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Resilience of the Nuclear Sector in Europe in the Face of Pandemic Risks

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Acronyms

AGR	Advanced Gas-cooled Reactor
BCP	Business Continuity Plan
BWR	Boiling Water Reactor
CANDU	CANada Deuterium Uranium
CT	Computed Tomography
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization
EDF	Electricité de France
ENTSO-E	European Network of Transmission System Operators for Electricity
EP&R	Emergency Preparedness and Response
ESA	European Supply Agency
FIP	Feed-in Premium
FIT	Feed-in Tariff
GDP	Gross Domestic Product
NMEu	Nuclear Medicine Europe
NPP	Nuclear Power Plant
NPP	Nuclear Power Plant
O&M	Operation & Maintenance
PET	Positron Emission Tomography
PPE	Personal Protective Equipment
PV	Photovoltaic
PWR	Pressurised Water Reactor
RN	Radionuclide
SPECT	Single Photon Emission Computed Tomography
TSO	Technical Support Organisation
VVER	Water-Water Energetic Reactor

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The authors are also very grateful to all contributors of the one-day seminar, on 23rd November 2021, gathering representatives from European regulators, nuclear industry, and international organizations. Their valuable inputs brought pertinent perspectives that we have tried to reflect in this report.

Abstract

The COVID-19 pandemic has had a substantial impact on the functioning of our societies and economies. Like any other sector, the nuclear industry had to adapt to these sudden new constraints and implement long-term strategies to ensure the continuous supply of electricity and radionuclides.

From the early spread of COVID-19 in Europe to the latest and successive pandemic waves, the nuclear industry has been successful (so far) in maintaining an uninterrupted supply, demonstrating the overall resilience of the sector. The intrinsic specificities of nuclear industry (risk assessment and safety culture, emergency preparedness and response, worker health monitoring, radiation protection, etc.) contributed considerably to limiting the impact of the pandemic on the sector. Some weaknesses appeared during the crisis, and the report proposes several recommendations for improving the overall resilience of nuclear industry against similar events.

Yet, future pandemics or major external threats could differ in terms of impacts on the different assets (political, human, financial or physical) needed to ensure safe, secure and sustainable operation of nuclear installations, some of them having a broader scope than the nuclear industry alone. Lessons learned from the COVID-19 crisis should therefore be used to continue developing the ability to reinforce the resilience of the nuclear sector, through European and international collaboration at industry and regulatory levels.

Executive summary

The COVID-19 Pandemic has led to unprecedented challenges in health, economic and social systems. The Nuclear industry, like other industrial sectors, has not been significantly impacted by the effects of the disease on its workforces, but has been very significantly affected by the consequences of the mitigation measures imposed at national and international levels.

The following report analyses the resilience of the nuclear sector in Europe in the face of pandemic risks from the consequences of COVID-19 on electricity and radionuclide production. It describes the way the main players in the nuclear industry (utilities, regulators, supply chain, services suppliers, etc.) acted, from the first wave of the pandemic until now. It indicates also the main drivers for long-term economic impact. Finally, it proposes recommendations towards a better resilience of the nuclear industry for the future.

COVID-19 has been an exacerbating factor on generic issues currently faced by the nuclear industry

The European nuclear fleet produces more than one fourth of the electricity generated in the European Union. In the 15 countries[1] considered in the study, 2020 electricity production was reduced by 96 TWh (-4%), and the balances among the various electricity sources shifted, with an increase from renewables (hydraulic, wind, solar) of about 62 TWh, while fossil sources (coal and gas) and nuclear saw a reduction of respectively 75 and 87 TWh. Aside from the impact of COVID on nuclear energy, permanent shutdowns of several reactors took place over the period and are responsible for roughly 25 TWh of this overall nuclear generation decrease.

During 2020, at country level, the net nuclear electricity generation variations can be summarized as follows:

- Stable nuclear electricity production, with a yearly variation below ±1% (Hungary, Czech Republic, Spain, Bulgaria, Slovakia, Romania), where nuclear plants are operated in baseload, or net increase of nuclear production in countries having only one reactor under operation (Netherlands, Slovenia), up to 9%, due to better availability in 2020.

- Significant decreases, between -5% and -26%, in several major nuclear countries (Switzerland, UK, France, Germany, Belgium, Sweden).

Most of the European reactors did not see significant variation of their load factors between 2019 and 2020, with values staying close to historical trends in the range 80-90% (Bulgaria, Finland, Hungary, Netherlands, Romania, Slovakia, Slovenia,

[1] 13 EU MS with nuclear power, along with the United Kingdom and Switzerland

Spain, Switzerland, Czech Republic and Germany). But in four countries (Sweden, Belgium, France and United Kingdom), significant changes appeared, with lower values, in the range of 60-70%. These 2020 load-factor drops originated from a significant planned unavailability of the European fleet. The duration of planned outages has increased by 25%, leading to a cumulative loss of 261 TWh in 2020, while unplanned losses (forced shutdowns) remained stable over the period 2019/2020.

This increase in planned unavailability comes from the ongoing structural challenges currently faced by the industry:

- some ageing reactors suffered from defects entailing temporary shutdown,
- others were stopped for major preventive revamping and safety upgrades.

On-site works have been severely disturbed by the COVID-19 mitigation measures imposed on workers, often leading to an extended duration of shutdown periods.

In addition, the COVID-19 pandemic also slightly impacted the availability of several reactors, which operated at reduced power to adjust to demand, or were temporarily shut down to manage medium-term fuel reload planning. Normal maintenance periods have also experienced loose planning to cope with sanitary constraints.

COVID-19's impact on new build construction projects varied according to their progress status

Most new build projects were under late commissioning stage during the COVID-19 pandemic (Olkiluoto-3, Flamanville-3 and Mochovce-3/4). The additional constraints raised by COVID-19 had a marginal impact on the activities performed. Despite the delays announced since the pandemic's start in Europe, owners and nuclear vendors have not reported any specific COVID-19 impact, these delays being the result of additional technical issues faced during hot commissioning.

Regarding the Hinkley Point C project, COVID-19 had a direct impact on construction activities. Instead of a start of commercial operation in late 2025, Unit 1 is now scheduled to start in June 2026 (a six-month delay). As of mid-2021, the share of responsibility for the specific delays in the Hinkley Point C caused by COVID-19 project remained undisclosed.

The pandemic limited impact on the front end of the nuclear fuel cycle

The COVID-19 impact on the front end of the fuel supply chain was limited, without foreseeable consequences in the short and long term. Nevertheless, it led to temporary closure of several uranium mines at the pandemic's peak, but without impacting Europe's security of supply.

The main future risks for the front end of the nuclear fuel cycle are highlighted by ESA in its latest yearly report[2]:

- uranium oversupply that continues to unbalance the market,
- insufficient investments in the supply chain,
- transport issues.

The nuclear fuel cycle has remained resilient so far and the impact of COVID, during the last year, has been very limited. As long as the overcapacity and large stockpiles remain in the front end of the fuel cycle, the risk of fuel shortage will be very limited, even with another pandemic. The lack of investment, in the long term, is by far the major risk for the upper part of the fuel cycle.

The capacity of Europe to maintain radionuclides production during the pandemic crisis

Considering the importance of nuclear medicine in diagnostic and therapeutic applications, supply/demand has been maintained during the pandemic, and only reduced in periods where healthcare systems were overloaded by COVID-19 patients. The European industry managed to sustain its production capacity and provide a continuous supply across Europe. Nevertheless, during the first period of the pandemic, exports have been reduced.

At the international level, the severe disruption in air routes, following the massive cancellation of passenger flights across the world, coupled with strong uncertainties in the flight schedules, induced several supply disruptions or tensions outside of Europe (North America, Africa, Latin America, etc.).

After the end of the first pandemic wave, supply chains gradually came back to normal operating mode, and had time to adjust to new realities and find alternatives for transportation. However, under the COVID-19 pandemic, air transportation appeared as the weakest link in the medical supply chain and calls for some reinforcement.

Nuclear sector resilience toward COVID-19 pandemic

The assessment of the nuclear sector resilience was performed through direct exchanges with the European nuclear industry and their regulators, using different questionnaires and direct interviews.

The first pillar of business resilience lies within the anticipation of threats. The nuclear industry is continuously prepared for large crises and has developed national regulations, internal procedures or simply enough supply reserves to face them. This basis helped in addressing and adapting to incoming COVID-19 threats

[2] Annual Report 2020 - final version – 2 July 2021
https://euratom-supply.ec.europa.eu/publications/esa-annual-reports_en

and avoided major disruption of activity. Nuclear industry anticipation capacity came from:

- The existence of a regulatory framework giving an "essential services provider" stamp to utilities, which has been practically extended in-the-field to some key external suppliers (service and equipment suppliers, etc.).
- The existence of Business Continuity Plans (BCPs) across the whole industry, that were quickly put into application in an early phase of the pandemic. BCPs are often country- or player-dependent, with close connection with Emergency Preparedness and Response considerations. The nuclear industry culture for handling emergency situations appeared to be a significant contributor to the resilience during the pandemic.
- The existence of internal strategies to secure workers' availability at all times (dedicated training, redundancy, health protection, etc.).
- Considering the weight of costs in capital, the purchase of goods and equipment is not realized through a continuous flow, but with stockpiles used as a buffer and through long-term contracts. Only the first few months of the COVID-19 disease were effectively disruptive – not sufficient to see a visible impact.

The nuclear industry reacted very quickly during the first weeks of the pandemic (March/April 2020), defining and implementing new ways of working (some of which are still in force now, as the pandemic is not over). The main events and adjustments which were developed over the period are summarized below:

- The COVID-19 pandemic had a major impact on utilities' internal organisation, with modifications to workforces. While NPP operation remained mostly unimpacted, the maintenance and outage strategies were reassessed to cope with COVID-19 constraints, often leading to postponement of some maintenance activities.
- Despite the potential direct consequences of the COVID-19 disease on personnel health, workforce availability was never at risk during the period. The mitigation measures taken by the industry enabled the securing of internal and external workforce without major difficulty. No large cluster or contamination inside the nuclear industry was reported. The mitigation measures taken by the industry drastically limited onsite risks of contamination.
- Training activities were reduced during the early pandemic phase in Europe, since they are generally conducted onsite with physical presence. Utilities first focused on maintaining authority-based training and progressively restarted all training activities, sometimes remotely. In general, COVID-19 partially delayed training activity, but it was quickly recovered.

