54362/7-ways-gen-z-and-you-can-get-involved-in-climate-action-now/
Ollitrault, S., & Villalba, B. (2014). Sous les pavés, la Terre. Mobilisations environnementales en France (1960-2011), entre contestations et expertises. In M. Pigenet, *Histoire des mouvements sociaux en France de 1814 à nos jours* (pp. 716-723). Paris: La Découverte.
O'Malley, B. (2022, March 5). *European Union halts scientific cooperation with Russia*. Retrieved March 2023, from universityworldnews.com: https://www.universityworldnews.com/post.php?story=20220305125136996
Orano. (2023). *Plutonium : ce qu'il faut retenir*. Consulté le January 2023, sur Orano Group: https://www.orano.group/fr/decodage/tout-savoir-sur-le-plutonium
Orano. (2022, November 22). *Arrival of the MOX Shipment from France to Japan*. Retrieved March 2023, from orano.group: https://www.orano.group/en/news/news-group/2022/november/arrival-of-the-mox-shipment-from-france-to-japan
Orano. (2023). *MOX, Recycling Nuclear Energy*. Retrieved April 2023, from orano.group: https://www.orano.group/country/china/en/our-stories/mox-recycling-nuclear-energy
O'Sullivan, M. (2013). The Entanglement of Energy, Grand Strategy, and International Security. In A. Goldthau, *The Handbook of Global Energy Policy* (pp. 30-48). Wiley-Blackwell.
Palmer, M. A. (1972, June 20). Weekly Hansard 902. *Nuclear Reactor Industry (Vinter Report)*, p. 431.
Pannier-Runacher, A. (2023, March 1). Financement des nouveaux réacteurs nucléaires : "On n'a pas besoin d'un nouvel impôt", assure Agnès Pannier-Runacher. (M. Fauvelle, Interviewer)
Passet, O. (2014, September 3). Politique économique : soutenir l'offre OU la demande, le faux débat. *La Tribune*.
Pierucci, F. (2021). *Le Piège américain.* Delcourt .
Pirani, S., Stern, J., & Yafimava, K. (2009). *The Russo-Ukrainian gas dispute of January 2009: a comprehensive assessment.* Oxford Institute for Energy Studies.
Playez, N., Courtin, E., & Ammirabile, L. (2020). *LW-SMRs main safety goals, WP 2: Development of safety analysis methodology for LW-SMRs.* Euratom.
Plimmer, G., & Pickard, J. (2022, May 23). UK must 'come clean'on cost of nuclear to consummers, says infrastructure chief. *Financial Times*.

