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THE GOVERNANCE OF NUCLEAR PHASE-OUT IN EUROPE
ITALY, GERMANY AND FRANCE: A COMPARISON

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Abstract

The issue of nuclear phase-out connects the three most important countries of the European Union: Germany, France and Italy, although to varying degrees and in different time-periods.

After a short historical introduction, the analysis of such phase-out process for each country is divided in three levels, and such examination systematically enables to identify similarities and differences between the situations of three European countries considered.

The first regards the political decision-making phase involving party-politics, public opinion trends and institutional and regulatory framework over nuclear power. In this respect, the consequences of the nuclear incidents on public opinion and the political pressure from anti-nuclear groups like the Greens differentiate Italy and Germany from the long-term commitment to the technology of France, which is found to resist the reversing thrusts.

The second concerns the implications of the implementation of the political decision by the utility companies operating the nuclear plants, which in fact have to directly carry the burden of the financial, labour and business model impacts of the policy. In this case, Italy and France are linked by the state-owned “monopolistic” feature of then ENEL and present-day EDF, which implies a cooperative relationship with the respective national governments despite the different political and social attitudes on the technology and the opposite size of the nuclear power program. Germany’s phase out process, instead, has been distinguished by the contraposition, even judicial, between national (and Land) governments and the four mostly private operators, which have experienced a radical and costly restructure of their business environment due to the phase out and its overall framework policy, the Energiewende.

The third covers the effects of the phase-out process on the energy market and system, namely its total costs and the repercussions on electricity prices and power import/export, replacement technologies and carbon emissions. In this regard, in all the three countries nuclear capacity is found or forecasted to be replaced by fossil fuel power generation at least in the short term (while renewables are a long-term option), with negative effects on system-costs, prices, electricity trade and greenhouse emissions. Thus, the phase-out would represent a more cost-effective decision if applied after the completion of the existing plants’ lifecycle.

In conclusion, the experiences of the three countries are on a case-by-case basis linked by some aspects and divided by others. Despite not representing a unified pattern of nuclear phase-out model, therefore, the replicability of most of the elements highlighted in this study is fairly conceivable, at any rate in the case of other European countries.

Key words: nuclear phase out, nuclear power, nuclear/atomic energy, Europe, France, Germany, Italy, party politics, decision-making process, energy system, electricity market, utilities, energy transition

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List of abbreviations

Bn: billion

BWR: Boiling water reactor

CAPEX: Capital expenditure

CCGT: Combined cycle gas turbine

CCS: Carbon capture and storage

CDU/CSU: Christian Democratic Union/Christian Social Union in Bavaria (Germany)

CEA: Atomic Energy Committee (France)

CIPE: Inter-ministerial Committee for Economic Planning (Italy)

CNEN: National Nuclear Energy Commission (Italy)

CNRN: National Commission for Nuclear Energy (Italy)

CO_2: Carbon dioxide

COVID-19: Coronavirus disease 2019

DC: Christian Democracy (Italy)

DW: Deutsche Welle

EDF: Électricité de France

EnBW: Energie Baden-Württemberg

ENEL: National Electricity Authority (Italy)

ENI: National Hydrocarbons Authority (Italy)

EPR: European Pressurised Reactor/Evolutionary Power Reactor

ERDF: Électricité Reseau Distribution France (Grid Operator for Distribution)

ETS: Emission Trading Scheme

EU: European Union

Euro, €: euro

FDP: Free Democratic Party (Germany)

FORATOM: European Atomic Forum

GHG: Greenhouse gas

GW: Gigawatt

I2EN: International Institute of Nuclear Energy

IAEA: International Atomic Energy Agency

ICSID: International Centre for Settlement of Investment Disputes

IFER: Imposition Forfaitaire des Entreprises de Réseaux (Flat-rate tax on network infrastructure companies)

LCOE: Levelized cost of energy

LN: Northern League (Italy)

MP: Member of Parliament

MSI: Italian Social Movement

Mton: Metric Ton

MW: Megawatt

MWe: Megawatt electric

MWh: Megawatt-hour

NCBJ: National Centre for Nuclear Research (Poland)

NEA: Nuclear Energy Agency

NGO: Non-governmental organization

OECD: Organisation for Economic Co-operation and Development

PCI: Italian Communist Party

PD: Democratic Party (Italy)

PdL: People of Freedom party (Italy)

PM10/PM: Particulate Matter/Particulate Matter 10

PR: Radical Party (Italy)

PRI: Italian Republican Party

PS: Socialist Party (France)

PSDI: Italian Democratic Socialist Party

PSI: Italian Socialist Party

PWR: Pressurized water reactor

RES: renewable energy sources

RTE: Réseau de Transport d'Électricité (Electricity Transmission Network)

SELNI: Società Elettronucleare Nazionale (National Nuclear Electricity Company, Italy)

SENN: Società Elettronucleare Italiana (Italian Nuclear Electricity Company)

SIMEA: Società Italiana Meridionale per l'Energia Atomica (Southern Italian Company for Atomic Energy)

SO_2: Sulfur dioxide

SOGIN: Società Gestione Impianti Nucleari (Nuclear Plants Management Company, Italy)

SO_x: Sulfur oxide

SPD: Socialist Democratic Party (Germany)

TSO: Transmission System Operator

TWh: Terawatt-hour

UK: United Kingdom

UNFCC: United Nations Framework Convention on Climate Change

USA/US: United States of America

USD, $: United States dollar

WNISR: World Nuclear Industry Status Report

Introduction

General context

"The use of nuclear energy remains limited to a small part of the world, with only 31 countries or 16 percent of the 193 members of the United Nations, operating nuclear power plants. [...] While three countries abandoned their programs, nine of the current 31 nuclear countries have either nuclear phase-out, no-new-build or no-program-extension policies in place. Eleven countries with operating plants are currently building new reactors."

This quote from the General Overview Worldwide of The World Nuclear Industry Status Report 2019 (Schneider & Froggat, 2019) provides a brief summary of the overall situation of the nuclear power sector, highlighting in particular three typical different situations facing the countries which, since the discovery of nuclear fission by O. Hahn and F. Strassman in 1938 and the demonstration of its energy use by E. Fermi's *Chicago Pile 1* reactor in 1942, have been somehow involved in the development of nuclear power programs: countries which used to operate nuclear reactors and chose to abandon this energy source, countries which implemented policies either to halt the program development or to phase out their reactors, and countries which actively carry on the exploitation of this energy source by building new plants.

A prominent member of the first of such groups is Italy, which gradually decommissioned its nuclear plants after the result of an anti-nuclear referendum in 1987, following the Chernobyl incident of the previous year. Germany, instead, belongs to the second group, having started the process of complete shutdown of its nuclear reactors by 2022 after the Fukushima incident of 2011 in the context of the broader country-wide "Energiewende" (energy turnaround). Conversely, France stands out among the countries with active nuclear energy policies, harnessing almost three-quarters of its electricity from this source, but anyway facing the problem of phasing out the most ageing of its reactors (and eventually replacing them with new ones). In the appendix, the energy mix of the three countries and the electricity generation mix of EU countries are shown.

The objective of this thesis is to compare these experiences of nuclear phase-out (even if partial and only planned in the case of France) in the three most important countries of the European Union (now that the United Kingdom is not a member state any more) from the point of view of the overall governance of the process, for trying to understand if the similarities allow to draw a European “model” for the abandonment of nuclear energy or if, on the contrary, the differences determine every situation to be considered specific cases. In this introduction, therefore, it is appropriate to start with a brief examination of what a nuclear phase out means for the energy system of a country.

The nuclear phase out process, as already displayed with the introductory words about the three countries covered here, starts with a political decision. For the measures to take effect, it does not seem to be too relevant if such decision is the result of a direct democracy expression (like a referendum) or of an initiative by ruling political parties, even if strong public support, as in any policy, is obviously essential both for its successful implementation in the long term and for reducing the chance of a later reversal. Anyway, after the initial proposal, the policy has to be shaped, approved and implemented by the parliament and the relevant ministries in the democratic legislative mechanism. Other agencies, like the local authority for nuclear safety, may play an important role, too.

The practical implementation of such political decision, which represents the second phase of the process, is however up to the operators of the nuclear plants. Here, the situation may vary depending on the organisation of the electricity market: national monopoly or liberalised and competitive environment. If the implications on jobs and the technical decommissioning problems can be roughly the same, the financial impacts can differ according to how the costs liability is assigned. In addition, the relocation (or loss) of jobs affects the communities of the areas hosting the nuclear plants.

The last phase regards instead the impact on the electricity market and on the energy system of the countries. In fact, the final relevant impacts are on the price of electricity and its effect on the consumers, but also on the system costs of decommissioning, nuclear waste treatment and power generation replacement. Besides, in the European Union, since the common internal market also applies to electricity, the impact on prices may not only be limited to the national level, but also expanding to the EU one.

Approach and methodology

The research will deal with the topic in the different contexts regarding nuclear phase out (or planned reduction in the electricity mix like in the case of France) given by the three countries and in three different time periods (Italy in the past, Germany in present-day and France in the near future), looking at the three interrelated relevant segments:

- The political level, analysing the decision making and policy process of such energy strategy;
- The operators level, trying to understand the implications of the nuclear phase-out for the utilities which manage the plants, for example from the point of view of business models, costs and loss of revenues, relocation of jobs, market reputation, but also looking at the technical part regarding nuclear waste treatment and the decommissioning of the nuclear plants;
- The market level, investigating the impacts of the nuclear phase out both on the internal electricity market in the three countries and on the European market.

The research will comprise both qualitative and quantitative aspects, taking into consideration that for some parts (particularly for the utilities level) the sources publicly available are very limited. Instead, technical information about the reactors, their decommissioning process and the treatment of nuclear waste will not be covered here.

The thesis avails of quantitative data publicly available in the relevant academic literature, newspapers articles, reports by external organizations like NGOs, and government and corporate documents. Unfortunately, only separated data and single figures about nuclear decommissioning costs appear to have been disclosed, while comprehensive quantitative data, comprising all the effects of the nuclear phase out policy on the budgets of the utilities, do not seem to be publicly available. The same consideration is valid for the quantification of the social effects of the policy: only rough estimates of the impacts on jobs and some modelling on the system costs and, in some cases, electricity prices are available. The topic, anyway, is both qualitatively and quantitatively defined.

The subject is widely covered in the media, particularly in political and economic press and in energy specialized journalistic sources, but the level of detail regards is adequate only for the political decision-making process, while for the utilities and market segments of the phase out process the media sources cover only the general aspects of the question, conceivably due to the lack of detailed information disclosed by the companies. The same is true for the academic literature, where there are examples of papers about the political level, about the modelling of the effects on electricity prices, or about the technical engineering challenge of the safe decommissioning of nuclear plants and treatment of nuclear waste (not covered here).

A precious main source is represented by the book “The Politics of Nuclear Energy in Western Europe” by Wolfgang C. Müller and Paul W. Thurner, which encompasses a general but detailed perspective of the evolution of nuclear energy in Western Europe from the policy point of view, and with particular focus exactly on Germany, Italy and France.

The nuclear phase out process involves different actors based on the three phases identified above:

- At the political level, the actors are obviously represented by the national governments and parliaments and the political parties which compose them, alongside the committees and agencies involved in nuclear energy. In the context of Germany, also the Land (federal state) level is relevant, so governments and parliaments of the different Länder have to be considered, too.
- At the level of the operators, the main actors are undoubtedly the utilities which operate (or operated) the nuclear plant and have (or had) practically implement the decision of decommissioning them. In the case of Italy, the only company involved was the then state-owned monopolist ENEL, while in Germany four private utilities had interests in the nuclear sector in 2011 (E.On, RWE, Vattenfall and EnBW); in France instead, the nuclear plants are again operated by the majority state-owned (84%) company EDF, but its situation compared to the past Italian monopolistic context is different due to the integration of the single European electricity market. In addition, transmission system operators (TSOs), trade unions and engineering services companies specialized in nuclear waste treatment and plants decommissioning can be relevant actors, too.
- At the market segment, the electricity consumers are the most important actors, both within the countries and at a European level. Organisations of them like environmentalist groups and activists can play a role, too, along the local regulatory agencies. The market-level analysis, anyway, will not deal with the involvement of specific actors, but with qualitative and quantitative considerations on the impacts of the nuclear phase out policies.

The nuclear phase-out process is always started by a political decision, even if in the case of Italy that was forced by the result of a national referendum. The implementation, instead, is up to the operators, while the actual impacts, other than on the operators themselves, fall on the consumers (business and private citizens) both in the countries where nuclear phase out happens (or happened) and in the other European countries due to the import and export of power within the European market.

The detailed institutional governance structure of nuclear power sector (and thus of its phase out) in the three countries examined will be analysed later in the first chapter as part of the political level of this process, but in general the approach followed by this thesis consists in an overall centralized planning on nuclear energy matters, since the technology has historically always been subject of national interest.

The thesis does not regard the evaluation of the appropriateness of the decision of phasing out nuclear, even if that probably represents the main controversy: in the case of Italy, for instance, the decision resulted in the dependence on imported natural gas for power generation, and for Germany a similar result is probable, along the delaying of coal phase-out, which would be much more important from the emission reduction perspective. In the case of France, instead, the reduction of nuclear capacity from around 75% to 50% would make sense only for leaving market shares to renewable generation, otherwise it would certainly represent a failure.

The substantial gap, as already expressed above, is represented by the lack of publicly disclosed corporate documents about the nuclear phase-out. The availability of media, government and academic sources allows to draw some considerations about the impacts for the utilities, but this issue nonetheless represents a critic factor for the adequate coverage of this thesis topic.

Goals and questions

The objective of this thesis is to analyse and compare the governance of the nuclear phase out process (namely, how it unfolds and with what consequences) in Italy, Germany and France, considering it as a unitary and coherent phenomenon (yet obviously divided in different phases) instead of focusing on one particular aspect. The thesis, however, will deal with the topic separating the political level, the phase of implementation by the operators, and the impact on the electricity market.

The final goal, indeed, is understanding if it is possible to draw a unique model of nuclear phase out governance (in other words, if the nuclear phase out process follows a basically unique pattern in the experiences of these comparable European countries) or if, on the contrary, the differences and national characteristics determine that every country follows a specific scheme of nuclear phase out, different from any other.

So, the main research question is the following:

- Can a (European) nuclear phase out model be drawn from the experiences and plans of Italy, Germany and France or should we conclude that every state follows specific experiences in this very particular transforming pattern?

Depending on the result of the research, in the conclusions of the study also two consequent sub-questions will be considered:

1) In the first case, what can we conclude about the transferability (replication) of this model to different countries and which kind of aspects of this model can be transposed?
2) In the second case, what are the singular features which identify the nuclear phase out experience of each different country in the absence of a unitary pattern? In other words, is there a "cultural" dimension allowing us to differentiate Italy, Germany and France?

Structure and outline

After this introductive part, the study will deal with the elaboration of the research question analysing the nuclear phase out process from an overall governance perspective and in the experiences and strategies of the three countries considered, always identifying relevant differences and common trends. More in detail, as outlined in the previous paragraphs, each chapter will deal with one phase of the nuclear phase out process, namely:

- In the first part, the political decision-making process responsible for initiating the nuclear phase out will be analysed, in particular related to the different political stances, the public opinion and the legal and regulatory framework on nuclear power.
- The second section will deal with the impacts on the electricity market of the nuclear phase out, with respect to the effects on the prices for the consumers but also, at a system level, on the overall costs of the policy, on the energy mix of the examined countries and for the climate-related emission trends.
- The analysis of the operators' level, with the implications on finances and jobs and some information on the consequences on the business models, will instead be

elaborated in the third chapter despite representing the second phase of the process, since the documentation is more limited and thus relevant considerations from the two previous parts may be helpful.

- Finally, the last section will be dedicated to the conclusions on the possibility of drawing a model of nuclear phase out with its main aspect common to the three experiences considered and assessing its replicability to comparable situations of different countries in the future.

Chapter 1: Political level

1.1. Historical background

In order to analyse the political environment which is involved in these nuclear phase out processes, it is obviously appropriate to begin from a general historical excursus regarding nuclear technology's development in these three countries, while the following subchapters will also present a historical reconstruction, but focused on the specific factors under discussion. Dealing with the development of nuclear energy in Germany before the reunification, only the Federal Republic of Germany (more commonly called West Germany) has been considered, so that the analysis remains about democratic political systems. The following information are mainly extracted from the different chapters of "The Politics of Nuclear Energy in Western Europe" edited by Müller and Thurner.

Both in France and in Italy, the starting point in nuclear involvement was represented by the creation of specialized research centres, respectively the Commissariat à l'Énergie Atomique (Commission for Atomic Energy, CEA) in 1945 and the Comitato Nazionale per le Ricerche Nucleari (National Committee for Nuclear Research, CNRN) in 1952, while in (West) Germany the first authority in the field was political-institutional, the Budesministerium für Atomfragen (Ministry for Atomic Affairs), established in 1955. It is interesting to notice that all these authorities have partially or totally changed their target activities over the years, even developing into completely different institutions: the French and Italian research agencies, in fact, have respectively expanded and fully reconverted to renewable technologies, while the German department has turned into the broader Education and Research ministry.

In Italy and Germany, anyway, the initial public initiative was complemented by several other public-private undertakings, while in France the development of nuclear technology always remained in the hands of the State, since its civil energy uses were closely interlinked with the military program for obtaining nuclear weapons. Being the only country of the three under consideration with an independent military nuclear program (even if Italy and Germany still host US atomic bombs in their air bases), in fact, France has always exploited the dual aspect of its involvement in nuclear technology, historically maintaining a single fuel cycle for both the applications, as admitted by its own officials (Schneider, 2008). This factor might have reasonably contributed to the undisputed long-term commitment of the country to the technology, and also to its underlying political and social support which will be analysed later.