- International and European collaboration allowed the sharing of a large quantity of technical information to support utilities and regulators in managing the COVID-19 pandemic.
- Regulatory inspection and control activities were maintained during the whole pandemic, at level satisfying regulators' expectations and requirements. According to regulators, COVID-19 had only a minor impact on control and inspection activities (i.e., activities maintained but with additional constraints). The standard approaches used for inspections were modified with new remote approaches that could be partially maintained in the future. All the regulators surveyed considered that the way inspections and control activities were performed during the last year is satisfactory.
- The COVID-19 pandemic has not negatively impacted safety and radiation protection standards within NPPs. Due to the modified operational organisation onsite and special care from the personnel, an improvement of safety indicators was even observed in some cases. NPPs remained in operation under standard safety frameworks and no deviations or agreed adaptations were reported.

Limits of the survey

All the previous findings are offset by the fact that the COVID-19 pandemic is far from being over; the emergence of new variants could challenge the current mitigation tools and practices used by our societies and the nuclear industry to overcome pandemics (e.g., vaccines, treatments, etc.)

The final impact of COVID-19 on the nuclear sector will only be known at the end of the disease (i.e., upon entering an endemic phase), with enough hindsight to assess both short and long-term pandemic consequences. The ongoing (and future) initiatives taken by the industry and the regulators will contribute to improving the overall understanding of nuclear industry resilience.

COVID-19's immediate and long-term economic impact for the nuclear industry

The financial position of many nuclear utilities has weakened during the last decade, for different reasons: the impact of policies regarding energy efficiency, renewables positions, deep decarbonization, diversity of national positions for nuclear energy use, etc.

The COVID-19 pandemic has not significantly disrupted utilities’ business. They all experienced limited variations in their earnings, positive or negative, according to their production means portfolio and the electricity market in which they operate. In the longer term, if the current weakening trends for electricity producers are maintained, it is not obvious that nuclear utilities will be able to easily digest a new pandemic.

Lessons learned from the COVID-19 pandemic

To date, the nuclear industry has shown resilience through an uninterrupted supply of electricity and radionuclides, while maintaining high-level quality and safety standards.

From the information collected within this study, several recommendations were gathered, aiming at reinforcing the ability to face similar crises in the future: ability to withstand, ability to absorb, ability to recover and ability to improve:

- A better mapping of key suppliers to essential service providers could be beneficial to Member States to improve the coordination with public bodies in the case of future health emergency situations.
- A specific analysis of business continuity plans across the nuclear industry would allow a review of their uniformity and effectiveness and develop good practices for business continuity plan requirements across Europe.
- Coordination between the industry and international and European organisations is crucial during regional/cross-border crisis to ensure the efficient transmission of information. It is recommended to assess the feasibility of setting up a dedicated exchange forum for external disruptions, that would bring together European nuclear industrial players, regulators and authorities to improve the efficiency of information exchanges across Europe.
- The coordinated development of practices derived from COVID-19 adaptations across the European nuclear industry could be beneficial to all stakeholders; thus it is recommended to launch, in relation with European international industry organisations, a strategic action plan to support the industry in setting new standards of operation.
- Only operational resilience has been evaluated in this study; thus it is recommended to specifically evaluate to what extent EP&R procedures are impacted by external disturbances, before concluding on the resilience of the nuclear sector in nuclear emergency situations.
- The lack of standardised transportation regulation among EU Member States had historically complexified administrative logistics management. That absence was already an issue before COVID-19 but became aggravated during the pandemic, due to additional constraints taken by Member States. Working towards a more harmonised approach for radioactive material transport could be beneficial to the radionuclide industry, easing transborder logistics administrative procedures.
- As the pandemic is still underway at the time of writing, it is recommended to pursue monitoring its impacts on the nuclear industry, especially

regarding the different decisions taken during the last year (delayed maintenance, remote inspections or more weight on the use of informed risks from regulators, etc.) that could impact the nuclear industry in the future. At this stage, no specific concern is expected, but such finding should be reassessed within a few years.

- Utilities have seen their financial health weakened during the last decade, while at the same time having to prepare for and take an active part in the energy transition, through large investments to secure Europe's future electricity supply. Member States shall then ensure that necessary future investments, both inside and outside nuclear sector, will be deemed possible by their utilities.

Based on the numerous lessons learned from COVID-19, the industry will then strengthen its overall resilience (from utilities to regulators) and improve its capacity to overcome future pandemics. In essence, any new pandemic will be fundamentally different from the ones faced in the past, but best practices successfully implemented and applicable, could result in better future resilience.

How to improve resilience for the future?

The COVID-19 disease is still spreading, but after the first shock in 2020, the situation has stabilized with new working processes, which have not been disturbed by the successive waves. The different variants were more and more contagious, but new tools, as vaccines, helped to keep the pandemic under control. Only a drastic mutation of the virus, more invaliding or lethal, may change the pattern we have seen during the last one and half year.

The pandemic is global and heavily impacted societies, economies, and infrastructures. Among infrastructures, the European nuclear sector held and was able to continue producing electricity and medical isotopes. Basically, nuclear industry personnel are continuously trained to face crisis, and organizations were ready to implement stringent rules, as they have been decided by governments.

Nevertheless, several weaknesses have shown up, mostly due to generic factors, such as:

- The age structure of the European nuclear fleet is unbalanced, with most of them being older than 30 years. Consequently, large revamping operations were on-going, and on-site works have been significantly disturbed by social distancing rules. In addition, several reactors saw simultaneously ageing defects and were shut down for repairs.

- The heterogeneity of rules for transportation of nuclear materials makes always complex the process of distribution of medical isotopes. During the first wave of the pandemic, the organization of shipments was aggravated.

Besides, the first wave of the virus induced severe disturbances in reactors reload, maintenance and repair operations, disturbances from which there is not yet a full recovery, leaving constraints for the incoming winter (2022).

This report proposes several recommendations for improving the nuclear industry reliance against the pandemic; several of them suggest strengthening the share of individual returns of experience among the various European stakeholders, in a coordinated way, and with a close follow-up.

Different European and International organizations already contributed to shape initiatives aiming at gathering and/or facilitating information exchanges inside the industry, either through the organisation of webinars, setting up communication channels or through the production of reports.

Such types of actions are expected to continue and will be of great interest to capitalize and share lessons learned and good practices under COVID-19 pandemic, reinforcing resilience.

As each major pandemic is likely to have its own characteristics (lethality, transmission pattern, etc.), the relatively good resilience of the nuclear sector to COVID-19 pandemic does not allow to conclude on its capacity to overcome new or different sorts of pandemic. The workforce availability, which was never at risk during COVID-19 pandemic within the nuclear industry, could become a challenging issue under different circumstances (more common long-lasting health impacts following contamination, high lethality, etc.). Nevertheless, in a certain way, the present pandemic may be considered as an effective "crisis exercise" for a more invalidating or lethal pandemic. The Business Continuity Plans of the various stakeholders will have to be adjusted accordingly, including explicitly severe pandemics.

The resilience of a system relies on several types of assets: physical, human, financial and political. On physical and human assets, nuclear industry has a strong leverage; based on the numerous lessons learned, the industry will strengthen its overall resilience (from utilities to regulators) and improve its capacity to overcome future pandemics.

On financial assets, its leverage is more limited and on political assets non-existent. The European utilities have seen their financial capacity degrading during the last decade, reducing their capacity to invest or to face unexpected crisis. If there is continuation of this trend, it is not obvious that they will be able to face a large new pandemic the same way they do against COVID-19. And specifically, for nuclear utilities, the political decision on the European taxonomy will shape their future, opening room or not toward new build, and consequently development of their human resources and competencies.

1. The COVID-19 pandemic impact on European nuclear industry

1.1. Overall evolution of COVID-19 pandemic across Europe

The COVID-19 is an infectious disease caused by a virus named SARS-CoV-2 that was first identified in late 2019 in the Chinese city of Wuhan. After having spread from the People's Republic of China to 20 other countries, the World Health Organization first categorized the COVID-19 outbreak as a Public Health Emergency of International Concern on 30 January 2020[3]. Then, on 11 March 2020, after a spreading to more than 100 countries, the COVID-19 outbreak was finally characterized as a pandemic by the WHO[4].

At the same time, in March 2020, Europe quickly became the new active centre of the COVID-19 pandemic. A first pandemic wave impacted Europe during the period March/April 2020, leading most European countries to implement restrictions on movement from/to their territories, and in some cases restrictions on movement in the countries.

The following table provides a summary during the 1st pandemic wave of the lockdowns duration, the use of protective personnel equipment (PPE) in public transports and closed environments and the travel restrictions implemented by different European countries that participated to this study (See Chapter 2). This illustrates the diversity of approaches considered by Member States to tackle COVID-19 pandemic.

Country	Stay-at-home orders for the general population (days)	Closure of public spaces of any kind (days)	Use of masks after confinement measures (until 3 July)	Travel restrictions
Belgium	53	51	Compulsory	Selective closure
Czech Republic	39	59	Compulsory	Selective closure
Finland	None	74	Recommended	Selective closure
France	55	55	Recommended	Selective closure
Germany	None	49	Compulsory	Selective closure
Hungary	52	66	Compulsory	Full closure
Lithuania	76	76	Compulsory	Full closure
Slovakia	None	65	Compulsory	Selective closure
Sweden	None	None	Not recommended	Selective closure
United-Kingdom	46	54	Recommended	Selective closure

Table 1: Containment and mitigation strategies adopted by European countries to address the first wave of the pandemic – Source OECD: Health at a Glance: Europe 2020: State of Health in the EU Cycle

[3] https://www.who.int/publications/m/item/covid-19-public-health-emergency-of-international-concern-(pheic)-global-research-and-innovation-forum
[4] https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020

Since then, different variants of the virus have emerged and progressively become dominant (e.g., delta or omicron variants). As of early December 2021, more than 270 million cases and 5.3 million deaths have been confirmed on a worldwide basis, making it one of the deadliest pandemics in history.