PoliMi. (2023). *Small Modular Reactors*. Retrieved 2023 March, from nuclearenergy.polimi.it: https://www.nuclearenergy.polimi.it/research/small-modular-reactors/
Posen, B. (2009, November). Emerging Multipolarity: Why Should We Care? *Current History, 108*, 347-352.
Potter, W. (1990). *Soviet Decision-Making for Chernobyl: an Analysis of System Performance and Policy Change.* Los Angeles: National Council for Soviet and East European Research.
Pouponneau, F. (2013). Les changements de la politique française d'exportations nucléaires (1974-1976) : un triple double jeu. *Critique Internationale*(58), pp. 95-116.
Pouponneau, F. (2013). Luttes nationales et politique étrangère : Analyse d'un changement de la « position de la France » dans la crise du nucléaire iranien. *Gouvernement et action publique, II*(3), pp. 461-486.
Proglio, H. (2022, December 13). *Henri Proglio, président d'honneur d'EDF, Assemblée nationale, 13 décembre 2022*. Retrieved December 2022, from youtube.com: https://www.youtube.com/watch?v=D3T0bAsUBXE
Pudil, P. (2010). *60 years of voicing coal interests in Europe.* Brussels: EURACOAL. Retrieved from euracoal.eu: https://public.euracoal.eu/download/Public-Archive/Library/Brochures/EURACOAL-60-Years-2010.pdf
Rühle, M., & Grubliauskas, J. (2015). *Energy as a Tool of Hybrid Warfare.* NATO Defense College - Research Division. Rome: DeBooks Italia.
Raso, B. (2023, March 4). *Il freddo blocca la produzione di energia eolica: l'Alberta si salva con i combustibili fossili*. Consulté le March 2023, sur meteoweb.eu: https://www.meteoweb.eu/2023/03/freddo-energia-eolica-alberta-combustibili-fossili/1001211564/?amp=1
Rauline, N. (2022, October 5). Energie : l'Etat va redistribuer les superprofits des producteurs aux entreprises. *Les Echos*.
Raynal, J. (2023, March 15). Petits réacteurs nucléaires : Nuward accélère la cadence tandis que la compétition s'intensifie… y compris en France. *La Tribune*.
Reno Energy. (2022, February 22). *Le recyclage des panneaux solaires, comment ça se passe ?* Retrieved March 2023, from reno.energy: https://reno.energy/blog/actu-energie/le-recyclage-des-panneaux-solaires-comment-ca-se-passe/
Reporterre. (2017, March 31). *L'ASN avait pointé des dysfonctionnements à l'usine du Creusot dès 2005*. Retrieved April 2023, from reporterre.net: https://reporterre.net/L-ASN-avait-pointe-des-dysfonctionnements-a-l-usine-du-Creusot-des-2005
Représentation permanente de la france auprès de l'UE. (2022, August 29). *La Communauté européenne de l'Energie Atomique (Euratom)*. Retrieved March 2023, from ue.delegfrance.org: https://ue.delegfrance.org/la-communaute-europeenne-de-l
Reuters. (2015, March 25). *Hungary in talks on Russian nuclear fuel supply with Euratom: EU*. Retrieved February 2023, from reuters.com: https://www.reuters.com/article/us-hungary-nuclear-eu-idINKBN0ML0K820150325
Reuters. (2023, April 28). *Russia fixing power line from Zaporizhzhia nuclear plant to land it controls, IAEA says*. Retrieved May 2023, from reuters.com: https://www.reuters.com/world/europe/russia-fixing-power-line-zaporizhzhia-nuclear-plant-land-it-controls-iaea-says-2023-04-28/
Reverdy, T. (2014). *La construction politique du prix de l'énergie.* Presses de Sciences Po .
Reverdy, T., & Marty, F. (2019). 11. Le marché de l'électricité : entre politiques énergétiques nationales et encadrement européen. *Regard croisés sur l'économie*(25), pp. 133-143.

Revue politique et parlementaire. (2022, December 2). *Audition à l'Assemblée nationale de Yves Bréchet*. Retrieved 3 December 2022, from revuepolitique.fr: https://www.revuepolitique.fr/audition-a-lassemblee-nationale-de-yves-brechet/

RFI. (2022, September 20). Prix de l'uranium: les prix restent hauts. *RFI*.

Ricci, M., Newsholme, G., Bellaby, P., & Flynn, R. (2006). *Hydrogen: too dangerous to base our future upon?* Crown Conference.

Roar Aune, F., Golombek, R., & Hallre, H. (2015). *Phasing out Nuclear Power in Europe.* CESifo.

RTE. (2022). *Futurs énergétiques 2050.* RTE France.

Ruth, M., & Cutler, D. (2017). *The Economic Potential of Nuclear-Renewable Hybrid Energy Systems Producing Hydrogen.* Joint Institute for Strategic Energy Analysis.

Sadatchy, P. (2011). *Mouvement des Nigériens pour la Justice (MNJ).* Bruxelles: Groupe de recherche et di'nformation sur la paix et la sécurité (GRIP).

Salerno, G. (2018). L'effondrement de la société industrielle, et après ? *Futuribles, VI*(427), 61-81.