Anyway, the development of civil nuclear energy in France started when first five-year development plan for nuclear energy was proposed in 1951 and adopted the following year. The CEA and the French state-owned electricity company Electricité de France (EDF) co-operated for building the first nuclear power plant in 1956, named G1 Marcoule, and the second in 1959. In the 1960's, though, this collaboration for the development of French nuclear policy was reshaped by the return to power of Charles De Gaulle: the CEA was tasked along the army with the production of plutonium for the military weapon program, while EDF pushed for implementing American-designed pressurized-water reactors (PWRs), more efficient and reliable for electricity generation. In 1969, therefore, the French government decided for splitting the military and civilian nuclear activities, and EDF was allowed to pursue the more congenial technology. This industrial program was further enhanced after the 1973 oil crisis, when Prime Minister Messmer announced a huge expansion plan for nuclear energy which took its name, aimed at producing most of France's electricity from nuclear plants: the "Messmer plan" of 1974, in fact, envisaged the construction of "thirteen new plants before 1980, fifty before the middle of the 1980s, and 200 before 2000" (Brouard and Guinaudeau, 2017). The plan was realised only in part, due to the overstatement of the growth of French electricity demand. As of 2019, 58 nuclear reactors were operating in France (Schneider & Froggat, 2019).

In Italy, in the beginning of the 1950s the establishment of CNRN was accompanied by researches on nuclear energy funded by private actors, and between 1955 and 1957 three different nuclear power ventures were founded: SELNI (Sociatà Elettronucleare Italiana) by private electricity company EdisonVolta SpA, with other minor partners, and state-owned Finelettrica, which later left for setting up SENN (Società Elettronucleare Nazionale), and finally SIMEA (Società Italiana Meridionale per l'Energia Atomica) by ENI (National Hydrocarbons Authority), the Italian Oil&Gas state-owned corporation. One nuclear power plant was independently launched by each of these ventures in 1964, taking advantage of the lack of regulation and of uniform national policy. In 1962, however, both a regulation for the peaceful uses of nuclear energy and the nationalization of the electricity system were passed, resulting in the transfer of ownership and control of the nuclear power plants to the new state-owned power monopoly ENEL (Ente Nazionale per l'Energia Elettrica) in 1965. This led to the centralization of the nuclear energy policy, but when Italian regions were established in 1970 with the fulfilment of constitutional requirement, they claimed coordination on the construction of the plants and the decision-making process suffered delays, or complete cancellation in other cases. In 1975, however, the first National Energy Plan ambitiously forecasted the construction of 20 nuclear power plants, but six years later just one had been added to the fleet, and the plans for new ones had been revised (even though new constructions were still projected). After the Chernobyl Incident in 1986 and the referendum of the following year, initially a moratorium for new nuclear capacity construction was issued, and later the complete abandonment of the energy source was decided. A nuclear power program relaunch was attempted between 2008 and 2011 by the incumbent government, but a new referendum (again after a major nuclear accident, Fukushima) confirmed the rejection of nuclear energy, once more halting the program.

Figure 1 - Nuclear power plants in Germany (Appunn, 2015)

In Germany, the first nuclear program launched by the Ministry for Atomic affairs envisaged the creation of groups of scientists working on research reactors imported from USA and UK for developing a German design of commercial reactors. This process on nuclear energy technology development was characterized by a tangible collaboration between the different actors (political spectrum, industrial apparatus, trade unions and scientific environment) and the different policy levels (federal, Land and local). In particular, the public-private water and power multiutilities proved to be very significant in this framework. This kind of plan was followed up by three upgrade programs, and between 1961 and 1989 the fleet of German reactors was gradually installed, largely of the PWR and BWR (boiling-water) type. A first policy reversal, aimed at the phase out of nuclear energy, was launched in the first 2000s by the socialist government of Chancellor Schröder, and after being cancelled by the centre-right coalition in the beginning of the following decade, this phase-out decision was later reaffirmed and accelerated by this same government after the nuclear incident of Fukushima Daiichi in 2011. As shown in the figure above, of the remaining 17 operating plants at that time, eight were closed almost immediately after the decision, and for the others a gradual phase out schedule was decided, to be completed in 2022. In 2019, seven nuclear power plants were still operational in the country (Schneider & Froggat, 2019).

1.2. Public opinion, social positions and role of nuclear incidents

The figure below provides the trend of opposition to nuclear energy from 1978 to 2011 in selected European countries. Looking specifically at Italy and Germany, it is reasonable to notice a correlation between these public opinion trends and the actual policies implemented, but also the role of nuclear incidents in influencing the public opinion and thus the policy process. In the case of France, instead, the degree of public opposition is historically more nuanced but, reaching relevant levels in some periods (even in the upper 40s), should not be underestimated.

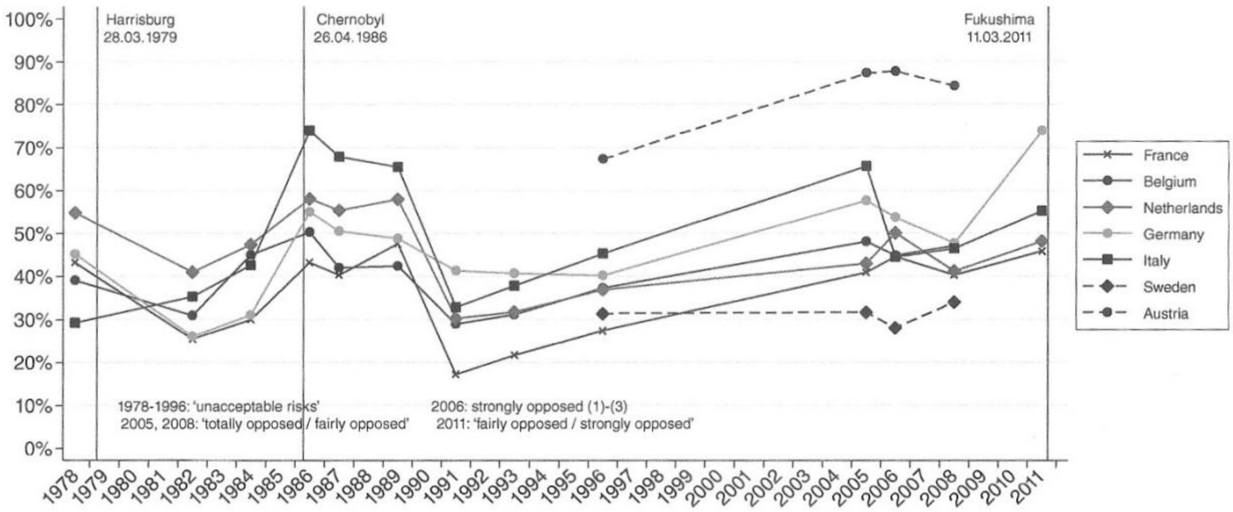


Figure 2 - Public opinion trends in selected countries: opposition to nuclear energy, 1978-2011 (Müller & Thurner, 2017)

All the related figures provided in the next paragraphs are obviously liable to extents of uncertainty and imperfection, but they nevertheless represent a useful tool for assessing the development of public opinion on nuclear power in the three countries considered.

In Italy, the beginning of the nuclear age in the country in the ‘60s had been characterized by a general low level of information among citizens regarding nuclear issues, both on the military and energy aspects (Ciglioni, 2017). The decade was anyway defined by a double perspective on nuclear applications: on the one hand, the fear of nuclear weapons in one of the peak periods of the Cold War, but on the other hand, the admiration for the technological advancement represented by the “peaceful atom” (Ciglioni, 2017). But the civil nuclear program only stepped into the public spotlight in 1963 when Felice Ippolito, the secretary of the CNEN (the atomic energy committee successor of the already mentioned CNRN) was accused of public funds mismanagement by the leader of the Italian Democratic Socialist Party (PSDI), and later President of the Italian Republic, Giuseppe Saragat. Even if the allegation and the subsequent conviction were probably exaggerated, this probably represented the first negative signal for the Italian atomic program, since it “marked the beginning of a sharp decline” on nuclear reactors research (Baracca et al., 2017) and on public investment in the field (Bini & Londero, 2017).

The ‘70s, instead, saw appearance of “green” movements, “first rallying against hydroelectric power plants, then against nuclear ones” (Paoloni, 2017); demonstrations started particularly against the choice of localisations of nuclear sites. Nevertheless, in 1978 only a minority of Italians perceived nuclear energy as too risky, but this figure had jumped to 77% just eight years after, following the incidents of Three Mile Island and especially Chernobyl, and this scepticism remained high even later (Franchino, 2017). In the absence of a single “nuclear law”, the anti-nuclear movements, at first opposing mainly the deployment of US nuclear missiles in Italy and then focusing also on nuclear power issues, collected enough signatures for calling a national referendum on the abolition of: 1) the power of the government to override regions in identifying the sites for the plants, 2) the incentives for municipalities hosting a nuclear power plant and 3) the authorisation of ENEL to participate in nuclear initiatives abroad. The referendums, held in November 1987, resulted in a relatively low turnout (65,1%) but a decisive win for the anti-nuclear stances, since the majority for repeal ranged from 80% to 70% in all the questions.

Interestingly, also Italy’s scientific environment was historically divided between the researchers involved in the CNRN-CNEN and in the industrial apparatus on one side and some physicists mainly concerned by the military implications of the technology and supporting nuclear disarmament on the other: intriguingly, both groups had their roots in Fermi's "Via Panisperna boys" of the '30s (Paoloni; Clavarino, 2017).

In the decades following the referendum, anyway, public opinion on the issue varied a lot, but before the attempted relaunch of the nuclear energy program by the 2008-2011 centre-right coalition and the Fukushima incident, the support seemed increasing (Franchino, 2017). After those events, however, a new referendum (June 2011) confirmed the phase out decision of 25 years before, with a 54,8% turnout and a 94,1% majority.

Interestingly, despite the same emergence of relevant anti-nuclear movements in the '70s as in Italy, the phase out in Germany was decided only three decades later, and then confirmed and initiated as a gradual process after another decade. If in the case of Italy, in fact, it was the Chernobyl accident in 1986 which marked the policy reversal in favour of the abandonment of nuclear power, in Germany this role was ultimately played in 2011 by the incident in Fukushima.

In the beginning, the catalyst of the mass anti-nuclear protests was in particular the "the open question of the final disposal of nuclear waste" which was to be solved by the construction of "a giant nuclear reprocessing and waste disposal centre" in a rural area of Lower Saxony, provoking fierce opposition of local farmers and their environmentalist supporters (Jahn & Korolczuk, 2012). The demonstration which represented "a role model for all subsequent protests", however, was in 1975 in Wyhl, when around 30.000 people gathered against the construction of a nuclear plant (Kirchhof & Trischler, 2018). Even if this sentiment remained active in part of the German public in the following years, also strengthened by the nuclear disarmament argument against US weapons in German territory as experienced in Italy (Wittner, 2003), the percentages of support and opposition to nuclear power in the polls were basically unchanged in that period, remaining both at roughly 40% also after the Three Mile Island accident in Pennsylvania of 1979, although the German public resulted more informed on the topic after that event (Thurner, 2017). In the same way and similarly to Italy's case, furthermore, German scientific community was significantly involved in nuclear research for the atomic energy program, but some important members sided strongly against military implications (Kirchhof & Trischler, 2018).

The anti-nuclear stance, though, gained further momentum in the public opinion after the nuclear meltdown in Chernobyl, and in fact the figure representing the Germans in favour of an expansion of the fleet of nuclear plants dropped dramatically, but on the other side the percentage of people preferring an immediate phase out did not increase to the detriment of the position in support of the continuation of the nuclear power use (but limited to the existing plants), which actually even earned some points retaining a solid majority (Thurner, 2017).

After the decision in favour of the gradual phase out was finally announced by the Socialist-Green coalition which won the government in 1998, instead, the "shut-down immediately" segment steadily decreased, but in the following years, when the first phase out decision was cancelled by the centre-right coalition, the groups supporting the phase out (some for 2022, others for 2035) regained a stable majority, which increased even further (particularly the "2022 phase out") after the Fukushima incident of 2011 and the government's decision of the re-phasing-out nuclear energy (Thurner, 2017).

In spite of being the country with the highest reliance on nuclear power, assuming that the huge extent of the civil nuclear program in France was accompanied by a level of public support of the same proportions would be particularly misleading.

The greater extension of the planned fleet of nuclear plants, in fact, did not exclude France from experiencing anti-nuclear protests similar to the Italian and German ones in the '70s, which escalated in mass demonstrations against the Superphénix fast-breeder reactor (designed for both reprocessing the nuclear fuel of the other French plants and generating power on its own) in the biennium 1976-1977 (Brouard & Guinaudeau, 2013). Even within the scientific environment of the CEA, despite the strong long-term commitment of French researchers in the military and civil program of the country, engagement "in the anti-nuclear activism in the mid-1970s" appeared, representing a relevant position of "counter-expertise" against the Messmer plan (Lehtonen, 2018).

And the generally favourable public opinion towards the nuclear program, which may be expected since the policy has not suffered a radical reversal so far, is far from being obvious: as calculated by Brouard and Guinaudeau (2013 and 2017), indeed, the degree of support in the last 50 years has exceeded 50% basically only in the first half of the '80s (thus, the Three Mile Island incident apparently did not influence the French public), dropping by ten percentage points in the following years after the Chernobyl incident, and then stagnating around 45%. The figure slightly rose rather counter-intuitively after the Fukushima accident and "the phasing-out decided by four of France's direct neighbours" including Germany: it seems that after the increasing media coverage and politicization of the issue, exponents of the industrial apparatus and supporting politicians were able to reaffirm the benefits of nuclear power, while “the ecologists did not manage to impose their framing in terms of risks” (Brouard & Guinaudeau, 2013).

Precisely this public salience could indeed contribute to the explanation for the lack of strong public push for a policy reversal, since after a peak in the aftermath of the events in Chernobyl, “the media attention quickly faded away” remaining on average very low until the turn of the century (Brouard & Guinaudeau, 2017). More recently, two polls had different findings regarding the approval of nuclear energy by the French public: in 2018, 53% of French resulted opposing nuclear plants in a survey conducted by Odoxa (The Connexion, 2018), while one year after a poll sponsored by French nuclear fuel cycle operator Orano (formerly New Areva) found that 54% of French believed that nuclear power was to “remain stable or increase in France” and that “an energy mix comprising nuclear and renewables” was in the future development of French energy system (World Nuclear News, 2019a).

As shown in the previous paragraphs, public opinion trends are definitely important for understanding the (partly) different paths undertaken by Italy, Germany and France on nuclear power policy and especially their reversals, even if it should be noted that other factors like “technical, constitutional and economic restrictions, powerful interest groups, and path dependence, constrain democratic responsiveness” (Brouard & Guinaudeau, 2013).

1.3. Political discourse, government decisions and positions in the parliament

After the short excursus about the development of the civil nuclear programs and the analysis of the social positions and general public opinion on nuclear issues in the three countries examined, it is opportune to investigate more in detail the political process (namely the positions of the political parties) which determined the policy reversal, complete and completed in the case of Italy, total but still ongoing for Germany, and partial and planned in the case of France.

In the framework elaborated by Müller and Thurner (2017) for assessing the dynamics which lead precisely to a policy reversal in the area of nuclear energy policy (the most prominent case of which is exactly the decision for a nuclear phase out), some interesting assumptions regarding the major role played by the political system are drawn. If the massing shifts in public opinion and the different salience of the issue for the voters have been already assessed in the previous section, this subchapter deals with the impact of factors like the commitments of parties (which assume government) towards this policy reversal and their willingness to replace the actors in favour of the status quo, but also the issue-inconsistency of their voters, the relevance of Green parties and the tendency of ruling parties of turning away from nuclear energy (in presence of an unfavourable public opinion) for holding the government.

It is probably appropriate to start again with Italy, where the party-political aspect of the policy reversal was less important considering that the phase out and its confirmation were an obvious choice for the governments in office after the results of national referendums which showed a clear majority of voters supporting this alternative, and that the country never experienced a relevant Green party. Nevertheless, some interesting considerations can be drawn. The figure below provides the development of Italy's nuclear policy.

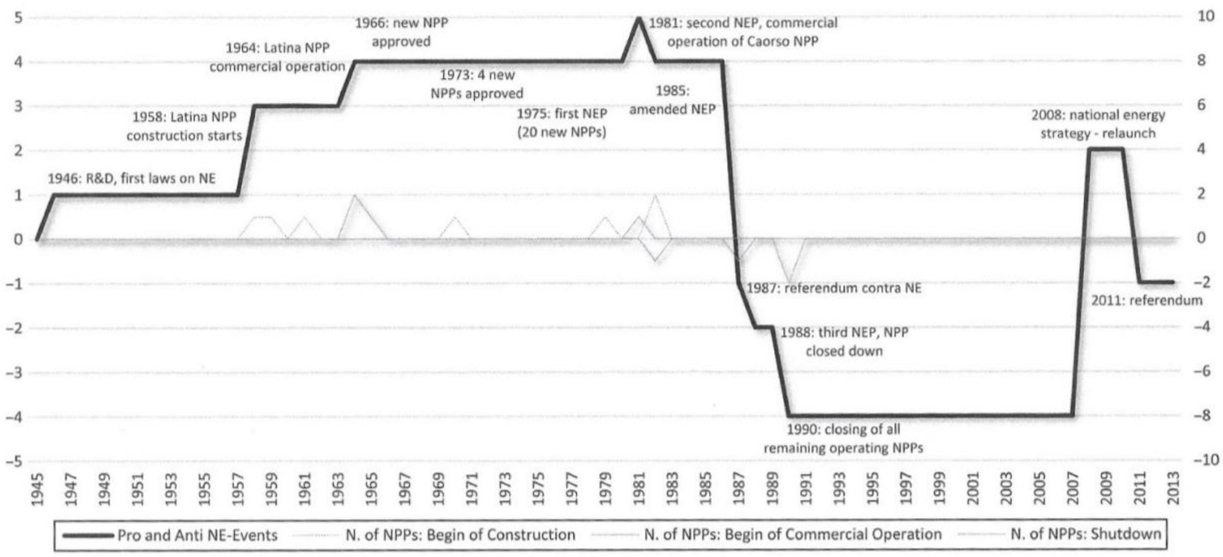


Figure 3 - Nuclear energy policy development in Italy, 1945-2013 (Franchino, 2017)

At the beginning of the Italian nuclear program in the '60s, "the issue was not contentious": "policy-makers simply reacted to the activism of market operators" which, however, actually had political sponsors mainly in the DC, the Cristian Democracy which has the pillar of every coalition government for the first 50 years of the Italian Republic (Franchino, 2017). The real bone of contention was the nationalization of the electricity system: proposed by the Communist and the Socialist parties (respectively PCI and PSI) and vigorously opposed by the Liberal one, it was supported by the DC government only when a centre-left coalition with the already mentioned PSDI and centrist PRI replaced precisely the liberal exponents. The nationalization was approved in the parliament by this majority and its original leftist proponents in February 1972, accompanied shortly after by a law supporting nuclear energy which was also approved with Socialist, Communist and even post-fascist (the MSI) votes. In the meantime, the construction of the first three different power plants was meeting with no relevant opposition in the society and the local authorities (Franchino, 2017). In the '70s, though, the first party positioning on the issue appeared: the planned construction of four new plants were approved by the majority coalition, but PCI and PSDI raised the issues of safety and consultation of local authorities and communities.