The COVID-19 pandemic has led to unprecedented challenges in health, economic and social systems. The nuclear industry like other industrial sectors has been challenged by the consequences of the mitigation measures imposed at national and international levels. The following report assesses the resilience of the nuclear sector in Europe in the face of pandemic risks, through different topics:

- (Chapter 1) The analysis of the specific COVID-19 pandemic impact on nuclear electricity production, nuclear fuel cycle and radionuclide manufacturing;
- (Chapter 2) The nuclear sector resilience against external threats, assessing the anticipation, adaptation and recovery capacity of the industry;
- (Chapter 3) The COVID-19 immediate and long-term economic impact on the nuclear sector;
- (Chapter 4) The recommendations towards a better resilience of the nuclear industry.

1.2. The COVID-19 pandemic impact on European nuclear electricity generation

1.2.1. Overview of European nuclear fleet

Europe has a long-standing history with nuclear energy and was among the first users of this source of electricity production.

Nowadays, out of the approximately 440 nuclear power reactors operating around the world, more than one quarter are in Europe. These power plants are located in 13 European-Union countries *(Belgium, Bulgaria, Czech Republic, Germany, Spain, France, Hungary, the Netherlands, Romania, Slovenia, Slovakia, Finland and Sweden)* and in some neighbouring countries, as *the United Kingdom and Switzerland*. The present study analyses the consequences of the COVID-19 pandemic on nuclear electricity production in these 15 countries.

The position of European countries on nuclear energy is quite diverse:

- In the EU, 13 countries are currently operating reactors,
- Several others have never built any nuclear plants,
- Some have built reactors, but decided later to phase out this energy source without any replacement within the next few years (Belgium, Germany),
- Several countries are preparing or considering new realizations (e.g., Czech Republic, Finland, Hungary, France). There are 6 reactors under construction,
- And a few countries are preparing a nuclear program (e.g., Poland).

The European nuclear fleet produces more than one fourth of the electricity generated in the European Union (809 TWh out of 2908 TWh for EU-27 in 2019). Reactor types cover a wide spectrum of technologies, with AGR, BWR, CANDU, PWR and VVER.

Table 1 lists the countries using nuclear energy, with its contribution to national production, which varies in a large band, from a few percent in the Netherlands up to 70% in France. So, the specificities of the COVID-19 pandemic and its impact on nuclear generation have greater or lesser consequences depending on this contribution.

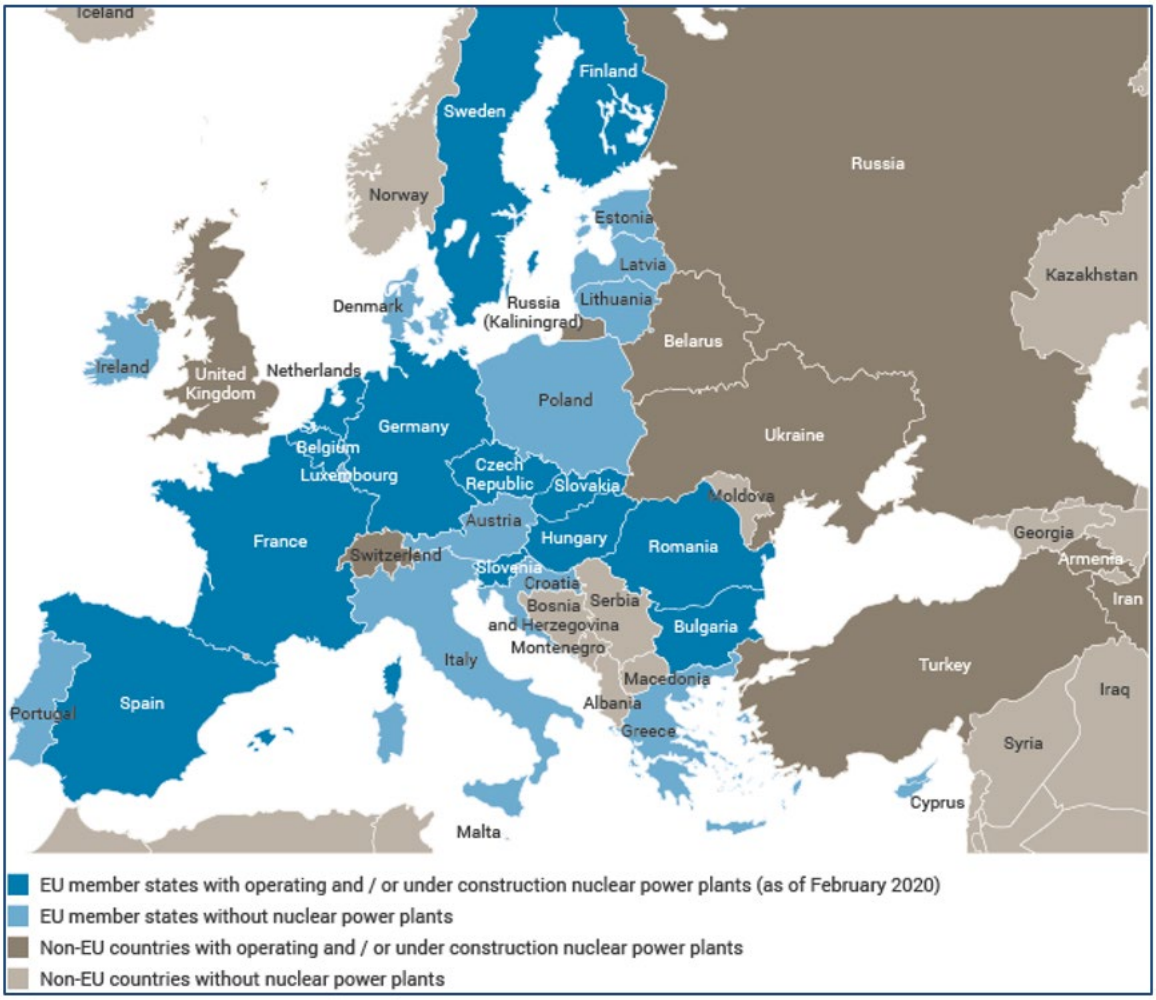


Figure 1: Nuclear Power in Europe – Source: World Nuclear Association

Countries	Nuclear electricity generation 2019		Reactors under operation As of January, 2020		Reactors under construction As of January, 2020	
	TWh	% elec	No	MWe net	No	MWe gross
Belgium	41.4	46.7%	7	5,942		
Bulgaria	16.6	37.8%	2	2,006		
Czech Republic	28.6	34.8%	6	3,932		
Finland	22.9	38.0%	4	2,794	1	1,720
France	378.0	71.0%	56	61,370	1	1,750
Germany	71.0	13.4%	6	8,113		
Hungary	15.4	51.2%	4	1,902		
Netherlands	3.7	3.6%	1	482		
Romania	11.8	20.2%	2	1,411		
Slovakia	15.3	54.6%	4	1,814	2	942
Slovenia	5.5	37.4%	1	688		
Spain	56.0	22.4%	7	7,121		
Sweden	64.4	40.7%	6	6,869		
Switzerland	25.7	37.0%	4	2,960		
United Kingdom	52.6	20.6%	15	8,923	2	3,260
EU + CH + UK	**809**	**26%**	**125**	**116,327**	**6**	**7,672**

Table 2: summary of European nuclear power plants - Source Eurostat

1.2.2. Electricity demand evolution during COVID-19 pandemic

Since 1990, after a steady growth of about 1.4% per year, the electricity demand in Europe fell in 2009, due to the economic crisis, and recovered partially in 2010. Since that year, growth did not come back and electricity demand has fluctuated around a lower level. During this last decade, consumption in services, households and transports remained stable while the fluctuations came from the industrial sector, following economic trends, but overall in reduction. In the meantime, nuclear production saw a peak in 2004, then progressively decreased with permanent shutdowns of several reactors, without new ones coming online.

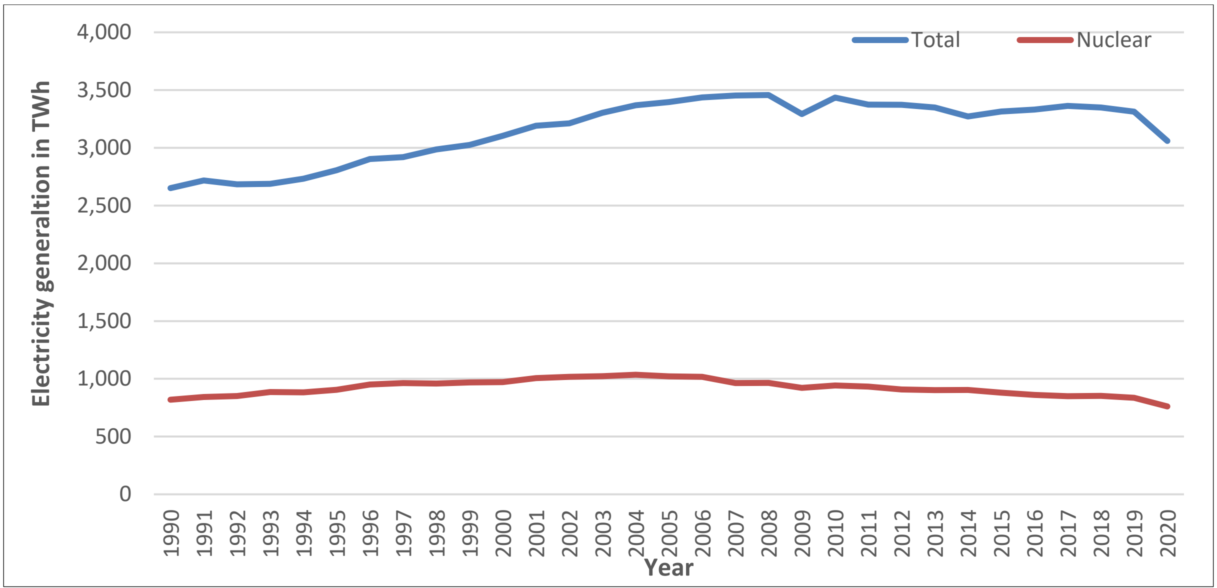


Figure 2: Electricity generation for EU-27 + CH + UK – International Energy Agency Data

In terms of electricity demand, the 2020 drop has been significantly higher than in 2009, about 7%, against 4.8%. In 2009, nuclear production decreased by about the same order of magnitude as total electricity generation.