Södersten, A. (2014). *Euratom at the Crossroads.* Florence: European University Institut.

Safety4sea. (2022, October 31). *What is the role of nuclear power in shipping decarbonization?* Retrieved 2023 March, from safety4sea.com: https://safety4sea.com/cm-what-is-the-role-of-nuclear-power-in-shipping-decarbonization/

Saheb, Y. (2021, February 12). Energy Charter Treaty strikes again. *Euractiv*.

San, L. (2022, December 15). *Fusion nucléaire : cinq questions sur "l'avancée scientifique majeure" qui suscite beaucoup d'espoir autour de cette énergie du futur*. Retrieved March 2023, from francetvinfo.fr: https://www.francetvinfo.fr/sciences/fusion-nucleaire-cinq-questions-sur-l-avancee-scientifique-majeure-qui-suscite-beaucoup-d-espoir-autour-de-cette-energie-du-futur_5543715.html

Saner, R., & Yiu, L. (2006). *International Economic Diplomacy: Mutations in Post-modern Times.* Netherlands Institute of International Relations 'Clingendael'.

Scahill, J. (2023, March 25). Russia calls for U.N. investigation of nord stream attack, as hersh accuses white house of false flag. *The Intercept* .

Schepers, N. (2019). Russia's nuclear energy exports: status, prospects and implications. *Non-Proliferation and Disarmament Papers*(61).

Schlesinger, A. (2004). *The Imperial Presidency.* New York: Mariner Book.

Schneider, M. (2008, September 19). *2008 world nuclear industry status report: Western Europe*. Retrieved November 2022, from thebulletin.org: https://thebulletin.org/2008/09/2008-world-nuclear-industry-status-report-western-europe/

Schneider, M. (2009). *Nuclear France Abroad History, Status and Prospects of French Nuclear Activities in Foreign Countries.* Paris: Mycle Schneider Consulting.

Schoenfisch, M., & Dasgupta, A. (2022). *Grid-Scale Storage.* International Energy Agency .

Senato della Repubblica. (2007). *La gestione del combustibile irraggiato e delle materie nucleari.* Senato della Repubblica. Roma: Senato della Repubblica.

Serin, E. (2022, December). *What is the role of nuclear in the energy mix and in reducing greenhouse gas emissions?* Retrieved March 2023, from lse.ac.uk: https://www.lse.ac.uk/granthaminstitute/explainers/role-nuclear-power-energy-mix-reducing-greenhouse-gas-emissions/

Serrajordia, E., & Lasserre, M. (2022, February 3). Nucléaire : ce qu'en disent les candidats à la présidentielle de 2022. *La Croix*.

Sfen. (2022, May 13). *La consommation d'eau des centrales nucléaires en France*. Retrieved April 2023, from sfen.org: https://www.sfen.org/rgn/la-consommation-deau-des-centrales-nucleaires-en-france/

Simões, M., & Farret, F. (2022). Future Renewable Energy Communities Based Flexible Power Systems. *Applied science*(12).

Simson, K. (2022, November 11). *Opening speech by Commissioner Simson at the 15th European Nuclear Energy Forum*. Retrieved March 2023, from ec.europa.eu: https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_22_6804

Singh, R., & Akram, S. (2022). Energy System 4.0: Digitalization of the Energy Sector with Inclination towards Sustainability. *Sensors*(22).

Sirot, S. (2022, December 12). Réforme des retraites : « La négociation n'est pas le mode privilégié du dialogue social en France en raison de notre histoire politique ». (M. Pouzadoux, Interviewer) Le Monde.

Smith-Nonini, S. (2022, June 8). *The Other Reason for Putin's Rush to War: Russian Oil Dependency*. Retrieved from resilience.org: https://www.resilience.org/stories/2022-06-08/the-other-reason-for-putins-rush-to-war-russian-oil-dependency/

Smil, V. (2010). *Energy Transitions: History, Requirements, Prospects.* Santa Barbara: Praeger/ABC CLIO.