However, the first half of the '80s saw a new five-party centre-left coalition (headed by PSI leader Bettino Craxi given the record-low result of the DC) whose positions over nuclear power "were still fairly homogeneous" in support of the policy, while among the oppositions also the PCI was notably in favour. In this period, despite the emergence of new environmentalist parties like the Greens and the Radicals (PR) and similar anti-nuclear instances in the PCI, but also the increasingly difficult negotiations with the local authorities regarding the localisations of the new plants, the 4th National Energy Plan of March 1986 envisaged a downsized but still supportive policy on the nuclear energy program, also because only a small fraction of scientific experts were against (Baracca et al., 2017). One month later, the 4th reactor of the Pripyat-Chernobyl plant in Soviet Ukraine exploded, and very rapidly motions were filed in the Italian Parliament asking the government for a safety review and moratorium in the construction of the plants. "PSI became decisively anti-nuclear" (Franchino, 2017), but DC remained committed to the programs and withdrew confidence in Craxi (nuclear power was not the only issue, obviously). The radicals in the meantime promoted the referendums for the abrogation of the nuclear plans, and PSI sided in favour. Such referendums were postponed by the government crisis and the subsequent elections which resulted in a stalemate, with the newly formed Greens and especially all major parties but DC supporting either halting or completely abandoning nuclear energy. The same five-party coalition was the only government option, but this time with different positions among its components. DC, fearing a heavy defeat, joined PSI and PCI in supporting the phase out position in the referendum, leaving just minor centrist parties against. Given the clear results for the abandonment of the nuclear program, the governments of the following years, after some initial resistances by the DC, gradually complied completely. In this case, therefore, DC and PSI acted against their previous policies for staying in power.

Issue-inconsistency of voters, instead, is more important in the attempted revival of the nuclear program between 2008 and 2011: in fact, polls suggested that favourable opinions towards nuclear energy were widespread among centre-left voters despite the opposite official positions of their parties (notably the Dems, PD), while the centre-right voters of Berlusconi's PdL and the Northern League (LN) were found more aligned with the supporting positions of their parties. So, the national energy strategy of the conservative coalition in charge between 2008 and 2011 provided for the construction of new nuclear power plants. When the new referendum was called by smaller centre-left parties (later supported also by the PD) and after the Fukushima incident, however, the government first tried to avoid it modifying its plans with a new moratorium (again a case of inconsistently acting for maintaining power), and then supported boycotting the consultation. After the new referendum reiterated the phase out decision, nuclear power has not been a relevant issue in the Italian political debate (Franchino, 2017).

In the case of Germany, instead, the willingness of parties with committed anti-nuclear stances and on the other side the more pragmatic positioning of historically supportive parties probably played a more relevant role. The policy development is shown in the figure below.

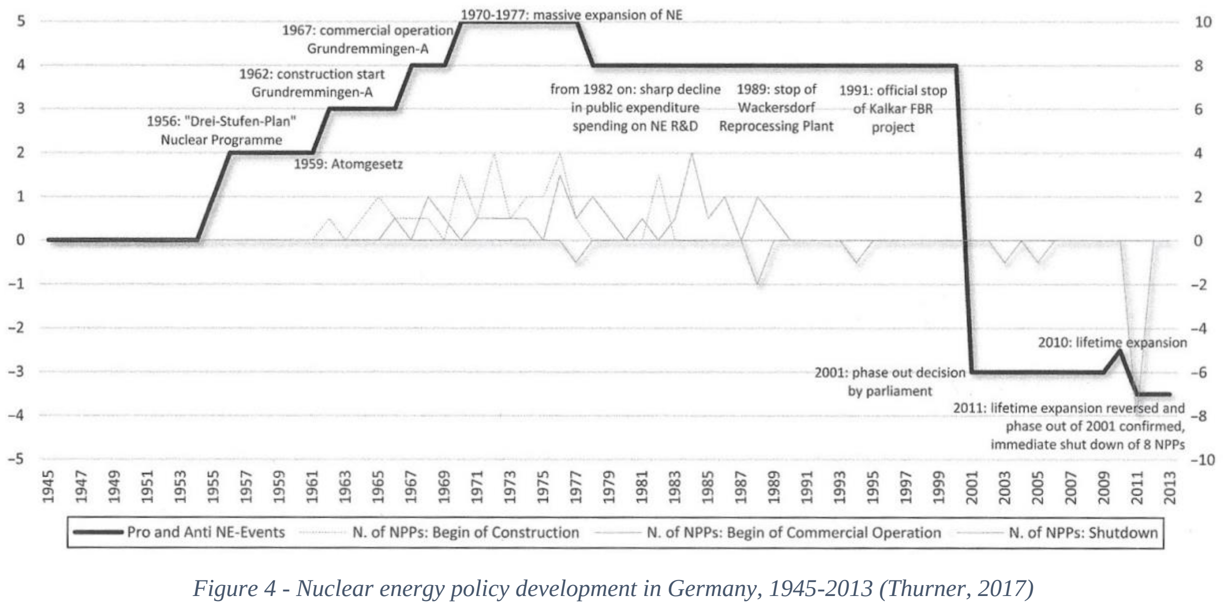


Figure 4 - Nuclear energy policy development in Germany, 1945-2013 (Thurner, 2017)

As in the Italian situation, however, "the nuclear energy issue was not politicized" and "a permissive consensus prevailed between the four major parties" (Christian-democratic

CDU/CSU, social-democrat SPD and liberal FDP) until the mid-1970s (Thurner, 2017). Nevertheless, already in the following years the first divisions appeared in the political spectrum on the issue, also within the parties and depending on the Land or national level: the centre-left SPD-FDP coalition governing North Rhine-Westphalia, in fact, was the first in opposing the construction of the Kalkar fast-breeder reactor (a joint project with Belgium and the Netherlands which suffered massive protests like its already mentioned French counterpart) against the official position of the national government composed of the same coalition. The SPD had indeed seen an anti-nuclear faction gaining support in its ranks in the late ‘70s.

The next decade, instead, showed that demonstrations could force also a centre-right CDU/CSU-FDP federal government with strong pro-nuclear stances to abandon a project, this time the atomic waste reprocessing plant of Wackersdrof (Bavaria), which in the plans had to replace the aforementioned one in Gorbelen. Even if at the same time other plants were being activated, this case, alongside the Chernobyl incident and the presence in the German territory of American nuclear weapons (an opposition stance to which the Greens remain committed still today; Wachs, 2020), gave another strong argument to the next anti-nuclear campaigns of the Green party: “the ‘unresolved’ question of the final disposal of the nuclear waste” (Thurner, 2017).

In the following years, the debate on nuclear power was postponed by the handling of the reunification, but in the meantime the Green party developed more pragmatic views, abandoning the aim of an immediate shut-down of the plants in favour of a more balanced compromise, while the SPD had also switched position in support of an “orderly” phase out since 1987, following the disaster in Chernobyl. So, when these two forces formed the government after the 1998 federal elections, this phase-out policy was already explicit in their coalition agreement, retracing the plans of the same coalition governing Lower Saxony of eight years earlier. However, the actual legislation on the gradual abandonment until the early 2020s was passed nearly at the end of the first Schröder government, in October 2002, with the vibrant opposition of CDU/CSU and FDP (Thurner, 2017). Although in a slower and more structured way than the initial expectations, then, the two parties lived up to their promises of reversing the status quo.

The Große Koalition (“grand coalition”) of 2005-2009 did not return officially to the issue for keeping together CDU/CSU and SPD, even if there were clashes between ministers of the two parties. When Mrs. Merkel was able to form his second government in a centre-right coalition with FDP in 2010, though, her cabinet proceeded with cancelling the 2002 decision on the phase out as campaigned, even if, considering the technology just a "bridge fuel", without eliminating the overall regulatory framework which maintained the abandonment of atomic energy as general policy direction (Thurner, 2017). In March 2011, however, just three months after the re-phasing-in decision, the government retraced its steps, announcing a moratorium and immediate shut-down of the older plants, and re-establishing the 2022 deadline for the complete phase out as part of the Energiewende policy: the Fukushima incident had made CDU politicians develop "a completely new assessment of risks" (Thurner, 2017). In all likelihood, they also sensed the strong public support for this alternative. In a very pragmatic (but probably also politically opportunist) move, therefore, Merkel's cabinet had reversed its historical positions on nuclear energy. Since that time, only CDU/CSU-SPD grand coalitions have governed Germany, and hence the phase out policy has never been questioned.

Alongside the specific behaviours of the traditional political parties which has been described, It can be concluded that the most important factor which made possible the implementation of the phase out in Germany was the institutionalization of the Green party, which pushed for anti-nuclear policies first at a local level and then in the federal parliament, putting pressure on the other components of the political spectrum (Thurner, 2017).

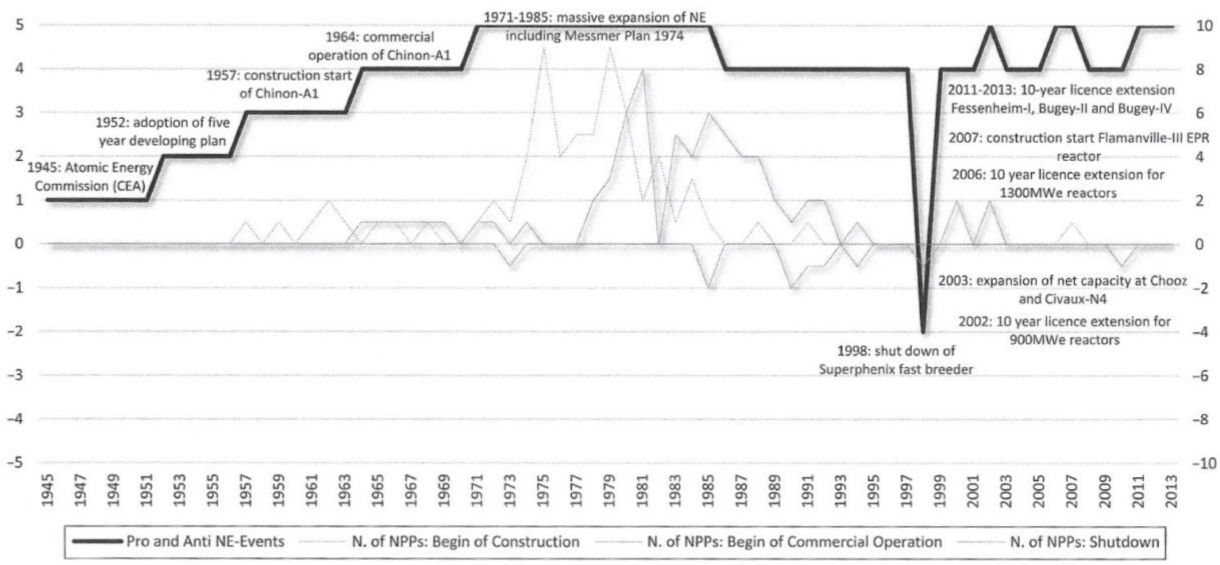


Figure 5 - Nuclear energy policy development in France, 1945-2013 (Brouard & Guinaudeau, 2017)

The French situation is definitely different than the two others big EU nations, since the size of the nuclear fleet is considerably higher and in fact no complete phase out has been decided, but only the decommissioning (and possible partial replacement) of the older plants. The figure above shows the French nuclear policy development, but the more recent decisions on the reduction of the nuclear capacity to 50% of the electricity mix are not included.

Anyway, one could have expected that “a pro-nuclear consensus amongst major political parties and the depoliticization of the issue have been among the conditions of the enduring commitment to nuclear energy in France” (Brouard & Guinaudeau, 2017). In fact, despite the anti-nuclear protests which in the 1970s affected France as much as the other European countries, basically no party was opposed to atomic energy before the creation of the Green Party in 1984, and the issue was almost never part of political manifestos (Brouard & Guinaudeau, 2017), probably due to the military implications, too.

However, two opposite political forces were the most favourable to nuclear technology: the generally centre-right Gaullists, which politically initiated and developed the French nuclear program (both civil and military) having their leaders elected president between 1959 and 1974, and the communist party, which were following the same positions of its trade unions in EDF and of its USSR’s homologue. The centrist forces, headed by President of the Republic V. Giscard d’Estaing during his 1974-1981 term (the peak period of the demonstrations), were also actively in support of the policy. His successors’ Socialist Party (PS), instead, was the most critical, even though it was never openly against: Mitterrand, in fact, even if forced twice to “cohabitation” centre-right governments, introduced safety reviews for the plants and limited the numbers of projects under construction throughout his two presidential terms, from 1981 to 1995 (Brouard & Guinaudeau, 2017).

Things changed (but not drastically) in the ‘90s, when the PS had to depend on the Greens to reach parliamentary majority which triggered Prime Minister Jospin’s long cohabitation government with centre-right President Chirac between 1997 and 2002. This coalition, indeed, decided on the closure of the fast breeder reactor Superphénix mentioned above. However, the stances of the two parties differed in the following years: the Greens committed to a phase out by 2030, the PS preferred the downsizing of nuclear power in the energy mix and its replacement with renewable energy, and remained true to this position (a reduction from around 70% to 50% of the electricity mix by 2025) during Francois Hollande’s 2012-2017 presidency (Brouard & Guinaudeau, 2017). His government, however, did not reverse the decision of building new reactors in Flamanville and in Penly, taken respectively by Chirac in 2005 (during his second term) and by his successor and party colleague Sarkozy in 2009. The current President of the French Republic, the independent centrist Emmanuel Macron, in 2018 delayed

Hollande's deadline to 2035 (World Nuclear News, 2018), but in November of the following year French newspaper le Monde reported that the government had asked EDF to prepare the plans for building 6 new reactors (denominated EPRs) over 15 years (Protard, 2019), a program whose estimated cost is €46 billion (Thomas, 2019).

Among the factors identified as facilitators for the reversal on nuclear energy policy, then, only the influence of the Green party had an effect on the French situation, mainly prompting the Socialists (and now also Macron) to forecast a reduction in the reliance on nuclear power. In all likelihood, the behaviour of the political forces, however, was not driven to change or to actively politicize the issue by the low public salience of the topic itself, and this can be understood from the lack of political response in France to international nuclear incidents. The partial phase out policy, in fact, was probably due to the ageing of the reactor fleet in the first place, rather than to a political decision.

1.4. The institutional and regulatory framework on nuclear power

In order to finalize the discussion on the political governance of the nuclear energy programs and the phase-out decisions, and before proceeding with the analysis of the implications of this kind of policy reversal on the electricity markets of the countries examined (and on the EU scenario), it is useful to briefly assess the jurisdictional aspect of the issue.

Representing a very particular energy source with relevant safety, national security and possibly also military implications, in fact, nuclear energy usually stands on very specific organisational patterns and legal schemes (covering for instance specialised authorities and committees, scientific and research councils, but also public subsidies and incentives or compensation systems for the communities hosting the sites), whose full understanding is essential to have a comprehensive view of what the a nuclear phase out means.

In a characteristic example of a centralised state like France, the policy making on nuclear energy has always been managed by the central government and its branches. This is even truer in the French context due to the military implications of nuclear technology in the country.

In the past, "the CEA and EDF developed plans that were submitted for the government's approval", and even after the partial privatization of the two organisations in the 2000s, the national government maintains a strong leverage on both of them through the appointment of "chairmen and administrators" (Brouard & Guinaudeau, 2017). The French executive also keeps “to exert a decisive influence over energy policy and planning as well as the regulation of the energy markets” with the competence of approving infrastructure projects and of controlling the energy regulatory commission’s activities on the energy prices, but also with the ownership of controlling interests in EDF, Orano (and previously in its predecessor New Areva) and a relevant minority share in Engie, the other multinational French energy utility company (Brouard & Guinaudeau, 2017). This kind of market concentration in the sector, even if maybe economically convenient given the already amortized investments and the regulated prices, is however difficult to reconcile with the EU competition policy, and indeed the liberalisation in France has been “slow and limited” due to the opposition of trade unions and government bodies, which have delayed the transposition of EU directives or bypassed them through the creation of new subsidiaries with minority, but relevant, public ownership share (Brouard & Guinaudeau, 2017).

Additional agencies charged with the control of other segments of the nuclear sector in France are the Nuclear Safety Authority (composed of five commissioners appointed by the President of the Republic and by the presidents of the two parliamentary chambers), the Institute of Radioprotection and Nuclear Safety, and the Nuclear Radioactive Waste Management Agency. Moreover, the Nuclear Policy Council assists the President in the legislation regarding atomic energy (NEA & OECD, 2011a).