The economy and electricity demand are intricately linked, and economic crises induce a fall in electricity demand. Figure 3 shows the GDP variation rate per year-quarter since 2008, with two large drops, the first one at the end of 2008 and the second one during second quarter of 2020.

The COVID-19 pandemic obviously had a strong impact on the economy, much greater than the 2008/2009 crisis; the preventive measures taken by public authorities to reduce virus propagation drastically slowed down activities: lockdowns, temporary closure or slowdown of shops, services, and industrial installations.

For the European Union, the economy suffered large losses, reaching an average of 14% in the second quarter of 2020, and varying, according to the country, in a range from -11 to -19%, while the fall in 2008, was only about 6%.

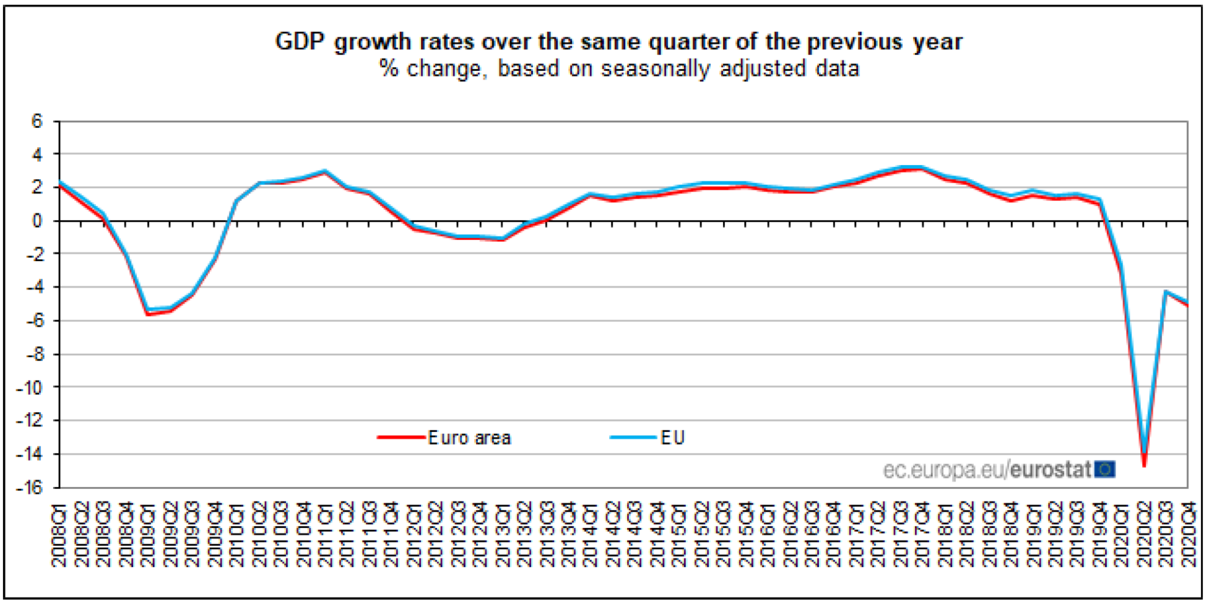


Figure 3: European Union GDP growth 2008-2020, Eurostat news release (02/02/2021)

As electricity demand culminated, in Europe, just before the 2008 crisis, a more in-depth analysis of the two crises and their responses will be developed in the Economy Chapter of this report, to underline the similarities and differences, taking into account the current strong need to develop electricity uses for decarbonizing various sectors, such as transport, industry or heating.

The most important differences between the current situation and 2008/2009 come from:

- the amounts of money available for keeping the economy up,
- the changes in the economic structures (e.g., industry vs. services),
- the use of digital tools which facilitated partially maintaining activities.

In addition, the COVID-19 crisis had a direct impact on the electricity generation means, suffering the same difficulties as the other industrial sectors, even when they were considered as essential services, and with the obligation to maintain production capacities.

Focusing now on the 15 European countries with nuclear capacities, the fall in electricity demand was 4.3% (96.6 TWh) during 2020, the first year of the COVID pandemic, compared to 2019.

Data collection methodology

Electricity generation statistics are published by numerous stakeholders in Europe: nuclear utilities, grid operators, ministries of energy, international public organizations, etc. The assessment of COVID-19's impact on nuclear electricity generation across Europe in the following chapters is based on national datasets published by ENTSO-E (European Network of Transmission System Operators for Electricity) through a standardized data collection and publication methodology.

Different ENTSO-E datasets were used in the context of this study:

- Actual generation per production type;
- Cross-border physical flows;
- Unavailability of production and generation units;
- Installed capacity per production unit.

Such datasets can be found on the ENTSO-E transparency platform: https://transparency.entsoe.eu/

All the countries studied have seen a reduction, ranging from 1.5 % (Hungary) to 6% (Finland, UK). The largest contributor to this reduction was the pandemic, which started hitting Europe significantly in March, and many countries decided their first lockdown, during the second half of March 2020.

Nevertheless, weather conditions were quite specific at the beginning of 2020, making it among the warmest winter ever recorded; this was particularly true inside the Nordic countries, where, in January, the electricity demand was significantly lower than during the previous year, -17.4% in Finland and -11.4% in Sweden.

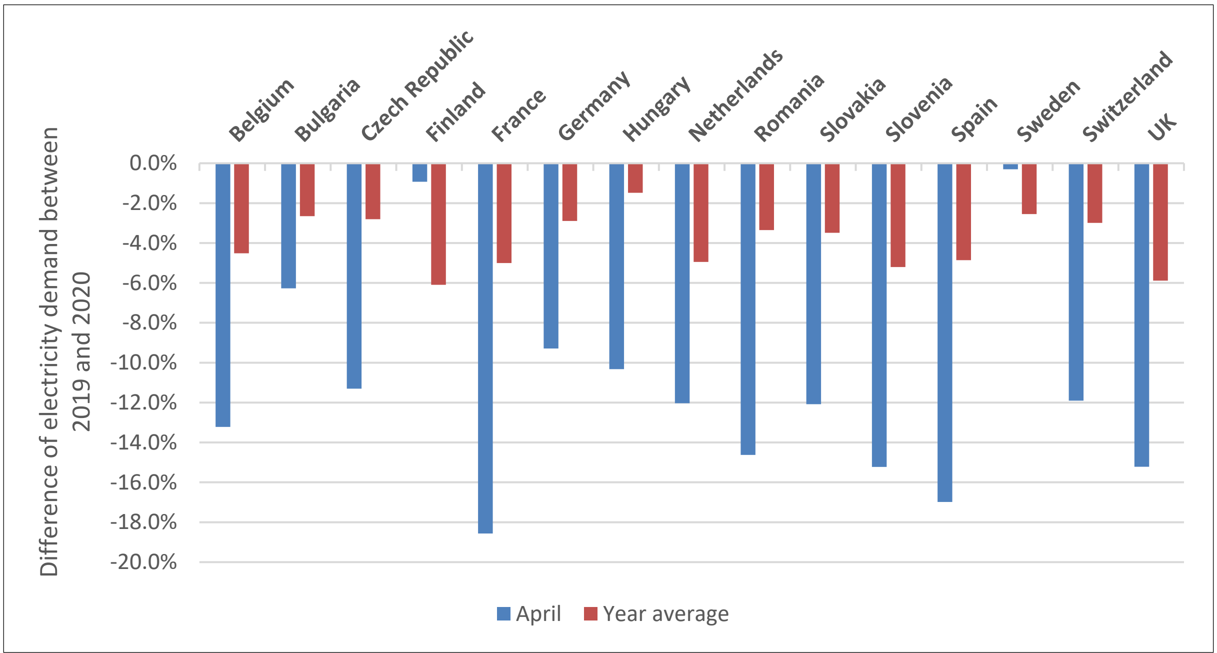


Figure 4: Electricity Demand variation between 2019 and 2020 (total year, April month)

For most of the countries, the same pattern can be observed: a rapid and significant drop in demand during March/April, followed by a gradual return to historic levels of demand after a few months (in September/October 2020). The largest drop in electricity demand was in April, peaking to -18% for France.