Spasic, V. (2023, January 12). *Germany sticks with natural gas as transitional fuel*. Retrieved from balkangreenenergynews.com: https://balkangreenenergynews.com/germany-sticks-with-natural-gas-as-transitional-fuel/

Stauffer, N. (2023, January 25). *Flow batteries for grid-scale energy storage*. Retrieved April 2023, from energy.mit.edu: https://energy.mit.edu/news/flow-batteries-for-grid-scale-energy-storage/

Sogin. (2014). *1 Audizione di So.g.i.n Spa presso le Commissioni XIII (territorio ambiente e beni ambientali) e X (Industria, commercio e turismo) del Senato della Repubblica.* Sogin.

Soutou, G.-H. (1991). La logique d'un choix : le CEA et le problème des filières électro-nucléaires 1953-1969. *Relations internationales*, 367.

Stefen, W. (2015, February 13). Planetary Boudaries: Guiding Human Development on a Chnaging Planet. *Science, CCCXLVII*(6223).

Steffen, R. (2022). *Un lien entre changement climatique et séismes à l'origine de tsunamis inattendus ?* Retrieved April 2023, from axa-research.org: https://www.axa-research.org/fr/projet/rebekka-steffen

Szarka, J. (2011). Climate policy in France: between national interest and global solidarity? *Politique européenne*(33), 155-183.

Tainter, J. (1988). *The Collapse of Complex Societies.* Cambridge: Cambridge Univeristy Press.

TASS. (2021, October 6). *Nuclear-powered LASH carrier Sevmorput's regular voyage scheduled for July 10, 2022*. Retrieved March 2023, from tass.com: https://tass.com/economy/1346241

Taylor, M. (1997). Greenhouse gases and the nuclear fuel cycle: What emissions? *IAEA BULLETIN*(39), pp. 34-36.

Techniques de l'ingénieur. (2011, April 4). *Une mini-centrale nucléaire sous-marine en 2017 ?* Retrieved March 2023, from techniques-ingenieur.fr: https://www.techniques-ingenieur.fr/actualite/articles/une-mini-centrale-nucleaire-sous-marine-en-2017-5907/

TEPCO. (2023). *Nuclear Power Generation*. Retrieved April 2023, from tepco.co.jp: https://www.tepco.co.jp/en/hd/about/facilities/nuclear-e.html

The Economist. (2022, October 20). Vladimir Putin says the world’s energy infrastructure is “at risk”. *The Economist*.

The Maritime Executive. (2022, August 25). *UK to Adopt Regulations for Nuclear Powered Commercial Ships*. Retrieved March 2023, from maritime-executive.com: https://maritime-executive.com/article/uk-to-adopt-regulations-for-nuclear-powered-commercial-ships

Therme, C. (2020). Le nucléaire iranien vu de France. *Confluences Méditerrannée, II*(113), 105-121.

Toner, H. (2022, March 22). *Will China Set Global Tech Standards?* Retrieved November 2022, from chinafile.com: https://www.chinafile.com/conversation/will-china-set-global-tech-standards

Topçu, S. (2013). *La France nucléaire, L'art de gouverner une technologie contestée* . Paris: Seuil .

Topçu, S. (2013). Technosciences, Critique, and Issues of Power: A Governmentality Approach. *Revue d'Histoire Moderne et Contemporaine*, *LX-XLIV*(4), 76-96.

Tropper, J. (2022, November 4). *Withdrawing from the Energy Charter Treaty: The End is (not) Near*. Retrieved from kluwerarbitration.com: https://arbitrationblog.kluwerarbitration.com/2022/11/04/withdrawing-from-the-energy-charter-treaty-the-end-is-not-near/

Turkish, F. (2004). *La France, l’Allemagne et l’enjeu nucléaire.* Institut français des relations internationales , Comité d'études des relations franco-allemandes (Cerfa). Paris: IFRI.