The adoption of executive initiatives on nuclear power, anyway, “is regularly submitted to a parliamentary vote”, and in much greater numbers than just considering the annual budget laws: the most important decisions, especially those that provided for public expenses, have indeed been “scrutinized and voted on by French MPs” (Brouard & Guinaudeau, 2017). Other issues, like the localisation and the timeframes for the construction of the plants, are however tackled directly by the government with decrees, but on the basis of laws which entitle the executive to do it.

Regarding fiscal matters, the most important consideration (looking particularly at the problems raised by the phase out and decommissioning of nuclear plants) regards the revenues collected with the “flat-rate tax on network infrastructure companies” (Imposition Forfaitaire des Entreprises de Réseaux, IFER), which are allocated to local authorities: in this case, typically the municipalities (or the communities of municipalities) hosting the nuclear plants (Bercy Infos, 2019). It is a relevant issue because when a plant is shut down, its local authority would suffer the loss of such tax revenues, as was feared to happen in Fessenheim, a long-time disputed nuclear plant at the border with Germany which is supposed to be completely closed in June 2020 after the first of the two reactors has already been disconnected in February of the same year (Proctor, 2020). To satisfy the local communities, in fact, the French Government had to create a 3 to 5-year-long compensation mechanism for the IFER losses and an intercommunal solidarity fund with the other localities hosting nuclear plants, for a total of €32 million in offsetting measures (Nguyen Ba, 2020).

This multi-faceted institutional organisation on nuclear power, along with the significant dimension of the nuclear sector for the economy of France (which will be further analysed later), the aforementioned civil-military interrelations and the political and social positions described above represent a very powerful status-quo establishment which contributes to explain why only a partial reduction of the nuclear capacity has been decided in the country, and a complete phase-out is instead very unlikely to be ever discussed.

Before moving on to the federal context of Germany, it appears appropriate to address the Italian situation, which lies halfway between a centralised and a decentralised state. In addition, as already mentioned, the Italian nuclear energy program started without a comprehensive national regulatory framework, but rather on the independent initiative of public/private ventures.

SELNI, SENN and SIMEA, in fact, built three of the total four nuclear plants which have ever entered in service in Italy, before being absorbed by ENEL with the nationalisation of 1962. However, the electricity monopolist was not fully vertically integrated in the atomic energy sector: its Oil&Gas counterpart ENI was in charge of the nuclear fuel supply, while the components were provided by engineering operator Ansaldo. Afterwards, when ENEL become a partly privatised joint-stock company in the ‘90s, all the phase out activities related to the waste management and decommissioning of the nuclear plants initiated after the 1987 referendum were transferred to state-owned SOGIN (Società Gestione Impianti Nucleari), which still manages them to the present day (Franchino, 2017).

The main government bodies responsible for nuclear energy were the Ministry of Industry (later Ministry of Economic Development), and the Inter-ministerial Committee on Economic Planning (CIPE), chaired by the Prime Minister and composed by the ministers with competences on economic policies and spending power. While the first was charged with “the licensing procedures” of the nuclear power plants and with the draft of the National Energy Plans (the comprehensive lay-out documents on the Italian electricity system), the latter was tasked with “establishing the national nuclear power programme” (NEA & OECD, 2010), namely with the most important decisions on the life cycle of the plants: localisation, construction and shut down; this kind of “green light” choices, however, depended extensively on the parliamentary support for the government, and this therefore downgraded in a relevant way the room for manoeuvre of the CIPE (Franchino, 2017).

After the legal framework on the regional competences was introduced in the ‘70s, furthermore, the consultation with the regions was required, and a multilateral body was created: the Consultative Interregional Committee, replaced since 1983 with a permanent State-Regions Conference; municipalities, instead, were not involved with this kind of cooperation and coordination congresses until 1996 (Franchino, 2017).

The Minister of the Environment traditionally has been responsible for the environmental impact assessments of the nuclear plants, while the competencies over nuclear safety, radiation protection and control on nuclear waste management have been reorganised several times before and after the phase out was decided and confirmed with the referendums of 1987 and 2011, and the former also enshrined the abolition of the rewards meant for compensating (similarly to the French IFER) the communities and local authorities hosting nuclear (but also coal) plants in their territories (Franchino, 2017).

The decommissioning activities on the Italian plants and their nuclear waste treatment, still under way, are being financed directly by the Italian consumers with a component of the electricity tariff (SOGIN, 2020).

The German context, in comparison to the two others, is instead described by “the inherent conflict between a policy-deciding federal government and policy-implementing governments at the Land level – even if they share the same party affiliation” (Thurner, 2017). The involvement of the federated states in the energy supply is guaranteed by the German Constitutional Court, which identifies this policy field as part of the public services to be provided by the Länder.

So, in the beginning of the program a comprehensive piece of legislation was needed in order to provide a regulatory and jurisdictional framework on nuclear power policy: this was exactly the case of the Atomic Energy Act of 1959/1960, which declared the objective of promoting nuclear research and development of its energy uses, but did not address the issue of the “concurrent competence” with the Länder. Since 2006, however, a constitutional reform has assigned exclusive competence over nuclear energy to the federal level of government (Thurner, 2017).

Therefore, it is important to identify the most important departments of the national executive for nuclear energy matters: apart from the Ministry for Atomic Affairs, which later become for Education and Research as already explained, it is mainly the case of the Ministry of Economic Affairs (and for Energy since 2013, too). The several changes in the denomination of such departments largely depended on the “jurisdictional and bureaucratic dynamics of the political agenda” (Thurner, 2019). At the initial stages of the nuclear program, such government bodies established the “Atomic Commission” and a range of atomic research centres, with the agreement and the cooperation of other relevant actors like local authorities, but also the scientific community and the private utilities.

Shortly after Germany joined the International Atomic Energy Agency (IAEA) in 1957, then, “a commission on reactor safety was set up” and nuclear research programs were launched. The Ministry for the Environment, also with nuclear safety responsibilities, was instead created after the Chernobyl incident in 1986, but its administrative position did not include critical opinions on nuclear energy until a Minister from the Green Party took office in 1998. This ministry was intended to supervise the coordination with the Länder over the control on nuclear power plants, but the increasing politicization of the issue which derived from the rise of the Greens in some Länder necessitated more elaborated negotiations between the different level of governments. This situation resulted in a sort of “veto power” for the authorities involved, and this is the reason for the recentralisation of the policy field in the hands of the federal government (Thurner, 2017).

The regulation and the control of the nuclear waste treatment, which represent the main activity required by the decommissioning of the plants decided with the phase out policy, is responsibility of the Federal Office of Radiation Protection (Thurner, 2017), coherently with the previous task of nuclear fuel custody and transport licensing (NEA & OECD, 2011b).

The costs liability scheme related to the decommissioning of the plants and the “nuclear fuel tax” levied on them were instead bone of contention between the utilities which operated the reactors and the German Government, as much as a controversial issue is represented by the lack of compensation for the loss of the “nuclear tax” which rewarded the areas hosting the plants (Kallgren, 2020); such aspects will therefore be further analysed in the third part regarding precisely the operators.

In conclusion, the assessment of the differences (and the similarities) in the regulatory organisation of the nuclear energy sector in the three countries under consideration is not only important for drawing their implications for the governance of the phase out process, whether complete or partial, but also for understanding their contributions to the decision on the policy reversal itself; probably, besides, one of these two aspects was more relevant than the other depending upon the country examined. In fact, it is reasonable to argue that while, for instance, the compensation mechanism established in France for the communities deprived of the IFER tax revenues and the electricity tariff component of the Italian power bills assigned to cover the nuclear decommissioning costs are interesting features of the phase-out process, the national influence of rise of the Greens in some German Länder is more an element of the reversal itself.

Chapter 2: Market level

After having reviewed the role of the political level of the governance system in shaping the nuclear energy policy and especially in determining its reversal towards a complete or partial phase out decision, this chapter assesses the effects of the renounce to nuclear technology in the power generation on the electricity market (internal and European) but also on the energy mix options at a system level and on the carbon emissions of the countries under consideration.

On the one hand, indeed, the objective of this chapter is not to provide a consistent mathematical modelling for the economical quantification of the effects of the three nuclear phase out experiences (or plans) and their influence on the electricity trade in the EU, but rather to gather the most relevant estimates already developed by the academia to draw both significant qualitative considerations and a general quantitative overview of the direction and order of size of such impacts.

On the other hand, this chapter also deals with an overall assessment of the phase out policy from the point of view of the environmental impact, trying to understand if the technological developments and the cost-effectiveness of renewable energies have enabled the replacement of nuclear plant with the “new” renewables (solar and wind) in order not to have a negative impact on the carbon content of the power system of a country in a period marked by the challenge of limiting climate change.

The following analysis will follow these common threads, starting with the Italian experience since the limitation of the effects to the internal market reasonably allow to simplify the identification of some impacts of the phase out process (even if probably not on the prices), while the second subchapter will also deal with the complexity of the import/export of power in the EU integrated market when assessing impacts of the phase out in Germany and, prospectively and partially, in France.

2.1. Internal market: the Italian case

The phase out of the Italian nuclear energy program was characterized not only by the monopolistic organisation of the electricity market, but also by the limited extent of the reactor fleet. In 1987, in fact, only three plants were operating, as shown in the figure below: two out of the original three ones built in the ‘60s (the third had already stopped operating in 1982), different from each other in the technology and pretty small for generation capacity by modern standards (ranging between 150 MWe and 260 MWe), and the Caorso nuclear site, by far the largest and most modern with 860 MWe of installing capacity, turned on in 1978 (Baracca et al., 2017).

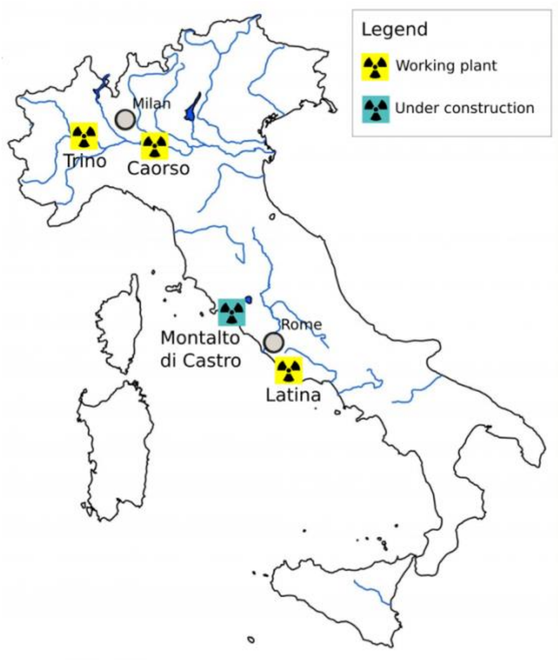


Figure 6 - Nuclear power plants in Italy in 1987: operating and under construction (Hardenberg, 2011)

Two other reactors, however, were under construction at that time in the new site of Montalto di Castro (around 980 MW each), while for two more (950 MW each), next to the already existing plant of Trino Vercellese in the plans, the final design had been approved and the procedures initiated (Franchino, 2017).

Also due to this small size of the program, anyway, the nuclear share of electricity generation had passed from 4,2% in 1965 (a world record at that time) to just 1,2% in 1980: over this period, in fact, the demand had more than doubled while the nuclear power supply had even reduced by one third due to the low prices of heavy oil sold to ENEL for electricity generation, which made "nuclear energy too expensive" (Zorzoli, 2017).

So, despite it seems reasonable that the World Nuclear Association in its "country profile" section on Italy describes the phase out as responsible for "major costs for the whole economy" and points out that "due to the high reliance on oil and gas, as well as imports, Italy's electricity prices are well above the European Union average" (World Nuclear Association, 2018), the topic probably deserves a closer and more in-depth look.

It is extremely difficult, in fact, to assign (exclusively) to the abandonment of nuclear energy the responsibility of high prices of electricity in Italy, and the assessment is complicated also because while the German and French cases concerned respectively the phase out and the downsizing of an already relevant source of electricity, in Italy the nuclear energy program was closed before arriving to full load regime.

Nevertheless, some considerations can be drawn anyhow, at least on the amount of the overall costs, considering indeed what could have been the further development of the Italian nuclear power program and what instead have been the real trend of the energy mix.

After the phase out of nuclear energy, in fact, the electricity generation in Italy has been based mostly on (largely imported) fossil fuels: initially oil-fired power plants and then, since the turn of the century, gas-fired (or CCGT) plants; electricity imports have also considerably increased, while the relevant hydropower production has remained roughly constant, but as a consequence its share of the electricity mix has declined (Gilardoni et al., 2009). The “new” renewables like solar and wind power, instead, have rapidly become significant only in the past decade, resulting in Italy’s achievement of its EU 2020 target already in 2014 (Eurostat, 2019).

On the other hand, to assess the potential development of nuclear power if there had not been the phase out decision, it is appropriate to consider (at least) two scenarios, as explained by Gilardoni et al. (2009):

- The first including only the three plants operating in 1987 (of which the two oldest supposed to complete their life cycle between 1992 and 1994) and the Montalto di Castro nuclear site;
- The second including, in addition, also the two more reactors planned in Trino and other 4 (1 GW each) forecasted in the National Energy Plan of 1981.

In both scenarios, the nuclear capacity would have replaced (or avoided) fossil fuel-based power generation, since as already stated first oil and then natural gas have been the sources which has emerged as the pillars of the Italian electricity system.

The cost-benefit analysis conducted by Gilardoni et al. in 2009, taking into account a fair number of factors (for instance, the trends in the development of fossil fuels prices, which influence the convenience of nuclear generation, but also the avoidance of the early decommissioning costs and the relative reduction of fossil fuel imports), concluded that the phase out had costed between €28 and €45 billion. Even if it is difficult to quantify specifically how much of this figure would have practically resulted in lower prices in the electricity tariffs for Italian consumers and industries, at least two components, the early decommissioning costs (around €17 billion in both scenarios) and the higher costs of power generation from fossil fuels (between €8 and €21 billion), seem to be directly related to the effects on electricity prices.

Given the high carbon content of the alternatives which replaced the nuclear power share in Italy, then, there is reasonably no doubt that the phase-out decision had negative effects on the environment, because the emission of between 291 and 699 Mton of CO_2 could have been avoided with the continuation of the nuclear program, alongside the release of other harmful gases like NOx, SO_2 and PM10 (Gilardoni et al., 2009). Other kind of impacts, related for example to the depletion of the know-how on nuclear technology in the Italian industries, will be analysed to the last section, dedicated to the operators.

Such effects (apart from those related to the CO_2 emissions) are all exclusively pertinent to the internal Italian situation. But, as briefly hinted above, the phase out of Italian reactors did have implications also at an international level, since the electricity imports of the country increased in the following decades, especially from France, Switzerland and Slovenia (which coincidentally all rely on relevant shares of nuclear power), reasonably contributing to the upward trend in the electricity bills: in 2012, they were 40% higher than the French ones (Urso, 2012).

In conclusion, it appears that, considering a net balance, the nuclear power phase-out in Italy had mostly negative effects on the electricity market and the energy system of the country. Considering the classic energy trilemma (Wyman, 2019), in fact, the decision:

- Reduced energy security given the fact that it triggered the further reliance on energy imports (both fossil fuels and electricity) and thus increased external energy dependence;
- Undermined energy equity (or affordability) because the electricity prices raised, especially since the early decommissioning costs were directly charged in the electricity bills;
- Affected environmental sustainability, because GHG emissions rose due to the replacement of nuclear power with fossil fuels-based generation capacity.

This quite negative conclusions are probably influenced by the fact that the phase out was forced by the result of the national referendum, and not managed as a gradual organised process initiated with a coherent political decision-making.

Moreover, in 1987 the level of political awareness and urgency on the problem of climate change related to the emissions of greenhouse gases was not comparable to what is today, and this probably influenced the energy alternatives which replaced nuclear technology for power generation, even if by the time the decision was being implemented with the shut-down of the plants in the early ‘90s, the international debate which laid the ground for the United Nations Framework Convention on Climate Change (UNFCC) of 1992 and the Kyoto Protocol of 1997 had already started.

Ultimately, the replicability of Italy’s features regarding nuclear phase out is probably limited (particularly regarding the limited size of the plants fleet), also considering that the different cost structure of the renewables nowadays probably allows to imagine different replacement options at least in part.

2.2. Consequences on national and EU integrated markets: Germany and France

In the case of the two other EU largest economies, the assessment of the impacts on the electricity prices and on the energy system of the nuclear phase out or decommissioning policies have been addressed more extensively also by academic sources, partly because such procedures have been taken in the context of a more orchestrated political decision-making (even if Merkel’s 2011 decision was a sudden reversion to his predecessor’s positions) and with the clear idea of a gradual process, although relatively rapid in the German situation.

The background conditions have also changed, as already mentioned, particularly considering that:

- renewable energies have become increasingly cost-competitive (especially, with respect to the topic of this thesis, compared to new, more technologically complex nuclear plants);
- the climate change issue has become increasingly pressing, and the EU have taken measures to push its member states to tackle the problem of carbon emissions and to promote renewables;
- the EU has introduced policies aimed at the liberalisation of the member states’ energy markets and their integration into a common market for electricity and gas,

with a view to ultimately establishing a complete “energy union” (European Commission, 2020).

The first two considerations, therefore, imply that is fair to assume that the underlying objective (and thus also the ultimate yardstick) of the ongoing phase-out in Germany and of the prospective nuclear capacity reduction in France is represented by the replacement of the nuclear generation share of the energy mix with renewable sources, at very least in the long term. In fact, this is specifically explicated in the German Energiewende, but the success of such energy strategy is complicated by the concurrent (and much more important for the reduction of low carbon emissions) process of phase-out of coal power generation, scheduled for 2038. For France, instead, the partial replacement of nuclear plants with solar installations and wind farms is basically the only choice for respecting its country-specific EU renewables target.