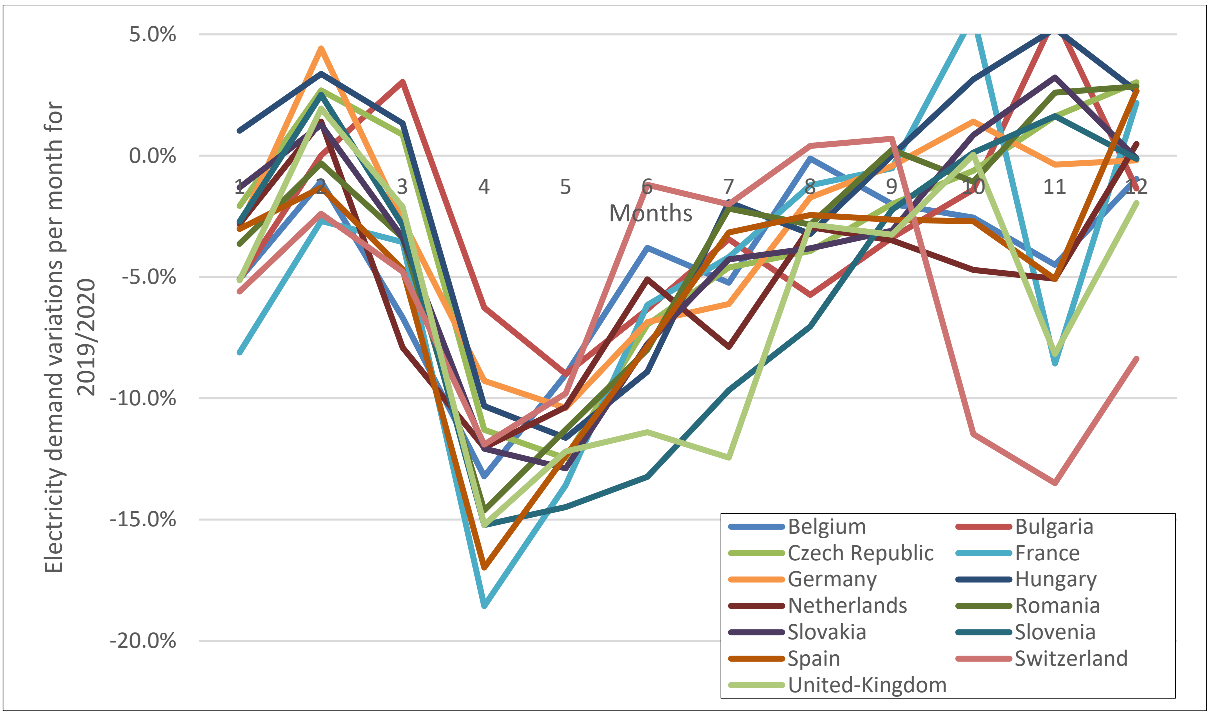


Figure 5: Monthly variation in Electricity Demand for period 2019/2020

Aside of the mild winter consequence, Nordic countries (Finland and Sweden) followed a different pattern, with very limited electricity demand variations during the first COVID-19 wave. The largest drop due to the pandemic was reached in Autumn.

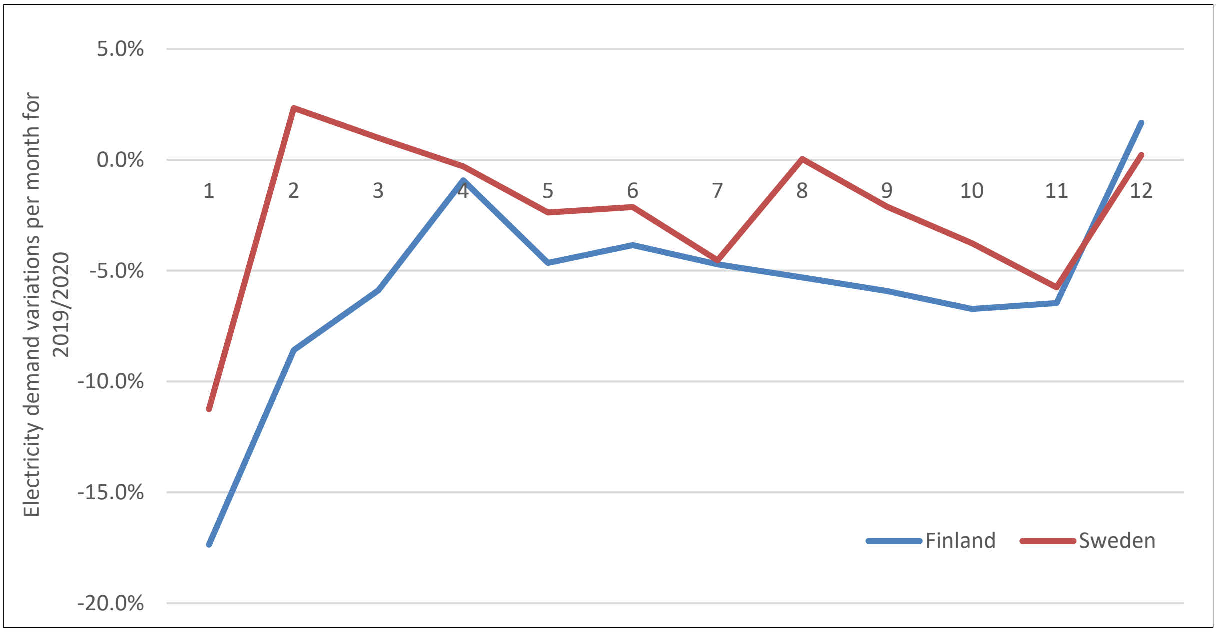


Figure 6: Monthly variation in Electricity Demand for period 2019/2020

In the 15 countries considered in the study, 2020 electricity production was reduced by 96 TWh (-4%), and the balances among the various electricity sources shifted, with an increase from renewables (hydraulic, wind, solar) of about 62 TWh, while fossil sources (coal and gas) and nuclear saw a reduction of respectively 75 and 87 TWh.

Growth in the hydraulic production come mostly from Nordic countries and France, while non-dispatchable sources have seen an increase in Belgium, France, Sweden, and the UK.

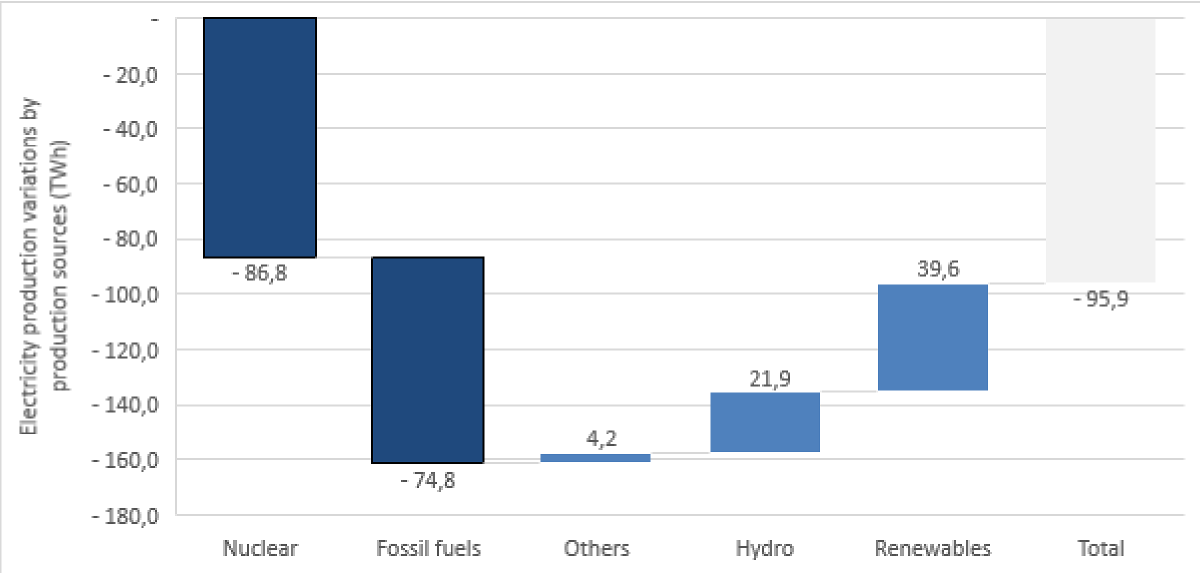


Figure 7: Electricity production variations 2019-2020

Finding #1 – Electricity demand was heavily impacted in 2020 due to the COVID-19 pandemic, with sudden drops in demand in March/April. A mild winter also contributed to the reduction. During 2020, electricity demand decreases in European Nuclear countries, as compared to 2019, in the range [1.5%;6%], depending on specificities of local conditions.

The largest reduction in production came from nuclear and is of the same order of magnitude than the total reduction. A part of this nuclear production decrease came from the simultaneous permanent shutdown of several reactors in France, Germany, Sweden, and Switzerland, the other part is being detailed later on in the report (long-term management, maintenance activities, etc.). The decrease in fossil production was mostly balanced by the renewables increase.

1.2.3. The European electricity markets

Since the Lisbon Treaty and the adoption of the Third Energy Package, there is, inside the European Union, a strong move for achieving a unique liberalized electricity market, with free flow of electricity across borders. In the past, all countries have developed their own structures, for generation, transmission, distribution and retail to final customers. Now, the value chain in the European market is based on three pillars: generation, trading, and distribution, ensuring competition among producers.

In parallel to the path toward market liberalization, the European Union and its Member States developed a strategy of drastic reduction of carbon emissions in the electricity sector and favoured the development of renewable sources through many financial incentives. Most of these new renewable sources are non-dispatchable (wind and solar) and they benefit from a priority against all the other sources when delivering on the grid.

As shown previously (see figure 7), the COVID pandemic arrived at a situation wherein non-dispatchable sources were increasing, while dispatchable ones (fossil and nuclear) were reduced. As the grid frequency and voltage are mainly controlled by dispatchable sources, such a situation deserves special attention, as similar ones will be more frequent and amplified in the future.

1.2.4. Nuclear energy contribution to electricity production during COVID-19 pandemic

This section assesses the general contribution of nuclear energy to electricity generation during the COVID-19 pandemic.

Aside of the impact of COVID on nuclear energy, permanent shutdown of several reactors took place over the period, to be deducted from the installed capacity in 2020. Some countries concerned by shutdown(s) lost the equivalent of 2.5 to 5% of their electricity production (see Table 3) and up 10-15% of their nuclear installed capacity (Sweden, Germany, Switzerland).

Country	Unit name	Reference net unit power (MWe)	Shutdown date	Nuclear production share[5]	Total production share[6]
France	Fessenheim-1	880	22/02/2020	1.4%	1.6%
France	Fessenheim-2	880	30/06/2020	1.4%	1.6%
Germany	Philippsburg-2	1,402	31/12/2019	15%	2.5%
Sweden	Ringhals-2	852	31/12/2019	10%	5%
Switzerland	Muehleberg	373	20/12/2019	11%	5%

Table 3: Permanent nuclear reactor shutdowns in Europe during 2019/2020

The 78 TWh [2019-2020] reduction in nuclear generation (figure 7) comes from a limited number of countries:

- France, which is the largest nuclear country in Europe, saw a reduction of 44 TWh. It must be noted that the 2019 French nuclear generation (377.7 TWh) was already lower than the 2018 production (391.6 TWh). The French nuclear fleet is currently conducting a large program for upgrading the

[5] "Nuclear production share" is defined as the nuclear electricity contribution share from this unit for the whole national nuclear fleet, operated at full power capacity all year long.
[6] As compared to 2019 electricity demand

safety of reactors, leading to planned long shutdown periods for each reactor.