UFE. (2022). *Synthèse Etude EY EDEC nucléaire.* UFE.

UK Parliament. (2000). *Mixed Oxide Nuclear Fuel (MOX) - Research Briefing.* UK Parliament

Ukrenergo. (2020). *Strategy: driving the power of changes.* Ukrenergo.

Ulstein. (2022, April 26). *Ship design concept from ulstein can solve the zero emission challenge*. Retrieved March 2023, from ulstein.com: https://ulstein.com/news/ulstein-thor-zero-emission-concept

U.S. Department of Energy. (2015). *Levelized Cost of Energy (LC.* Retrieved from energy.gov: https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf

US Office of nuclear energy. (2022, May 4). *5 Facts to Know About Three Mile Island*. Retrieved April 2023, from energy.gov: https://www.energy.gov/ne/articles/5-facts-know-about-three-mile-island

Usine Nouvelle. (2023, February 15). Le chantier d'Iter réceptionne un aimant géant de la Russie. *Usine Nouvelle*.

UNSCEAR, United Nations. (2017). *Souces, Effect And Risks of Ionizing Radiation.* New-York: UN General Assembly .

UNSCEAR. (2018). *UNSCEAR 2018 Report. Evaluation of data on thyroid cancer in regions affected by the Tchernobyl accident.* New York: United Nations.

UNSCEAR. (2022). *Members of the Committee*. Retrieved October 2022, from unscear.org: https://www.unscear.org/unscear/en/about-us/member-states.html

UNSCEAR. (2022). *UNSCEAR 2020/2021 Report to the General Assembly with Scientific Annexes. Sources, effects and risks of ionizing radiation.* UNSCEAR. New York: United Nations.

Vaïsse, M. (1992, October-December ). Le choix atomique de la France (1945-1958). *Vingtième Siècle, revue d'histoire*(36), 25.

Valkenburg, G., & Gracceva, F. (2016). Chapter 8 - Towards Governance of Energy Security. Dans P. Lombardi, *Low-carbon Energy Security from a European Perspective* (pp. 207-229). Academic Press.

Valova, Y. (2023, April 27). *Russia is preparing to defend Zaporizhzhia nuclear power plant*. Retrieved May 2023, from emerging-europe.com: https://emerging-europe.com/news/russia-is-preparing-to-defend-zaporizhzhia-npp/

Vampouille, T. (2011, June 27). Kadhafi frappé par un mandat d'arrêt international. *Le Figaro*.

Van Dine, A. (2017, April 1). After Stuxnet: Acknowledging the Cyber Threat to Nuclear Facilities. *Project on Nuclear Issues: A Collection of Papers from the 2016 Nuclear Scholars Initiative and PONI COnference Series*, 101-114.

Van Rompuy, H., & Barroso, J. (2014). *EUCO 58/14.* Brussels: European Council - The President.

Van Rythoven, E. (2022). Walter Lippmann, emotion, and the history of international theory. *International Theory, XIV*(3), 526-550.

Vella, H. (2019, December 5). *Does the European Pressurised Reactor have a future?* Retrieved from power-technology.com: https://www.power-technology.com/features/does-the-european-pressurised-reactor-have-a-future/

Vie Publique. (2019, February 7). *Programmation pluriannuelle de l'énergie : le projet publié*. Retrieved March 2023, from vie-publique.fr: https://www.vie-publique.fr/en-bref/21859-programmation-pluriannuelle-de-lenergie-le-projet-publie

Vircoulon, T. (2023, February 28). Emmanuel Macron en Afrique : "On est de retour dans une logique de Guerre froide". (L. Dépêche, Interviewer)

Voitovych, O. (2023, April 27). *2 dead after Zaporizhzhia region hit with over 80 Russian attacks, official says*. Retrieved May 2023, from egyptindependent.com: https://egyptindependent.com/2-dead-after-zaporizhzhia-region-hit-with-over-80-russian-attacks-official-says/

vonder Leyen, U. (2021, March 16). *European Commission Press Corner*. Retrieved January 2023, from European Commission: https://ec.europa.eu/commission/presscorner/detail/de/speech_21_1182

Wajsbrot, S. (2021, March 10). Trois pistes pour un nucléaire plus sûr « post-Fukushima ». *Les Echos*.