The last consideration, on the other hand, means that such nuclear phase-out or downsizing plans increasingly carry implications for the energy systems of other European countries, too. In fact, the import/export of electricity within the EU has become increasingly relevant, and for the cases in point, as will be analysed in this chapter, the effects of the German nuclear phase-out policy and of the French reduction plans could be particularly significant respectively in Poland and Italy.

2.2.1. The market and energy system impacts of the German nuclear phase-out

Since the decision of phasing out nuclear energy was taken by the second Merkel cabinet in 2011, many researches have tried to assess the effects on the electricity prices, but also on the emissions trend and on the composition of the prospective energy mix. In this situation, too, like in the Italian case, it is difficult to identify and isolate the impacts of this specific policy on the electricity market, because the German energy system has been going through a drastic overhaul in implementing the so-called Energiewende.

In addition to the nuclear phase-out by 2022, in fact, Germany has undertaken a wide range of actions for transitioning to a low-carbon and nuclear-free energy system (Wettengel, 2018), namely:

- phasing out coal for electricity generation and coal mining activities by 2038 as already stated;
- promoting renewable sources (solar and wind power) and sustainable transport and storage technologies like hydrogen;
- expanding the power grid and improving its reliability in supporting the growth of renewables;
- fostering energy efficiency initiatives;
- curbing greenhouse gases emissions.

The discussion on the success performance of this massive ongoing energy transition program is not the focus topic of this thesis, but this overview of its huge scale is important to understand the difficulty in identifying the effects exclusively related to the nuclear phase-out.

However, as mentioned, researchers have provided estimates of such consequences since the first decision of phase out in the early 2000s, and not only limited to the German internal context, but also related to the European level.

At first, in fact, the financial impacts for the operators of the plants were assessed, concluding that the "distribution of phase-out costs across companies changes considerably for the various regulation schemes, revealing an important equity dimension of phase-out policies" and thus that the German regional utilities "have different stakes in the negotiations with the government on alternative regulation schemes" (Böhringer et al., 2002). This particular aspect of the topic will be further assessed in the section dedicated to the operators, alongside the estimates of the costs to be covered by them through specific provisions.

Then, anyway, the evaluation of the kinds of prices impacts as such become matter for discussion.

In this respect, these kinds of effects have been differentiated between direct and indirect (Bode, 2009). The first "can be observed on the electricity market as a change in the merit order", meaning that since electricity suppliers use their marginal costs of production as a reference for their price offers in a (liberalised) spot market, "in case there is no substituting power plant for the missing electricity production at similar marginal costs, a shift in the supply function to the left is induced, followed by the formation of a new equilibrium in the marketplace" at a higher price (Bode, 2009), as can be observed in the figure below. This effect is obviously independent from the presence of an emission trading scheme like the European ETS.

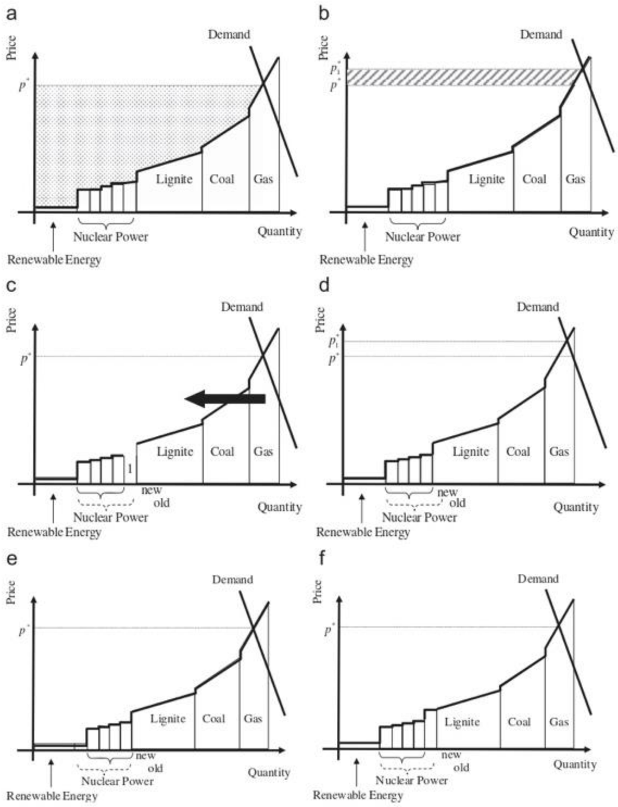


Figure 7 - Representation of the direct effect in the merit order (Bode, 2009)

On the other hand, the second effect regards the type of power generation technology which compensate or replace the capacity lost with the shut-down of the nuclear plant. In presence of an emission trading scheme (with a positive price of carbon), in fact, if the generation capacity of the nuclear plant is replaced by a CO_2-emitting power station (for example coal or gas-fired), "the marginal costs of electricity production rise and consequently the electricity price does too" because power production "becomes more expensive" in fossil fuels plants when their operators have to consider this carbon price in their cost function (Bode, 2009).

Later works have started to quantify the impacts of these price effects, mainly in wholesale prices, since generation costs represent only a fraction of the retail bills. Such kind of estimates "either focuses predominantly on empirical evidence […] or the simulation of the phase-out with numerical models for the analysis of future impacts", with the latter depending on the assumptions on the timeframe of the process, on the competition level of the market, and on the extent of the scenario under consideration, namely if the analysis is limited to the German national context or includes the wider European one, too (Traber & Kemfert, 2012).

The empirical assessment described an increase of around 1 Euro cent per kWh in 2011 as direct effect of the moratorium (Matthes et al., 2011, as cited in Traber & Kemfert, 2012), while different model calculations ranged between 0,5 and 2,5 cent per kWh of price increase “in off-peak hours” respectively due to the moratorium and the complete phase-out in Germany (Kunz et al., 2011, as cited in Traber & Kemfert, 2012); and between 0,4 and 0,9 cent per kWh in 2030 European context as result of a fully implemented phase-out in Germany (Füsch et al., 2012, as cited in Traber & Kemfert, 2012).

The result of a “dynamic long term Cournot-Nash equilibrium model of the electricity sector of the European Union with market based supply and investment decisions under the presence of an emission trading system” conducted by Traber and Kemfert (2012), instead, revealed that prices in 2020 were forecasted to increase between 0,2 and 0,6 Euro cent per kWh in Germany due to the nuclear phase out, depending on the scenarios regarding the EU ETS (which influences the extent of the indirect effect) and the energy efficiency policies. The impacts were calculated to be comparable in Austria and Switzerland due to their high degree of integration and connection with the German energy system, while in other European areas even the highest price effects would have represented half of the German figures (Traber & Kemfert, 2012).

In this kind of estimates, no single specific technologies are exclusively identified for the replacement of the nuclear capacity, on the contrary the prospective electricity mix is considered exogenous for the plants already under construction, while the others (whether renewable or fossil fuels) are based on the legislative measures in place (for instance the EU requirements on renewables share and the Energiewende plans) and tested for profitability endogenously.

Similarly, a mix of fossil fuels and renewables is supposed to replace nuclear capacity in the model set up by Bruninx et al. (2013), but particularly in the short-term coal-fired generation is identified as the main replacement option. This study also envisaged the inadequacy of the power network in the perspective of the higher penetration of renewables gradually triggered by the Energiewende policies, and evaluated such factor as responsible not only fir forcing relevant curtailment measures, but also to significantly obstruct (and thus reduce) Germany’s electricity exports mainly to Poland (Bruninx et al., 2013).

Another approach, on the other hand, consists in assuming a specific technology to replace nuclear capacity in the first place, and then assessing the price effects. This was the case of the evaluation conducted by Knopf et al. in 2014, where either coal or natural gas (or a combination of them) were envisaged to replace nuclear generation in Germany. Additionally, this kind of model was based on exogenous fossil fuels and carbon prices, and the results forecasted increasing electricity (spot) prices for baseload power until 2020 and a decreasing trend for the following years due to the growing predominance of the renewables in the electricity mix. Carbon emissions, although limited by the ETS allowances at an overall European level, were also supposed to be affected in Germany by a 2022 phase-out, meaning that the national reduction would have been more pronounced with a life-time extension for nuclear plants until 2038 (Knopf et al., 2014). This study, however, pointed out that the sensitivities over CO_2 and fossil fuel prices were both critical for the results of the model and more influential for the wholesale price impacts "than the nuclear phase-out itself" (Knopf et al., 2014).

Nevertheless, the assumption of fossil fuel replacement of nuclear capacities was not far-fetched, as a more recent paper by Jarvis et al. (2019) found out precisely that "the lost nuclear electricity production due to the phase-out was replaced primarily by coal-fired production and net electricity imports". Availing of machine learning algorithms, in fact, these researchers have estimated not only the costs of the German electricity production after the phase-out policy (and thus their effect on the electricity prices), but also the social costs resulting from the higher "global and local air pollution emissions". Similarly to the analysis conducted for the Italian case, also this model have been used to assess what could have been the development trends (particularly of prices and emissions in this instance) in a "counterfactual no-nuclear-phase-out scenario", after having tested its good performance of predictability of the real figures observed in the data between 2015 and 2017 (Jarvis et al., 2019).

The machine learning algorithm applied to this context concluded that the phase out had resulted in an increase in wholesale prices between \$0,5 and \$8 per MWh (all the figures have been converted in constant 2017 USD) for an average of \$1,80 per MWh, "a 3.9% increase relative to the prices that would have prevailed if the phase-out had not occurred"; in the same way, the phase out caused an emissions increase by 13% for CO_2 and around 12% for SO_x, NO_x and PM which could have been avoided with the continued usage of the nuclear plants in the period under consideration (Jarvis et al., 2019).

The subsequent aggregate cost-benefit analysis, including on the first side the higher estimated power generation (private) costs (\$1,6 billion per year), the costs for higher emissions (and the monetary quantification of the health damages caused by the aforementioned increase in the emissions (so-called external costs, \$8,7 billion per year) and on the second the (quantified) lower risks of nuclear incidents and the savings in the waste management treatment and storage, results in an overall cost of $12,2 billion per year. Interestingly, the investments in fossil fuel-generation capacity have been evaluated to largely offset the ones needed for the lifetime extensions of nuclear plants in the no-phase-out scenario, thus not affecting the general picture.

The results of the academic estimates are at least partly in contrast with the observations of the 2019 edition of the WNISR cited in the beginning of this study, which states instead that the "remarkable increase of renewable electricity generation (+120.9 TWh) and the reduction in domestic consumption (–20.3 TWh) were far more than sufficient to compensate for the reduction of nuclear generation (64.6 TWh)", for the reduction in power generation from fossil fuels and for an increase in net electricity exports, as shown in the figure below (Schneider & Froggat, 2019).

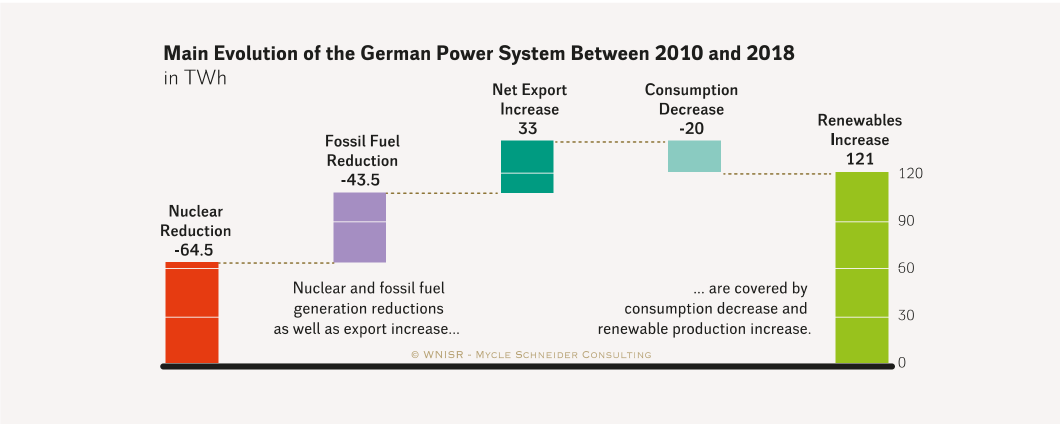


Figure 8 - Evolution of Germany's power system between 2010 and 2018 (Schneider & Froggat, 2019)

The main reasons for this discrepancy between the conclusions of these academic and consultancy sources may lie in inconsistencies in the methodologies and in the objectives of the researches, alongside in the differences between the overall development of the German electricity mix and the specific replacement of the nuclear capacity (known to represent baseload power) with other generation technologies presumably with a comparably stable output. Additionally, precisely the WNISR points out that "within the fossil-fuel generating segment, for the first time in 2018, all primary fuel-uses decreased compared to the previous year *and* remained below the 2010 level", while all the academic works consider the period previous to 2017 (Schneider & Froggat, 2019). Therefore, it remains fair to assume that, at least in the short-term, nuclear capacity was actually replaced by coal power generation (particularly lignite), although renewables have genuinely become the pillar of the German electricity system in more recent years.

Anyway, even if the cost estimates materially depend on the replacement technology, the negative effects on the wholesale electricity prices and on greenhouse gases emissions are clear in their direction. Without the nuclear phase out, in fact, the reduction in the power generation from fossil fuels and thus in the carbon emissions from the power sector would have arguably been larger and faster, with benefits both for the economy and the environment.

Such impacts were calculated to be considerably higher in the internal German context than even in neighbouring countries (except Austria and Switzerland due to their energy integration), but nonetheless the decision had sparked debate outside its borders, too: for instance, in fact, in 2019 a group of around 100 Polish academics wrote an open letter to the German people and institutions asking to reconsider the nuclear phaseout plans, "serving as an example" for other countries in the climate change fight (World Nuclear News, 2019b).

2.2.2. The prospective effects of the partial French phase-out

The planned reduction of the nuclear capacity in France, as already stated, is probably more the result of an ageing reactor fleet than a of a specific policy direction. The country remains committed to atomic energy, and in fact it was the main advocate for its recognition as eligible of EU green and sustainable financing taxonomy, against the opposite position of Germany (Barbière, 2019).

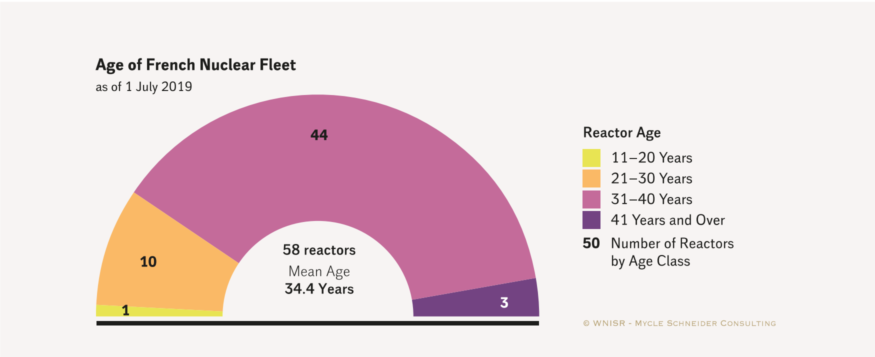


Figure 9 - Age groups of French nuclear fleet (Schneider & Froggat, 2019)

Anyway, as highlighted in the figure above, the French nuclear fleet has a quite old average age, since most of the French nuclear plants (37 out of 58) have been built in the decade between 1975 and 1985, and will therefore "reach the end of their lifetime between 2025 and 2035 and will need to be either replaced by new plants or retro-fitted via investments in order to prolong their lifetime" (Malischek & Trüby, 2016). The replacement with new nuclear plants, given their increasing engineering complexities, is hindered by the huge investment costs required. As already mentioned, and as further demonstrated by the stance on the recognition of nuclear as sustainable option, the French government seems ready to follow this path at least in part, with the new plan for EDF's 6 new EPR reactors. But the company's estimates for the investment expenditures for such plan, already amounting to €7,5 - €7,8 billion per reactor for a total of €46 billion (Thomas, 2019), do not appear to take into account that the costs of its only reactor of this kind under construction in France so far, the third of the Flamanville site, had been revised upwards several times until the current estimate of €12,4 billion, as much as its commissioning was delayed over and over to 2022 (Keohane, 2019b).

Therefore, even assuming the successful outcome of this new program, such prohibitively expensive investment costs would probably prevent the full replacement of the existing reactors fleet with new ones also without the other relevant factors like the political intention and the EU requirements on renewable share. France, in fact, (leaving aside the implications of the COVID-19 pandemic) is unlikely to meet its national target of 23% of energy (consumption) from renewable sources for the 2020 EU framework (Psaledakis, 2019), highlighting the need for speeding up the efforts in this direction. This is precisely why it has been stated previously in this study that the renewable option appears to be the only replacement choice in the partial phase out policy (in addition to the planned new EPR plants).

Anyway, academic cost estimates have been conducted both for a complete phase out of the French reactors and for other (more realistic) scenarios of partial reduction in the internal national context and, given the relevance of France as net exporter of electricity in particular towards Italy and Belgium (Bianco & Scarpa, 2018), the effects of such scenarios on other European countries have been assessed, too.

The complete phase-out scenarios (and especially the ones hypothesizing no gradual implementation period after the decision), however, assume that the replacement technologies are represented by conventional fossil fuel generation, since in this situation rapidly compensating for the waiver of large baseload capacity would be needed (Malischek & Trüby, 2016). Such immediate phase-out estimates, indeed, are also the most expensive alternatives, particularly because prolongation of the lifetime of the plants may represent a much more affordable option: renouncing to these lifetime extensions and opting instead for an immediate phase-out would represent the costliest policy choice, amounting up to around €76 billion (constant 2010 figures) depending on the starting year decided (Malischek & Trüby, 2016). The costs of the partial reduction would be obviously significantly lower, but this figure provides nevertheless a useful order of magnitude.