- In Sweden, nuclear production in 2020 was lower by 17 TWh, mostly due to the permanent shutdown of Ringhals-2 and a long maintenance & repairs period on Ringhals-3.
- For Belgium, there was a drop of 8.6 TWh, with heavy maintenance and repairs on several reactors to ensure long-term operation.
- In the UK, the reduction was 5.2 TWh. Like France, the UK had already seen lower nuclear production in 2019, compared to 2018 (2018: 60.4 TWh; 2019: 52.5 TWh). This is due to unexpected shutdown of several ageing AGRs for safety reasons and repairs.

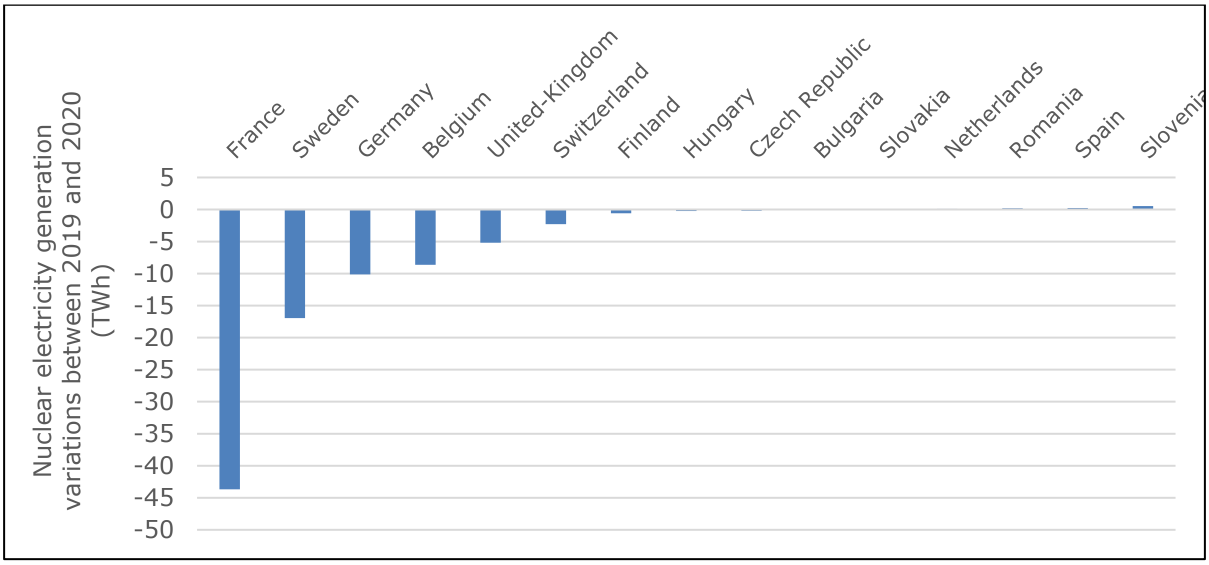


Figure 8: nuclear electricity generation variations between 2019 and 2020

When normalizing these values to the 2019 country nuclear production, we get the following figure:

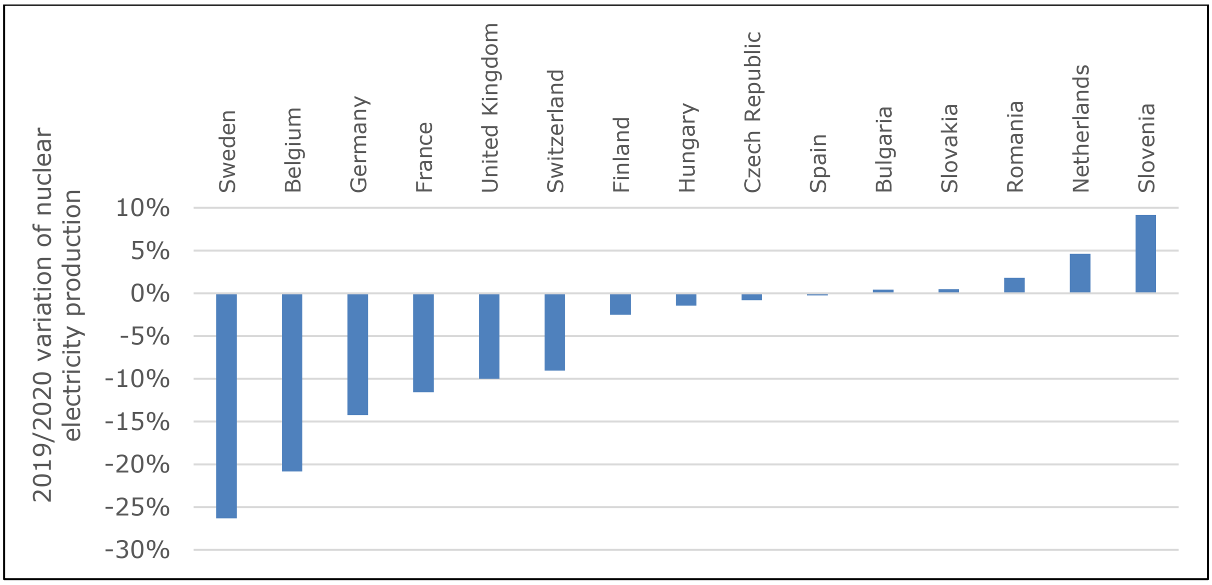


Figure 9: Variation of nuclear electricity production between 2019 and 2020

During 2020, the net nuclear electricity generation variations can be summarized as follows:

- Stable nuclear electricity production, with yearly variations in the range of ±1% *(Hungary, Czech Republic, Spain, Bulgaria, Slovakia, Romania)*, nuclear being operated in baseload.
- Net increase of nuclear production in countries having only one reactor under operation *(Netherlands, Slovenia)*, up to 9%, due to a better availability in 2020 *(e.g., the Krško reactor in Slovenia had one month of refuelling operation in 2019 while no major planned unavailability in 2020, same situation for Netherlands).*
- Significant decrease, below -5% and up to -26%, in several major nuclear countries *(Switzerland, UK, France, Germany, Belgium, Sweden)*.

When comparing these nuclear generation variations to the reduction in electricity demand (see Figure 10), it can be noted that, in most countries the decrease in nuclear production was lower than the reduction in demand, implying that nuclear kept its "market ranking" for electricity bids and did not suffer particular problems compared to the other sources (coal, gas, renewables).

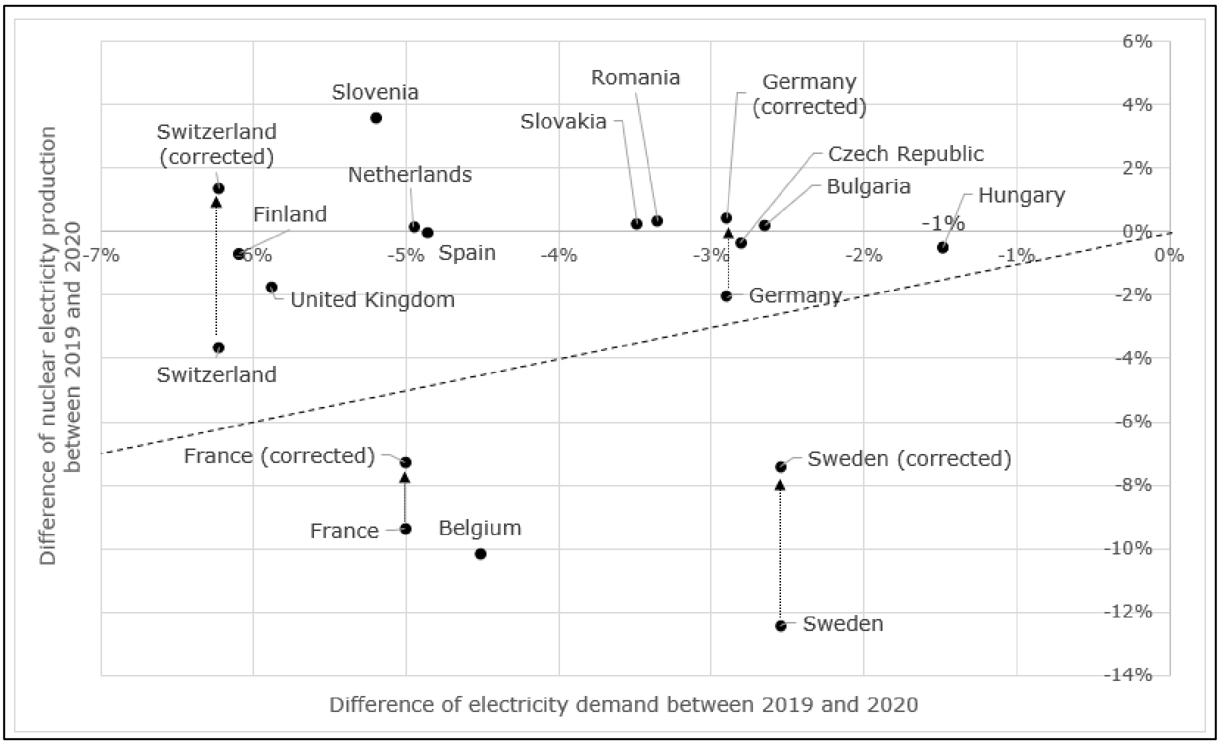


Figure 10: Comparative variations of electricity demand and nuclear electricity production between 2019 and 2020 (correction, when permanent shutdown of reactors, is indicated)

On the other hand, this is untrue for Belgium, France, and Sweden, which have seen larger reductions in nuclear production than in demand. Many reactors, in these three countries, have been under heavy maintenance operations during

2020 for various reasons, and, obviously, on-site works were significantly impacted by the COVID pandemic. A specific focus on Belgium, France and Sweden is presented later in the report (See §1.2.8 for details per country on the onsite work that impacted negatively nuclear electricity production).