Waltz, K. (1981). The Spread of Nuclear Weapons: More May Be Better: Introduction. *The Adelphi Papers*(171).

Waltz, K. (1988). The Origins of War in Neorealist Theory. *The Journal of Interdisciplinary History*(18), 615-28.

Weber, M. (1963). *Le savant et le politique* . Plon, Éditions 10/18.

Weill, J. (1955). *Automatisation complète de la conduite des réacteurs nucléaires.* CEA.

Wilson, W. (2023 [1917]). *The Fourteen Points*. Retrieved April 2023, from theworldwar.org/: https://www.theworldwar.org/learn/peace/fourteen-points

Woessner, G., & Siraud, M. (2022, June 2). Elisabeth Borne : 'Sortir des énergies fossiles exigera une transformation radicale'. *Le Point*.

World Commission on Environement and Development. (1987). *Our Common Future.* Oxford University Press.

World Nuclear Association. (2023, January). *Nuclear Power in Ukraine*. Retrieved March 2023, from world-nuclear.org: https://world-nuclear.org/information-library/country-profiles/countries-t-z/ukraine.aspx

World Nuclear News. (2018, October 30). *Vanadium drives uranium project developments*. Retrieved April 2023, from world-nuclear-news.org: https://world-nuclear-news.org/Articles/Vanadium-drives-uranium-project-developments

World Nuclear News. (2021, February 26). *Japanese utilities revise MOX utilisation plan*. Retrieved March 2023, from world-nuclear-news.org: https://world-nuclear-news.org/Articles/Japanese-utilities-revise-MOX-utilisation-plan

World Nuclear News. (2022, September 13). *Beloyarsk BN-800 fast reactor running on MOX*. Retrieved April 2023, from world-nuclear-news.org: https://www.world-nuclear-news.org/Articles/Beloyarsk-BN-800-fast-reactor-running-on-MOX

World Nuclear News. (2022, August 26). *Construction licence issued for Paks II*. Retrieved April 2023, from world-nuclear-news.org: https://www.world-nuclear-news.org/Articles/Construction-licence-issued-for-Paks-II

World Nuclear News. (2021, November 22). *Westinghouse signs initial contract for Ukrainian AP1000s*. Retrieved from world-nuclear-news.org: https://www.world-nuclear-news.org/Articles/Westinghouse-signs-initial-contract-for-Ukrainian

World Nuclear Association. (2017, October). *Mixed Oxide (MOX) Fuel*. Retrieved January 2023, from World Nuclear Association: https://world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/mixed-oxide-fuel-mox.aspx

World Nuclear Association. (2022, June). *Supply of Uranium*. Consulté le January 2023, sur world-nuclear.org: https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx

Yee, A. (2019, May 12). Electronic Marvels Turn Into Dangerous Trash in East Africa. *The New York Times*.

@yjadot. (2019, August 30). *738 millions d’euros d’argent public qui s’ajoutent aux milliards atomisés dans la faillite nucléaire. Imaginons les sauts technologiques -et les emplois!- que ces fonds publics auraient générés dans les renouvelables !* Retrieved April 2023, from twitter.com: https://twitter.com/yjadot/status/1167481819970883585

6Medias. (2017, November 14). *Seriez-vous évacué en cas d'accident nucléaire ?* Retrieved December 2022, from lepoint.fr: https://www.lepoint.fr/sante/seriez-vous-evacue-en-cas-d-accident-nucleaire-14-11-2017-2172405_40.php