These huge "deterministic cost differences in France are mainly driven by higher variable costs due to increased utilization of existing and newly built fossil-fueled power plants as well as a reduction in export revenues/higher import costs", and interestingly the burden of even such drastic reversal would be carried largely by the internal French energy system (and therefore its consumers), "with only a small fraction being passed onto the rest of the [European] power system", mainly attributable to "higher variable costs due to the non-availability of low-cost nuclear power in France" (Malischek & Trüby, 2016), resulting directly in lower imports from France and higher electricity generation costs, and additionally in rising CO_2 emissions-related prices as described by the aforementioned indirect effect.

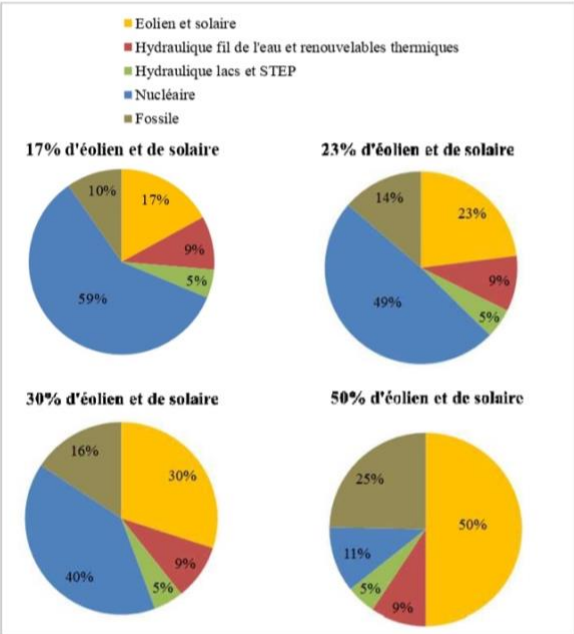


Figure 10 - French electricity mix scenarios with nuclear baseload (Cany, 2017)

More interesting scenarios regards the analysis of a prospective electricity mix with increasing renewable component, which lead to the emergence of "flexibility costs" for the adaptation of the French reactor fleet: if nuclear power is assumed to act exclusively as base-load generation, in fact, such estimates envisage the partial replacement of the reactors with fossil fuel generation, too (Cany, 2017). In this case, indeed, considering different levels of renewable (solar and wind) penetration as shown in the figure above, a rising renewable share in the French electricity mix would be matched by a troubling growth of fossil fuel based power, other than by the reduction of the nuclear capacity (Cany, 2017).

To avoid this option, which would increase the carbon content of the French power system even meeting the national and EU targets for the renewable share, nuclear reactors would need to be adapted to provide not only base load generation but also power modulation, namely reducing the load factor depending on the output of renewable production. The quantification of the overall costs and of the effects on the prices is extremely difficult, but the analysis conducted by Cany (2017), shows that this option, at least considering the LCOEs, is competitive with, for instance, the partial replacement with CCGT power generation both in the 2030 and the 2050 scenarios. This is even truer assuming the possibility of curtailing excess wind and solar generation (which would be of marginal relevance anyway) and an increase of the CO_2 prices in the EU ETS, and it even assume the deployment of the EPR plants for replacing all French remaining earlier generation reactors (Cany, 2017).

To understand the implications of the French nuclear reduction plan for other European countries, on the other hand, can be useful to consider the Italian case as example. Electricity imports, in fact, "covers ~15% of the Italian electricity consumption and most of the flow, ~85% of the total […], comes from France and Switzerland", even if at a closer look "it can be said that the largest share of energy which arrives to Italy from France and Switzerland is to be ascribed to French power plants, in particular the nuclear ones" (Bianco & Scarpa, 2018).

In all scenarios considered in a study by Bianco and Scarpa (2018), the phase out of French nuclear plants:

- "can increase fossil fuel prices" (and thus electricity prices) due to the replacement to a significant extent with thermal power stations and the "consequent increase of fossil fuel demand and price";
- "will reduce the import flow from France to Italy", and this have to be compensated by "alternative sources of electricity", including "a further development of renewables".

The results of this analysis, in fact, do not envisage the commissioning of new fossil fuel power stations, but only of solar PV plants and wind farms, even if it should be noted that the Italian electricity system is already affected by an overcapacity of thermal generation (Rossetto, 2015), and thus just increasing its exploitation and load factor would have the aforementioned effects on costs and prices.

The import reduction would be comprised between around 2,8 TWh and 0,5 TWh per month (which represents the figures of the two extreme phase-out scenarios), resulting in the need of respectively ~3,7 GW and ~700 MW of alternative source of power. In the first extreme case, which assume a complete decommissioning of nuclear reactors after 40 years lifecycle, the reduction is very problematic for the Italian electricity system, while in the other case (which appears more realistic assuming extension to 50 years lifetime for the plants), the reduction is relevant but manageable with the increased exploitation of the CCGT stations and the phasing in of new renewable capacity.

In the tightest market conditions considered (rising demand, low RES penetration, 40 years lifecycle of reactors), the baseload power price in the Italian electricity system would experience an increase from the baseline of 118€/MWh up to 132€/MWh, and the "clean spark spread" (margin of natural gas plants, including fuel costs and CO_2 prices) would also increase, from 5€/MWh to 18€/MWh (Bianco & Scarpa, 2018).

2.3. Common trends

Other than the significant unavoidable costs resulting from the decommissioning of plants before the end of their lifecycle or due to the renounce to relatively affordable lifetime prolongations, the most striking result which can be identified as common in the vast majority of the analysis considered on these three countries is the significant level of replacement of nuclear capacity with fossil fuel power generation, at least in the short to medium term.

Even if framed within large renewables expansion programs, in fact, nuclear phase out policy systematically appears to be damaging for the environment from the point of view of carbon emissions at the very least in the earlier stages of the process, requiring either new thermal generation capacity or the increase in the exploitation (load factor) of the existing one for maintaining the level of baseload power needed by the system.

This has implications for the replicability of the "nuclear phase-out model" outlined either by these country-specific experiences or by their common features. Unless new technological advancements further improve the reliability and stability of wind and solar power, enabling them to achieve baseload capabilities, or CCS technologies achieve cost-efficiency and adequate maturity, indeed, future decisions on phase-out policies in other countries will have to face the issue of triggering an increase of carbon emissions (or in the best case additional difficulties in curbing them) when renouncing to a reliable low-carbon energy source like nuclear power.

Given the construction delays and extremely high costs of next-generation nuclear plants, however, the phase out could still represent a reasonable choice after the completion of the lifecycle of the existing reactors (or when the maintenance costs and refuelling investments prevent the cost-effectiveness of additional lifetime extensions), because at that point the initial CAPEX would have been fully amortised and the low-carbon power generation would have drained its economic potential from the cost-benefit perspective.

The following table summarise the data and the information described in this chapter. Despite the inconsistency of methodologies, figures and measurement units, it still provides a general insight of the impacts of a nuclear phase-out process. For Germany, even if they will be assessed in detail in the next chapter, data from estimates by the Federal government and the operators are included, too.

	Source	Methodology	Impacts				
			Phase-out costs	Price increase (wholesale)	Replacement technologies identified	Electricity import/export	CO_2 Emissions
Italy	Gilardoni et al. (2009)	Cost-benefit analysis with scenarios	€28 to €45 billion	(Increasing)	First oil-fired, then natural gas/CCGT	Imports increasing	291 to 699 Mton
Germany	Bode (2009)	Merit order: direct and indirect effect	-	Increasing	Coal and gas	-	-
	Traber & Kemfert (2012)	Empirical assessment / dynamic long term Cournot-Nash equilibrium model	-	0,5-2,5 €cent/kWh (2011, moratorium and 2030, phase-out) 0,2-0,6€cent/kWh (2020, phase-out)	-	-	-
	Bruninx et al. (2013)	Multi-nodal unit commitment model with scenarios	-	Increasing	First coal, then renewables	Exports obstructed by inadequate network	Increasing
	Knopf et al. (2014)	Conventional replacement simulation model, sensitivity analysis	-	Increasing until 2020, then decreasing (baseload)	Coal and gas	-	-
	Jarvis et al. (2019)	Machine learning algorithm, empirical data and forecasts	$12,2 billion per year	1,8$/MWh (0,5-8$/MWh, 2017)	Coal (mainly)	Imports increasing	13% increase
	Schneider & Froggat (2019)	Empirical system-level data	-	-	First fossil fuels, then renewables (system-level)	Net exports increasing	Decreasing (long-term)
	Operators and Federal government	-	€875 million (2011, moratorium) Total: €48,2 billion, proj.	-	-	-	-
France	Malischek & Truby (2016)	Stochastic linear programming model, uncertainties scenarios	Up to €76 billion	-	Conventional fossil fuels	Exports decreasing	
	Cany (2017)	Interdisciplinary approach: LCOE scenarios, supply/demand forecasts	-	-	New EPRs, renewables, fossil fuels	-	-
	Bianco & Scarpa (2018)	Power market bid stack (merit order) model with scenarios	-	Increasing (France) 14€/MWh (baseload, Italy)	Renewables, gas (exploiting overcapacity, Italy)	Exports to Italy decreasing	Increasing

Table 1 – Nuclear phase-out impacts on costs, power prices, technologies and emissions for Italy, Germany and France

Chapter 3: Operators level

The operators of the nuclear power plants targeted by the phase-out policy decided at a political level are obviously the “implementers” of the process. It is up to them, in fact, to manage the decommissioning of the plants, and to bear the costs of the process (unless there is an agreement on compensation systems) but also the consequences on their business model (for instance the reconversion of the activities and relocation of jobs) and on their market reputation.

In this regard, therefore, it is appropriate to start with listing some factors, mainly related to the different time periods, which in certain respects are common for the situations of the utilities in Italy, Germany and France, and in others differentiate them:

- First, the organization of the energy system and thus of the electricity market had varied from the national monopoly in operation in Italy at the time of the 1987 referendum, and the integrated EU market of which Germany and France (but also present-day Italy) are part now, where liberalisation and competition are increasingly implemented also in the national contexts due to EU policies;
- Second, the situation regarding the role of the utility companies in these different levels of market competition is another element to keep in consideration, in part because nuclear power typically presented regulatory peculiarities which often go beyond the organisation of the market, but also because for instance EDF’s situation, given the market power at its disposal, is probably closer to the former ENEL’s one than to the German utilities even after the introduction of the liberalised market;
- Third, the technological advancement of the renewable energies and also the awareness of the urgency of the carbon emissions and climate change problem have both increased significantly and, in all likelihood, this has influenced not only the system-level and policy choices on the replacement sources, but also the utilities’ plans.

Keeping these considerations in mind, this chapter will deal with the implications of the nuclear phase out process on Italian, German and French operators, taking into account, however, that the public availability of sensitive business information, especially regarding market and financial impacts, is extremely limited, as already stated in the introduction. The analysis will start with the comparison of the situation of former ENEL and present-day EDF, while the second subchapter will be dedicated to the phase out implications for the “Big Four” German utilities.

3.1. Different kinds of “monopolistic” players: ENEL and EDF

It makes sense to analyse the phase out implications for former ENEL and present-day EDF together, because the situations of the two corporations are linked by the strong interrelationship with their respective governments, representing in both cases their main (or only) owner, but also by the dominant positioning in their respective national electricity markets, ensured by law in the past Italian case and by historical legacy (and the “special relationship” with the government) in the current French case. This, at very least theoretically, results in a cooperative position between the countries’ institutions and the electricity providers in managing the consequences of nuclear phase-out policies, for instance on the required costs or on the repercussions on labour, as opposed to the contraposition between these two kinds of actors experienced in the German situation, which will be assessed in the next subchapter.

When the referendum of 1987 enshrined the abandonment of nuclear energy in Italy, the state-owned monopolistic utility ENEL was the only operator of Italian nuclear plants, even if, as previously explained, was not fully integrated in the fuel cycle and in the componentry of the reactors.

However, only one of the three questions submitted for referendum involved directly ENEL, calling for forbidding the national electricity corporation from joining nuclear power programs abroad. The other questions, indeed, aimed to hit the regulatory framework of the nuclear power program decided at political level, and only indirectly the activities of the state monopoly. It is possible that for the promoters of the referendums was more convenient to focus the draw attention of the voters on such aspects rather than on the business of the national corporation which implied jobs.

The employment related to the nuclear plants was indeed the first issue after the implementation of the phase-out. The quantitative evaluation of the direct impact of the decision, as stated by Gilardoni et al. (2009) would be extremely difficult and characterised by unreliable results due to the high level of approximation. Therefore, following the analysis of the aforementioned academicians, it is appropriate to report just some qualitative considerations.

Firstly, as would be expected in the context of a state-owned provider, the workers employed in the constructions of the plants and in their day-to-day operations (presumably in the range of 10.000 people using rough quantification by NEA, OECD & IAEA, 2018) were largely relocated to alternative energy industries (mainly oil-fired stations in the beginning and natural gas turbines thereafter). For instance, the Montalto di Castro plant, which could not be completed due to the referendum, was indeed reconverted into a fossil multi-fuel power station.

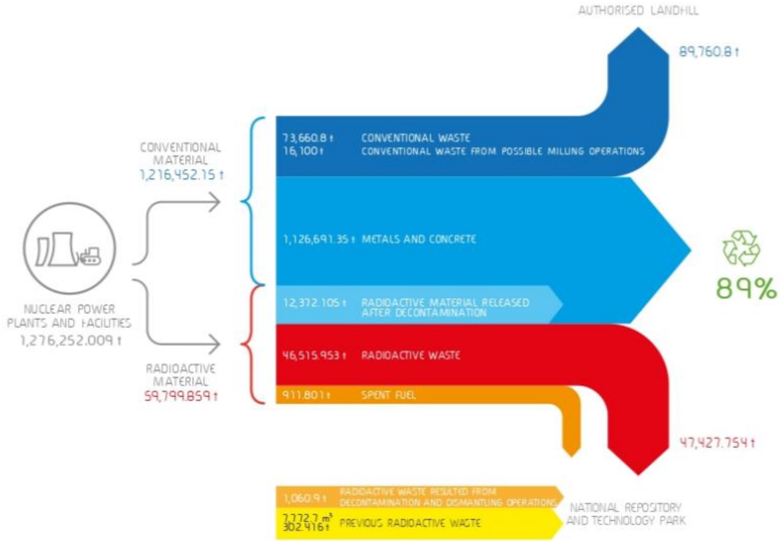


Figure 11 - Nuclear sites decommissioning process: destination of materials (SOGIN, 2020)

On the other hand, part of the workforce was employed first by ENEL and then by SOGIN for the decommissioning activities highlighted in the figure above. A similar path was probably followed by the indirect jobs employed in the ancillary companies (notably AnsaldoNucleare), which could also direct their attention to the nuclear industry abroad, not being subject to ENEL’s limitations; thus, drawing a net balance of the jobs impact is very complex.

Enel was finally able to return to nuclear activities after its partial privatisation in 1992, even if obviously not in the Italian territory: through the acquisition of Spain’s leading utility Endesa S.A., finalised between 2007 and 2010, the Italian multinational gained interests in 5 nuclear plants in the Iberian Peninsula, while it also manages several soviet-designed reactors in Slovakia through local branches, and has been involved in the sector in Romania, too. A stake of EDF’s already mentioned French EPR plant of Flamanville, instead, was relinquished by the Italian company in 2012. Anyway, the long-term consequences of the phase-out on the industrial know-how on nuclear technology may have been mitigated by the presence abroad of the former monopolist and of the ancillary companies.

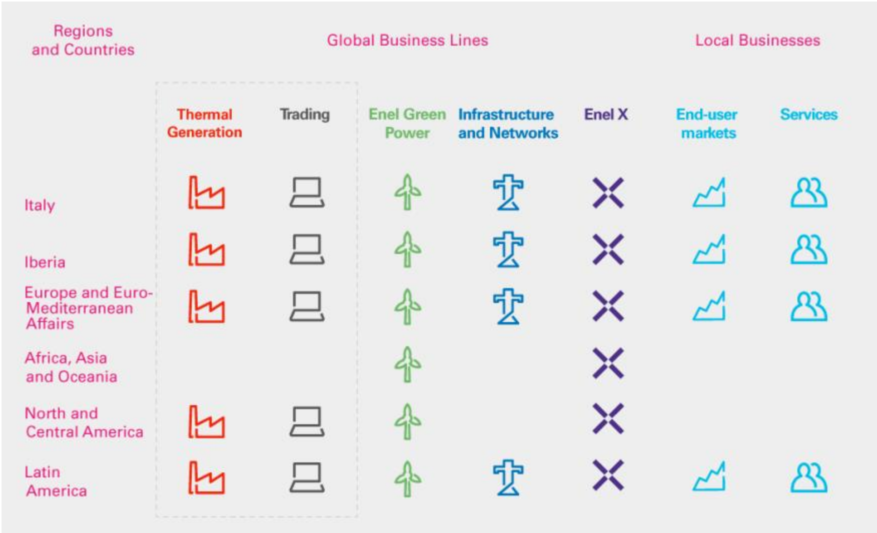


Figure 12 - Business model and international presence of Enel SpA (Enel, 2020)

The internationalisation of the Enel Group, as shown in the figure above, has been accompanied by a massive expansion of network, digital and retail services, but most of all of renewable activities: with its dedicated subsidiary Enel Green Power, in fact, the Italian multinational has become a leading player in this segment of the energy industry, with around 46 GW of renewable installed capacity across 32 countries in 6 continents (Enel, 2020).

EDF's situation, as already introduced, is comparable in some respects. The French multinational utility is still a dominant player in its home country with a market share of around 80% as of the end of 2012, also owning both the French transmission system operator Réseau de Transport d'Électricité (RTE) and the distribution network operator Enedis, formerly ERDF (Deloitte, 2015); furthermore, the company is owned by the French Government with 83,6% of the shares (EDF, 2020). Despite not representing a national monopoly, therefore, EDF's position in the French electricity system is still similar to the former ENEL's one.

The differences between the two providers (in the different time periods), indeed, do not concern the market positioning despite the liberalisation and competition policies which have been gradually introduced by the EU, but lie instead in the size of the nuclear assets operated and their importance for the company and for the energy system of the country: while ENEL managed just a few reactors representing a limited share of Italy's power mix at the time of the 1987 referendum, EDF operates 78 reactors in the world as shown in the figure below, of which 58 in France, representing 78% of the total electricity produced by the company and roughly 70% of the power mix of France (EDF, 2020).