Finding #2 – Nuclear electricity's contribution to demand fluctuated among European countries. For most of them, nuclear production remained stable or improved as compared to 2019, while a limited number of countries experienced important nuclear electricity generation decreases (United-Kingdom, France, Sweden, and Belgium).
Heavy maintenance operations were significantly impacted by the COVID-19 pandemic.

1.2.5. European reactor availabilities during the COVID-19 pandemic

The reasons for the nuclear production variations in 2020 can be easily derived from several performance indicators on European reactors, and from their comparisons with the previous years.

The standard performance indicators used by IAEA are indicated and defined in the following table. As indicators provided by utilities are not exactly similar, the values used hereafter have been calculated from raw data coming from ENTSOE in a homogeneous way.

Indicator	Definition
Reference Energy Generation (REG)	The reference energy generation (MWh or GWh) for the period is the net electricity output that would be produced if a reactor unit is operated at its rated power output for the entire period.
Load Factor (LF)	The load factor, for a given period, is the ratio of the energy which the power reactor unit has produced over that period (EG) divided by the energy it would have produced at its reference power capacity over that period (REG).
Energy Availability Factor (EAF)	The energy availability factor is the ratio of the energy that the reference unit power could have produced during a period, considering planned energy losses (PEL), unplanned energy loss (UEL) and external energy losses (XEL), to the energy that the reference unit power could have produced during the same period without losses.
Operation Factor (OF)	The operation factor is defined as the ratio of the number of hours the unit was on-line to the total number of hours in the reference year, expressed as a percentage. It is a measure of the unit time availability on the grid and does not depend on the operating power level.
Utilization factor (UF)	The utilization factor is the ratio of the actual energy generation over a period of time, to the potential output if the plant were operating at full power when available during the same period (REG – UEL – PEL).

Table 4: definition of nuclear reactor performance indicators – source IAEA PRIS

The Load Factor is an important indicator; it depends on the reactor technology (on-line refuelling or not) and reflects all the sources of unavailability (caused by normal or unexpected events, and planned or unplanned operations: power reduction, load follow, maintenance, repairs, safety constraints, etc.); for PWR and BWR, it is usually in the range of 70-90%, while, in CANDU, it can be close to 100% for several years as long as no maintenance operation is necessary *(Darlington-1 unit in Canada set a new record[7] with 3 years of uninterrupted production, with a load factor of 99.1% in 2019)*. In 2019, the total world fleet had an average load factor of 76.4%[8].

As expected, Figure 11 confirms that most of the European reactors did not see significant variation of their load factors between 2019 and 2020, with values staying above 90% (Bulgaria, Finland, Hungary, Netherlands, Romania, Slovakia, Slovenia, Spain, Switzerland). Czech Republic and Germany had lower load factors in 2020 (respectively 82% and 85%), but stable as compared to 2019.

Nevertheless, significant changes appear in 4 countries, with lower values, in the range of 60-70%:

- Sweden 69.7% (-15.8% compared to 2019)
- Belgium 62.8% (-16.7% compared to 2019)
- France 61.4% (-6.9% compared to 2019)
- United-Kingdom 60.4% (-6.9% compared to 2019)

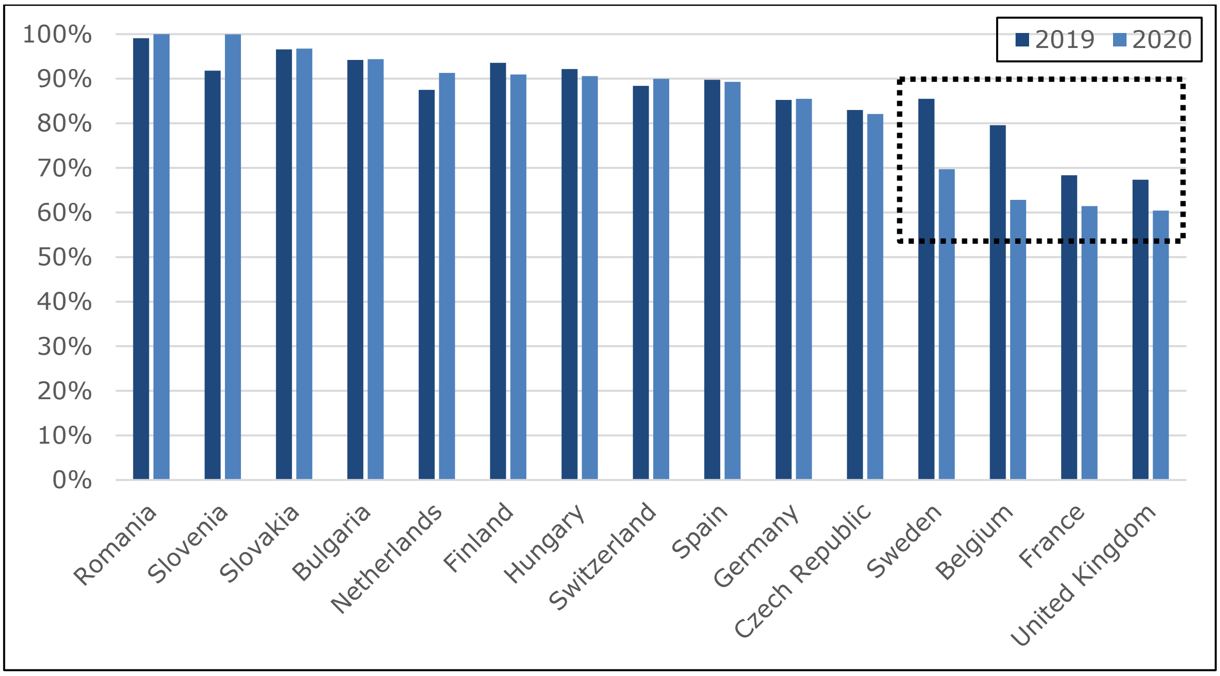


Figure 11: Load factor variations for European nuclear countries between 2019 and 2020

[7] https://world-nuclear-news.org/Articles/German-Canadian-reactors-set-new-world-records
[8] https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendinAverageLoadFactor.aspx

The load factor is a combination of the three performance indicators (Utilization factor and the planned and unplanned availability factors); they are analysed in the next sub-sections.

1.2.6. Nuclear reactors utilization during the COVID-19 pandemic

Nuclear reactors are generally operated in baseload, considering their high capital costs and their low marginal cost (O&M and Fuel). Nevertheless, some flexibility is necessary for adjusting to the grid demand; they always operate in frequency control of the grid and accommodate small variations of power. They have daily load-following capacities, which are not extensively used for economic reasons except in France, due to the large share of nuclear generation on the grid. French reactors even have specific features for ensuring large variations of power, when needed.

When nuclear reactors are under operation, the volume of electricity generated then depends on:

- Electricity demands and market considerations on the one hand, and available production and price, on the other hand.
- The Utilities strategy for optimizing the use of their reactors (fuel cycle management, revamping, etc.).

Therefore, nuclear reactors are not operated full-power, full-time and the Utilization Factor (UF) is a good indicator for assessing whether utilities were able to maximize nuclear electricity output during the COVID-19 pandemic.

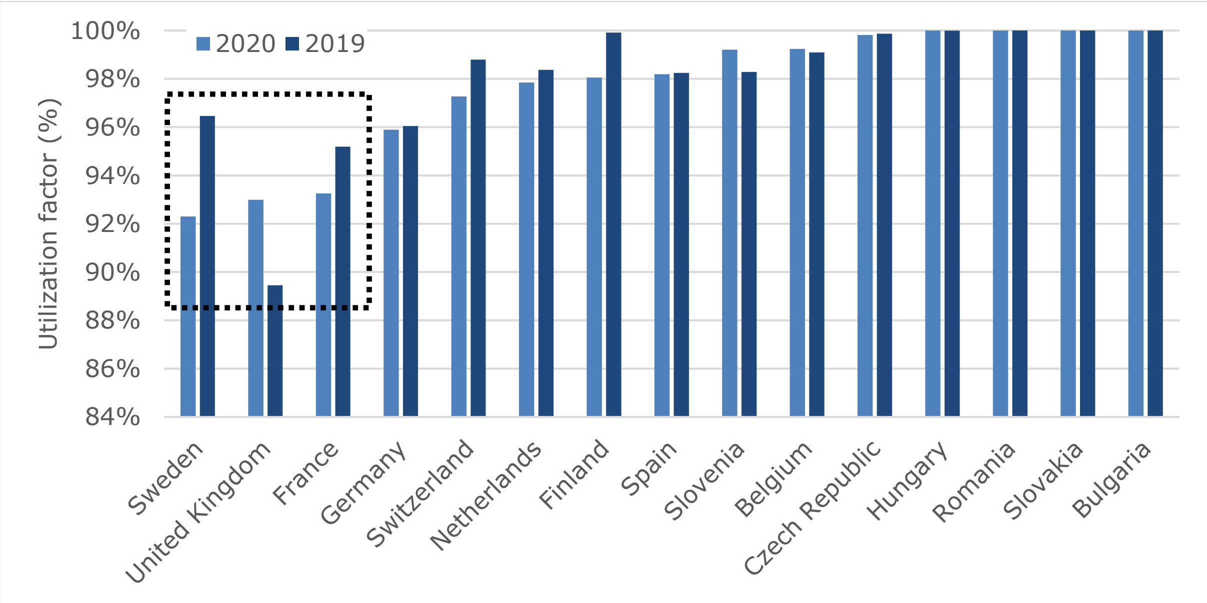


Figure 12: Variation of Utilization Factor between 2019 and 2020

The Figure above shows that, when in power, the European reactors are operated close to their nominal capacity (with a few % margin for grid power and frequency adjustments in narrow bands). Sweden and France, in 2020, called less on their available facilities while, on the contrary, the United Kingdom increased the use of their operating reactors, but it remains within a band of a few percent.