Figure 13 - EDF's nuclear power plants and reactors (I2EN, 2018)

Likewise, the relevance of the sector for the economy of France is not comparable to what it was in Italy: nuclear energy, indeed, currently represents “France's 3rd-largest industrial sector”, with “200.000 non-relocatable skilled jobs” employed in 2600 companies, and “a positive contribution to France's balance of trade” amounting to €6 billion a year (Orano, 2020). In particular, of the overall 220.000 work force (1% of the total employment in the country), 125.000 are direct jobs (representing around 4% of all industrial jobs, of which 30.000 employed by EDF) and 95.000 are indirect jobs working in ancillary companies (I2EN, 2018).

Consequently, the implications of the French nuclear share reduction (particularly on its nuclear energy champion EDF) are extremely different than the consequences observed in Italy. The company has already lost some of its edge due to the delays and the cost rise in the Flamanville and Hinkley Point C (England, UK) EPR plants, but also to the challenge of covering its €15 billion per year of cash needs required to “maintain its aging nuclear reactors, build new atomic and renewable projects, upgrade its electricity network and roll out smart meters”, which piled up a €37,8 billion net financial dept despite continuous cost cuts and efficiencies implemented in the past years (De Beaupuy, 2019). Consequently, the stock performance has been poor compared to peers like today’s Enel, which (considering the situation before the coronavirus pandemic) posted a market cap of €69 billion in recent years, twice as much of EDF’s €28 billion, but also with respect to “smaller” players like Danish wind power operator Ørsted A/S and German provider RWE AG (De Beaupuy, 2019).

In order to “turn the wind”, then, EDF’s management has undertaken some initiatives, on the one side asking the French government (its main shareholder) to raise the regulated prices (unchanged since 2012) at which competitors like Oil&Gas majors Total and Eni, but also other utilities like Engie, can buy its nuclear power to resell on the French market (De Beaupuy, 2019), and on the other side planning a significant restructuring to split core-businesses of nuclear and hydropower (“EDF Bleu”) from new renewable activities, networks and services (“EDF Vert”), with an operation referred to as “Project Hercules” (Keohane, 2019a).

So far, Mr. Macron’s administration has not accommodated EDF’s requests on new price regulations (De Beaupuy, 2019), presumably not to back off on the few liberalisation features introduced in front of the EU Commission’s positions, while the Project Hercules has sparked strong disapproval from the trade unions, fearing that “EDF Vert will eventually be fully sold off” (Keohane, 2019a).

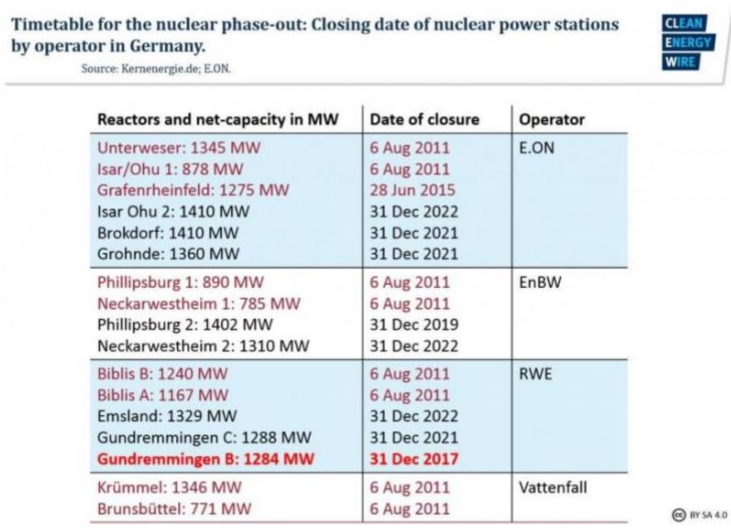
The planned reduction of the nuclear capacity, however, may further exacerbate the aforementioned difficulties, forcing the French government to take a more favourable position towards its controlled energy champion, probably even at the expense of EU’s competition policy. It appears reasonable to assume, indeed, that the financial and job burden on EDF would be eased by specific government measures and provisions, since the company and the sector still represent a significant strategic asset for the credibility of French economic penetration but also military deterrence. An example of such public intervention is the restructuring of nuclear operator Areva S.A. in 2016, which was split mainly in reactor designer and builder Framatome S.A. and nuclear fuel cycle operator Orano S.A., controlled respectively by EDF and directly by the French government (Proctor, 2018).

3.2. The Big Four of the German electricity system: E.On, RWE, EnBW and Vattenfall

The situation of the large utilities operating in Germany, on the other hand, is very different from the past ENEL and present EDF: they had to manage both the costly process of the phase-out (specifically, the decommissioning and the nuclear waste treatment) and its consequences on their financial soundness, profitability, market reputation and, not least, personnel, carrying this burden basically on their own, as independent actors and with the mistrust from the government, rather than the cooperation, as will be further examined later in this subchapter.

When the phase out was reconfirmed by the German government in 2011, the remaining 17 nuclear plants were operated by the “Big Four” electricity suppliers of the country: E.On SE, EnBW AG, RWE AG and the local branch of Sweden’s Vattenfall AB, as shown in table below. The figure shows instead the main area of operation of the power generators of these utilities in Germany: Vattenfall in the former East, E.On in the central north-south corridor, RWE in the western part and southern part, and EnBW in its home Land of Baden-Württemberg.

Figure 14 - Nuclear phase-out scheduling of German plants by operator (Appunn, 2018)


Timetable for the nuclear phase-out: Closing date of nuclear power stations by operator in Germany.

Source: Kernenergie.de; E.ON.

CLEAN ENERGY WIRE

Reactors and net-capacity in MW	Date of closure	Operator
Unterweser: 1345 MW	6 Aug 2011	E.ON
Isar/Ohu 1: 878 MW	6 Aug 2011	
Grafenrheinfeld: 1275 MW	28 Jun 2015	
Isar Ohu 2: 1410 MW	31 Dec 2022	
Brokdorf: 1410 MW	31 Dec 2021	
Grohnde: 1360 MW	31 Dec 2021	
Phillipsburg 1: 890 MW	6 Aug 2011	EnBW
Neckarwestheim 1: 785 MW	6 Aug 2011	
Phillipsburg 2: 1402 MW	31 Dec 2019	
Neckarwestheim 2: 1310 MW	31 Dec 2022	
Biblis B: 1240 MW	6 Aug 2011	RWE
Biblis A: 1167 MW	6 Aug 2011	
Emsland: 1329 MW	31 Dec 2022	
Gundremmingen C: 1288 MW	31 Dec 2021	
Gundremmingen B: 1284 MW	**31 Dec 2017**	
Krümmel: 1346 MW	6 Aug 2011	Vattenfall
Brunsbüttel: 771 MW	6 Aug 2011	

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Figure 15 - Regional presence of Big Four utilities in Germany (NCBJ, 2020)

Moreover, as disclosed by them in their corporate website, none of these utilities is (majority or partly) owned by the German government, at least not at national level: the Land of Baden-Württemberg, in fact, owns a 46,5% stake of EnBW and the City of Essen 3% of RWE’s shares, while E.On is controlled by private institutional investors and Vattenfall, as already hinted, is the 100% state-owned utility company of the Swedish Government. This aspect presumably has had an influence on the fact that the cooperative relationship between operator and national executive body in the management of the nuclear phase-out and its effects, experienced in Italy and conceivably expected for France, has not been observed in Germany: the two actors, on the contrary, have given rise to a confrontation which even ended up in court.

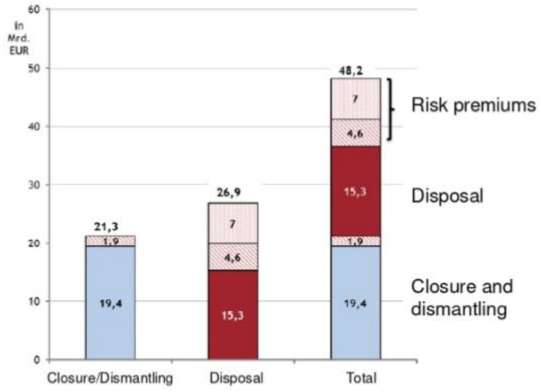
Three out of the four utilities, in fact, firstly challenged the 2011 moratorium seeking compensation for a total of €875 million: RWE, in particular, sued the Land of Hesse and federal authorities “for loss of profit and extra costs during the three months that its reactors at Biblis didn’t run because of the standstill order” with a €235 million request, and E.On did the same with the Bavarian, Lower Saxony and federal governments for €380 million; even the Land-participated EnBW claimed €260 million from its home federated state of Baden-Württemberg and the federal government (Appunn, 2015). The several court decisions have ruled in different directions: both federal and Hessian administrative courts found that RWE’s claims had legal ground since the 2011 standstill order was unlawful (Vasagar, 2014), while E.On's and EnBW's complaints have been dismissed respectively by the regional courts of Hanover and Bonn, both stating that the two utilities should have appealed the governmental decision immediately (Fischer, 2016).

The other (and much more significant in the figures) bone of contention was instead represented by the financial losses caused by the phase-out itself: considering the phase-out plans a violation of their property rights ("a new form of expropriation"), indeed, RWE, E.On and Vattefall sought compensation in front of Germany's Federal Constitutional Court of Karlsruhe, which ultimately ruled in their favour in 2016, but failed to specify the amount of the compensation, leaving room of manoeuvre to the executive (DW, 2016). Consequently, in the face of (at that time) declared losses of €8 billion for E.On, estimates amounting to €6 billion for RWE and claims totalling €4,7 billion for Vattenfall (DW, 2016), the German federal government envisaged only a compensation not exceeding slightly more than €1 billion (more likely several hundreds of million euros) when it amended the German Nuclear Energy Exit Act two years after Karlsruhe's ruling (Graupner, 2018), but left anyway "the actual sum of compensation payments open – they will first be decided in 2023, when factors such as lost generation hours, generation costs, and obtainable power prices are known" (Appunn & Wehrmann, 2018).

The government proposal was welcomed by RWE, but Vattenfall "criticised it, arguing that it would reduce the amount of compensation too much and would force operators of decommissioned nuclear plants to sell the remaining volume of electricity" (Appunn & Wehrmann, 2018). As a non-German company, indeed, the Swedish utility had already appealed for an independent arbitration at the International Centre for Settlement of Investment Disputes (ICSID) of Washington, D.C. in 2012: the German government "questioned ICSID's jurisdiction in the case and sought to have the case thrown out", stating "that decisions by international courts are inadmissible in the event of investment arguments between two EU member states", but the ICSID rejected this position, affirming that it had competence on this damages claim (DW, 2018).

In any case, "the projected total cost of nuclear phase-out amount to € 48,2 bn. (including a risk premium accounting for uncertainty)" in terms of expenses to be covered by the utilities (given the unclear status of compensation so far) through specific provisions amounting to €38 billion in 2016 (Brunekreeft et al., 2016), as highlighted in the figures below.

Figure 16 - Projected costs of nuclear phase-out in Germany (Brunekreeft et al., 2016)



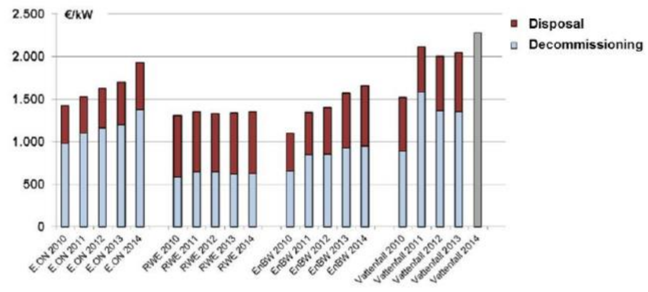


Figure 17 - Big Four's provisions for nuclear phase-out in Germany (Brunekreeft et al., 2016)

Nevertheless, "the detailed structure of the provision is not very clear", since their accrual varies depending on the company and their dismantling strategy, but also on the reactor type, timetables, discount periods and rates; and even if "the companies claim that the provisions are sufficient", it should be noted that "the final repository for nuclear waste still needs to be determined" (Brunekreeft et al., 2016).

Germany's highest constitutional court of Karlsruhe, anyway, in 2017 has also ruled "that a nuclear fuel tax imposed on energy utilities was unconstitutional": such tax, introduced back in 2010 even before the phase-out, "required the companies to pay €145 per gramme of fuel rods deployed in their nuclear reactors", generating €6,3 billion in revenues for the German budget before the sentence of unconstitutionality; this decision clearly paved the way for new refund claims from the four utilities, prospectively amounting to €3,3 billion for E.On (including interests), €1,7 billion for RWE and €1,44 billion for EnBW (Chazan, 2017).

The gradual phase-out schedule showed in the figure below, therefore, results also in impacts on two strictly interrelated aspects: the utilities' financial accounts and work force, as hinted in the introductory words of this subchapter. According to a report prepared by consulting firm Deloitte for nuclear industry trade association FORATOM in April 2019, the atomic energy sector in Germany was the second-largest in the EU both for GDP (roughly €70 billion) and employment generated, representing 136.300 people (Deloitte, 2019); in should be noted, however, that Deloitte's calculations for France, the first nuclear industry in the EU, estimated the sector to employ 457.000 people, more than twice the aforementioned figures disclosed by French atomic energy operators even including indirect jobs.

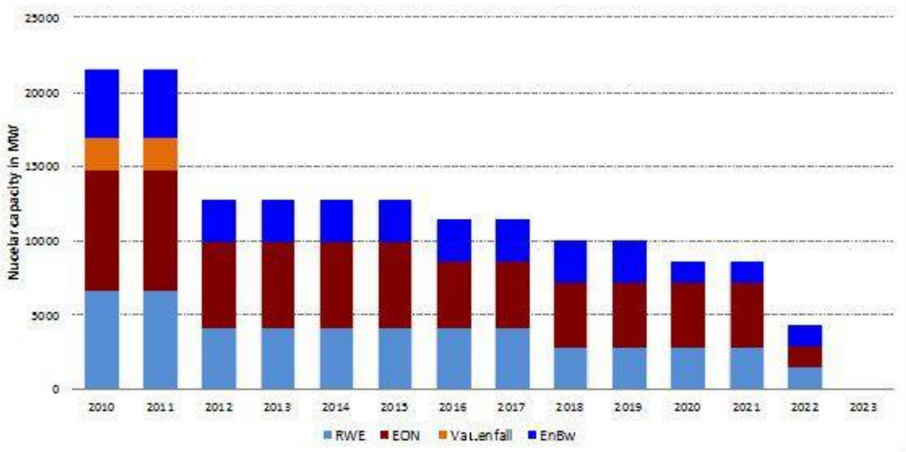


Figure 18 - Gradual phase-out scheduling of nuclear power capacity by operator in Germany (Brunekreeft et al., 2016)

In the months after the phase-out decision was announced, anyway, utilities were forecasting relevant job reductions in order to cover the costs of the process. E.On's executives, in fact, seeking "controllable costs" of €9,5 billion, were envisaging between 6000 and 11.000 staff cuts (out of a workforce of 79.500 at that time), while RWE "was planning to axe about 8.000 jobs from its staff of 72.000" after having announced divestments for €11 billion and additional cost cuts of €1,5 billion to cope with a quarterly loss, explicitly citing that the measures were "the direct result of decisions to close its Biblis nuclear power plant and to replace coal-fired plants with new renewable energy facilities requiring fewer people" (Blau, 2011). For their part, the two other utilities did not rule out reductions in the personnel, too: Vattenfall (at that time employing 20.000 people in Germany) in order to cut costs by €600 million, and even the Land-participated EnBW, after its first half-yearly loss due to the shutdown of two of its four reactors (Blau, 2011).

As a result of "Germany's abrupt change in energy policy", additionally, utilities have seen their market cap shrinking between 2011 and 2019, too: for instance, E.On from €46 to €21,5 billion (with a record net loss of €16 billion in the balance sheets of 2016 due to diminishing value of power generation assets), while RWE from €27 to €14,6 billion (Chazan, 2017; and Dholakia et al., 2019).

Such consequences have also sparked concern in the communities hosting the nuclear plants, fearing both the closing of their major employers and the loss of revenues from the nuclear tax (supposedly similar to the French IFER previously mentioned), especially since no governmental financial support plan has been drafted, in contrast to the €40 billion assigned to the areas affected by the coal phase out (Kallgren, 2020).

Furthermore, the business implications of the nuclear phase-out and its overall policy framework, the Energiewende, have triggered a radical overhaul of Germany's largest utilities. E.On and RWE, in particular, since 2016 firstly both "separated their conventional generation business from network, retail and renewable business units": RWE assigned its renewable, distribution grids and retail activities to its new subsidiary Innogy, while E.On retained them, leaving the conventional power production business to its controlled company Uniper (Buchmann, 2018). Two years later, however, the two operators signed an asset-swap deal which reshaped the energy market of the first economy in Europe: Innogy's activities, in fact, were split between the two parent companies as described by the figure below, with RWE retaining renewables (becoming a pure power generation company) and leaving the network and retail business units to E.On (thus focusing on regulated assets) in exchange for an equity interest (Buchmann, 2018).

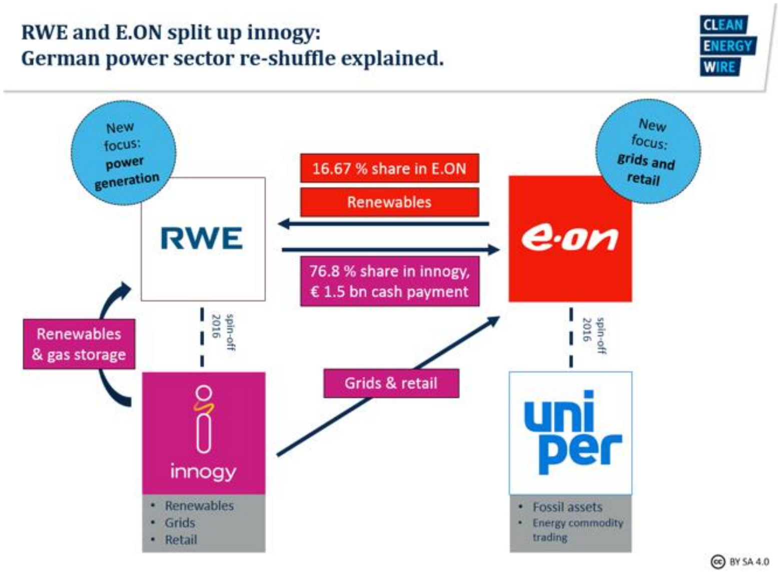


Figure 19 - E.On-RWE 2018 asset-swap deal (Wettengel, 2018)

Due to this deal, E.On has increased its staff numbers to almost 80.000 people in 2019, up from the 43.000 of the previous year (of which 17.000 in Germany), while RWE has currently about 20.000 employees, around the same numbers (21.000) of EnBW. On its part, Vattenfall has sold its coal (lignite) power assets, representing 7500 people in total, to Czech energy provider EPH in 2016, "citing a commitment to sustainable energy" (Zimmermann, 2016), and now has a workforce of around 7000 in Germany out of a total staff of 20.000 (Amelang & Bieler, 2018).

All these utilities, in any case, have (at least in part) either changed their activities or diversified towards new segments of the energy sector, notably wind and solar assets, directly or indirectly trying to ride the crest of the massive expansion of renewables and of the digital innovations which accompany them.

The consequences of the phase-out have affected also other kinds of industry players: in the same period of 2011, indeed, the management of Siemens AG, "the largest engineering conglomerate in Europe", announced that the company was abandoning the nuclear power business, aligning with the political and social positions in Germany (Dempsey, 2011).

In conclusion, it seems clear that the nuclear phase-out had significant effects on the four utilities' business models, alongside the more extensive implications of the Energiewende. The shut down and the anticipated decommissioning of the plants, indeed, triggered financial, labour and legal issues, and forced the companies to restructure, diversify or refocus their activities, in all likelihood developing more resilience. E.On and RWE's split in new subsidiaries and their successive asset-swap deal, but also Vattenfall's disinvestments of the German coal assets are the direct result of the increasingly challenging business environment in the German energy transition. Although, it is interesting that the companies never intended to question the phase out decision itself, presumably realising that the political and social consensus for this policy reversal was (and still is) widespread in the German society, but they rather insisted in demanding compensation due to the investments made in good faith (Graupner, 2018), and this course of action was almost entirely followed also by the Land-participated EnBW, despite the justifiable influence definitely exerted by its relevant public shareholder.

What is surprising in the level of the operators in this nuclear phase out process in Germany, however, is the difference in treatment compared primarily to the coal sector. In that case, the compensation system for companies (worth €4,35 billion) and for the involved Länder and communities (€40 billion) was decided basically from the beginning by the German government, and additional direct investments and funding are set to be provided also by EU institutions though the "Just Transition Mechanism" (Stam, 2020). The German nuclear sector, in contrast also with the measures forecasted by France, was instead fully burdened with the consequences of a political decision, in an application of the "polluter pays principle" which appears even more unequal given the low-carbon feature of nuclear power as opposed to coal-fired electricity.

Conclusions and recommendations

After having examined the nuclear phase out process in Italy, Germany and France, it is possible and appropriate to draw some conclusions on the similarities and differences between such experiences and plans, and thus on their bonding elements and eventual replicability of a unified “European model”.

From the political side, the three countries have been linked by some aspects and divided by others. The public opinion has been historically favourable (or simply unconcerned due to the lack of widespread information) in the beginnings of the nuclear energy programs, then the three countries considered have been affected by protests and demonstrations against nuclear power infrastructures, in Germany and Italy also related to the presence of American nuclear weapons in their territories; in France, instead, the military aspect was not significantly opposed due to the indigenous nature of the program, seen as a pillar of the national interest and state security.

Afterwards, two paths connect and distinguish the three countries in two different configurations. First, a growing public discontent in nuclear power was triggered by the incident of Chernobyl, while the previous event in Three Mile Island did not have suck kinds of consequences. The accidents, in any case, were responsible for the phase out in Italy and marked the starting point of the descending arc of the technology in Germany. Secondly, the influence of a proper Green party started to shape the discussion, but Italy’s policy reversal, however, was not characterised by this factor, which on the contrary gained significance in Germany and also in France, even if in the latter’s case the size of the program and the commitment of the other political actors (although in different extents) limited the effect of the Green’s activism.

Ultimately, such drivers determined the phase out decision in Germany with the first plan of 2002 and then its reaffirmation in 2011, carried out by the opposite side of the political spectrum (even after a short-lived revival of the technology sponsored by the same conservative parties) due to the massive shift in the public opinion in the aftermath of the incident in Fukushima Daiichi. The same event was responsible to the confirmation of Italy’s abandonment policy with another referendum. The French reduction plan, instead, is probably more related to technological costraints like the ageing of the reactor fleet and to the political expediency of following EU’s directives on renewables, but in any case does not mean the end of the commitment to nuclear power of the country, as proved by the new EPRs projects and given the relevance of the sector for the country's economy.

In the same way, the implications of the phase out for the nuclear operators of the three countries are similar in some respects and different in others.

The former monopolistic feature of Italy's ENEL can be recognised at least partially in today's French energy champion EDF, but the two situations are differentiated by the sizes of the nuclear sector, the technological developments in the renewables for its replacement and the influence of the climate change mitigation policies. The latter of these factors are in some ways related to the different time periods, but despite them, the French situation can be assimilated to the past Italian one due to the overall cooperative relationship between the governments and the utilities, likely necessitated by the public ownership of the companies.

Precisely this aspect, on the other hand, distinguishes the German phase out process: the lack of planned compensation mechanisms and the subsequent legal quarrels, but more in general the disparity in treatment of nuclear operators and of the involved communities compared to the "Just Transition" envisaged for the coal sector, alongside the broader implications of the Energiewende strategy, have all triggered radical restructurings in the companies' business models towards renewable and innovative digital activities like retail and network segments, but at the cost of severe financial and labour consequences.

The impacts of the nuclear phase out process on the system costs, on the replacement energy choices and (when quantifiable) on the electricity prices, instead, ultimately bring together the experiences of all three countries.

On one side, in fact, the phase out decision, especially if set to be implemented before the cost-effective end of the lifecycle of the plants, is inherently expensive for the country as a whole, and measurable in any case in the range of several billion (of euros, in our case). Obviously, the division of the costs can be different: more impact can burden the operators (and the local communities involved) than the national public exchequers, and it can be translated in higher (wholesale) prices differently, depending on their varying structure and on the applicability of the direct and indirect effects previously explained, but the underlying substance does not change. Obviously, the expenses for the decommissioning and the nuclear waste treatment and storage or reprocessing are partly unrelated to the phase-out decision, since after the end of the lifetime (including cost-effective prolongations) of the plants they would have to be covered anyhow; nevertheless, anticipating the shutdown to a moment when the plants could still generate power at a competitive cost (even considering maintenance and reactor core refuelling) determines the loss of revenues and profits and the renounce to affordable power which tip the balance of the cost-benefit analysis on the negative side.

On the other side, also the consequences of the nuclear phase-out on the countries' generation mix are, to some extents, quite clear: at least in the short-term period after the initial shutdowns of the plants, indeed, the capacity is replaced by fossil fuel power generation, with negative consequences on the environment both regarding carbon emissions in the climate change perspective and air pollution related to particulate matters; therefore, the abandonment of nuclear energy means facing additional difficulties in phasing out more polluting and climate-damaging power sources like coal even in presence of massive renewable energies programs, as the case of Germany.

Such considerations are indicatively valid for all the three countries considered and, as proved primarily by the Italian case, imply significant impacts on external dependence and energy security, as well as the negative economic consequences. France, however, may still avoid some of these effects if the planned reduction of the nuclear capacity concerns exclusively plants which at the completion of their life cycle.

In conclusion, therefore, the features of these nuclear phase-out experiences (or reduction plans) may allow to ensure their replicability (at least partial) to other situations, even if probably do not identify a unique European "model" describing how a nuclear phase-out process is articulated and governed. In other words, each of the characteristics observed in the processes assessed in this study could link them with other possible phase-out experiences, but with different configurations, meaning that similarities and differences may not be the same. In any case, the analysis of these three situations provides relevant clues on the development of an eventual nuclear phase-out process in other countries.

Obviously, the applicability of this kind of "adjustable pattern" would be smoother and more meaningful depending on the similarity of the situation considered with the three countries examined here: in this respect, other European states (particularly where the abandonment of nuclear power is already planned or discussed) like Sweden, Switzerland, Belgium, the Netherlands or Spain would be the perfect candidates for expecting a comparable phase-out process due to the analogous features regarding (democratic) government system, party politics, public opinion, market organisation, sector size, level of technological advancement and public awareness of the climate change problem. For this reason, in other realities like China, Russia, Brazil or even Japan and the United States, such applicability would be certainly more limited.

The implications of the COVID-19 pandemic

It is difficult to assess the impacts of the current COVID-19 pandemic on the processes examined in this thesis, because it is unclear which of the opposite aspects in action will prevail.

On one side, in fact, the sudden and sharp drop in electricity demand due to the lockdown measures imposed in many countries (including, to different extents, Italy, Germany and France) has led the power systems in relying largely on renewables given their top spot in the merit order of the supply: since this kind of situation has been generally proved manageable at the hands of the TSOs, one could argue that the baseload feature provided by nuclear power is not essential to the system functioning any more, and therefore the phase out process could proceed unimpeded or even accelerate. To some extent, this appears to apply for Germany, where the shutdown of the reactors and their disconnection from the grid is supposed to be carried out as planned, but also for France, where EDF has confirmed its intention of powering down the remaining reactor in Fessenheim on schedule. Additionally, this aspect and more generally the severe economic consequences of the pandemic could reduce the propensity for investing in high-CAPEX new nuclear plants or in investments for the extensions for the operating ones.

Especially in France, however, it is also possible that these very same economic consequences could make such prolongations more convenient that the replacement investments, also taking into account that the low prices of fossil fuels (for instance, gas imports) would foster such sources as replacement, going against the low-carbon direction promoted by the French government and by the EU with the purpose of limiting the problem of climate change.

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Appendix

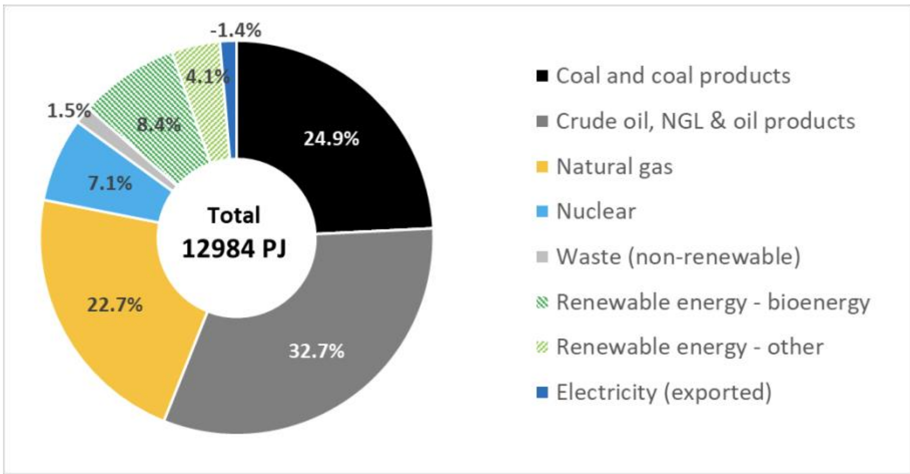

Figure 20 - Total primary energy supply mix of Germany in 2016 (IEA, 2018)

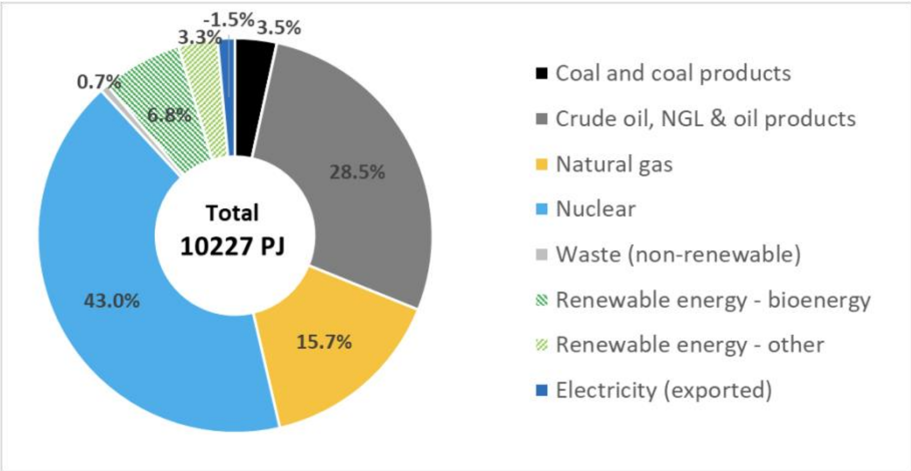

Figure 21 - Total primary energy supply mix of France in 2016 (IEA, 2018)

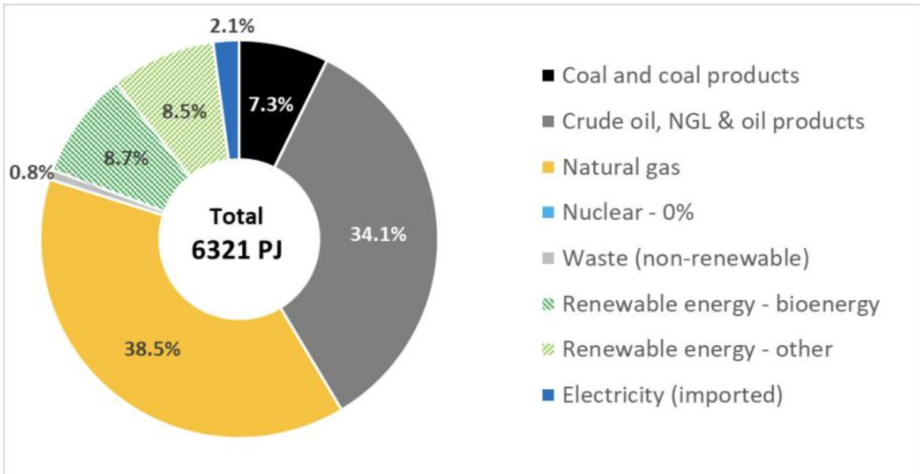

Figure 22 - Total primary energy supply mix of Italy in 2016 (IEA, 2018)

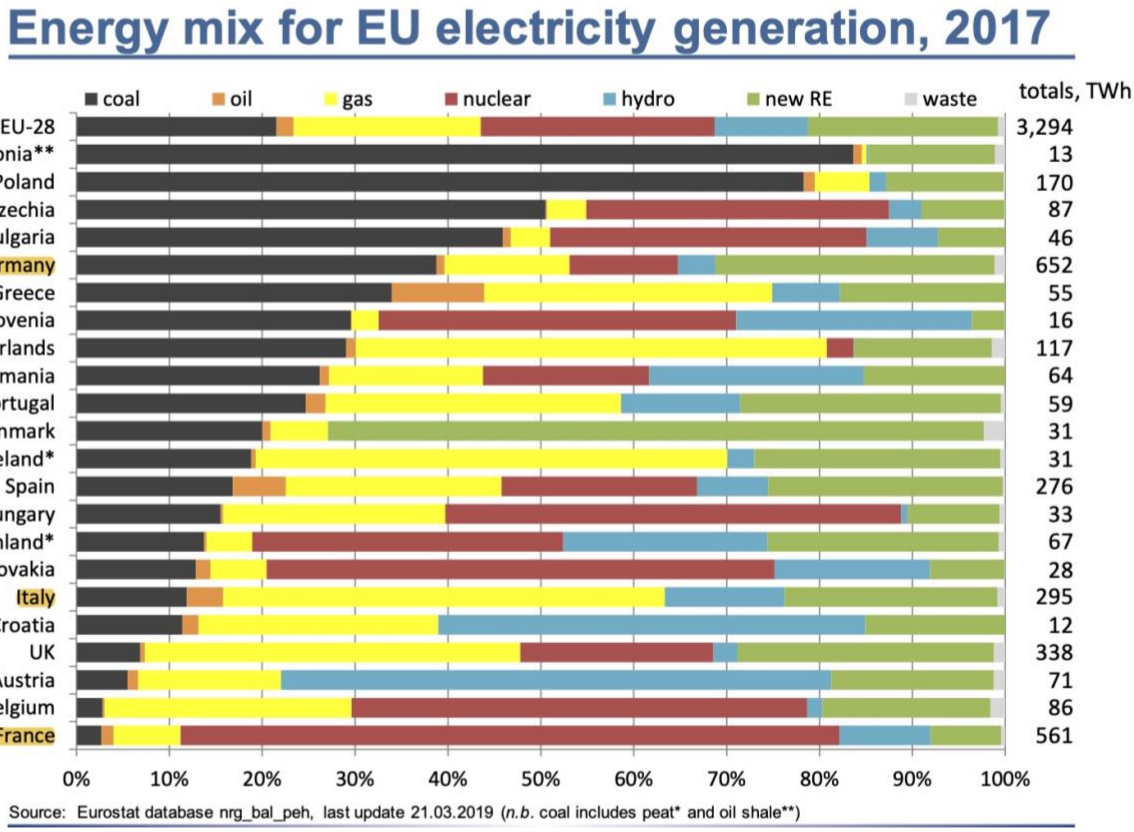

Figure 23 - Electricity generation mix of selected EU countries in 2017 (EURACOAL, 2020)