Finding #3 - No major variations could be seen between 2019 and 2020 regarding reactor utilization, despite major demand variations. European reactors were operated close to full power capacity when available.

1.2.7. Impact of planned and unplanned unavailability events

As the nuclear reactors were utilized in a similar way between 2019 and 2020, the variations of the Load Factors in several countries are coming from the reactors being put out-of-operation over long periods.

Different types of events can lead to temporary reactor shutdown:

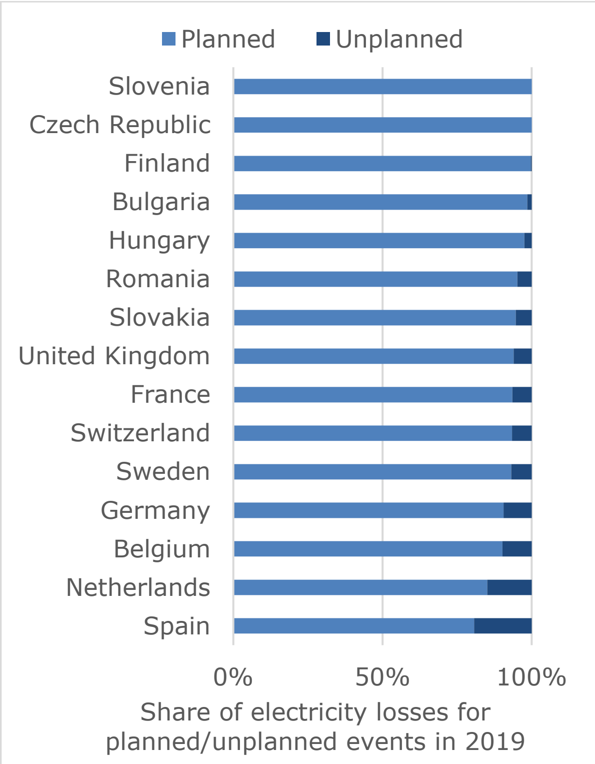
- Planned unavailability (PEL), such as:
  - Normal outages (refuelling and regular maintenance), with a usual impact of several weeks every 12 to 18 months (for PWR/BWR).
  - Heavy maintenance and modernization (e.g., decennial upgrades), with large modifications for safety improvement and life extension (heavy components replacements, digital I&C implementation, etc.), with durations of several months.
  - Long shutdowns for safety reasons, after discovery of defects during regular controls, until the justifications or repairs are accepted by Regulators, specific to each event.
  - Temporary shutdowns or power decrease, to cope with operational constraints *(electrical overcapacity, saving for longer fuel cycle, etc.)*.
- Unplanned unavailability (UEL), generally occurring following a technical failure (e.g., reactor trip) or due to regulatory constraints. Impact can range from a few hours to very long durations depending on the nature of the incident.
- External electric event (XEL)[9], occurring when a major issue is occurring on the grid, outside the nuclear site (e.g., transmission-grid incident).

During a standard year, planned unavailability periods have the greater responsibility for load-factor decreases, generally representing more than 90% of losses in nuclear electricity output. During the last two years, in many European countries unplanned events represented less than 10% of production losses (see

[9] As external energy impacts are independent of utilities perimeter, they are not part of the study's perimeter. Moreover, no major external incident on the electricity grid having an impact on nuclear electricity production could be identified.

Figure-12) and no specific trend could be observed during the COVID-19 pandemic.

For most countries, the balance of planned/unplanned events impacts on generation remained the same (Spain, Czech Republic, Bulgaria, Hungary, etc.), and the major variations observed between 2019 and 2020 are only the result of non-generic forced outages (Finland, Netherlands).



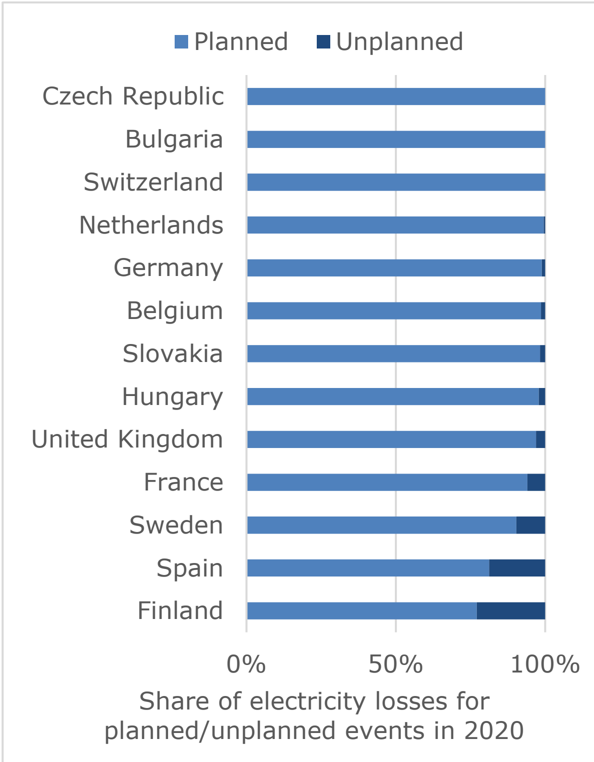


Figure 13: Share of electricity losses between planned/unplanned events in 2019 and 2020 for European nuclear countries – Data ENTSO-E

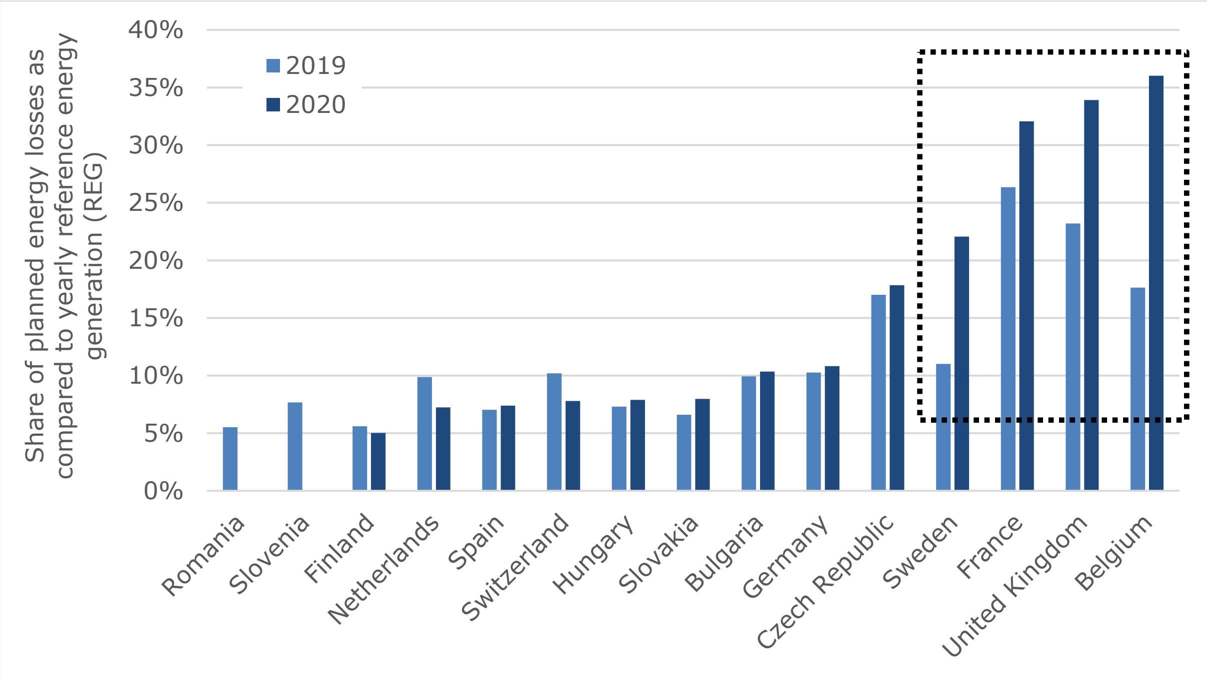


Figure 14: Planned unavailability variations between 2019 and 2020 for European countries

Taken separately, the variations of planned and unplanned reactor shutdowns provide a relevant view of the overall impact of the COVID-19 pandemic on operation.

- Planned outages (See Figure 14) led, in 2019, to a total cumulated loss of 210 TWh for all European reactors. In 2020, the loss increased up to 261 TWh (+25%). Major variations in planned electricity losses *(as compared to national REG)* confirmed the major load-factor drops of some previously identified countries:
  - Sweden Increase from 11 to 22% losses.
  - France Increase from 26 to 32% losses.
  - United-Kingdom Increase from 23 to 34% losses.
  - Belgium Increase from 18 to 36% losses.

- On the other hand, at European scale, the impact of unplanned shutdowns remained stable, around 15 TWh of yearly cumulated losses.

These four countries shall be assessed, on a separate basis, to identify the specific events that ultimately led to such large variations in planned availability.

Finding #4 – The sharp load-factor drops seen in 2020 originated from a significant increase in planned unavailability events. The impact of planned outages increased by 25% over a single year (cumulated losses of 261 TWh in 2020). Unplanned losses (forced shutdowns) remained stable over the period 2019/2020.

1.2.8. Specific assessment of planned unavailability variations in 2020 for Belgium, France, Sweden, and the United-Kingdom

After identification of countries which have experienced availability problems during 2020, the analysis is hereafter deepened at the reactor level, in order to identify, for each facility, how COVID-19 impacted planned outages, along the specific strategies which were developed by utilities owning multiple reactors (France, United Kingdom).

Nuclear utilities plan maintenance and refuelling operations well ahead (to ensure workforce, fuel, and equipment availabilities); they continuously update the schedules (start/end-date of each event), to optimize shutdown period durations. Thus, variations in subsequent planning provide effective means of identifying COVID-19 impacts on planned outages.

Belgium

Considering the 7 reactors located at 2 sites in Belgium (Doel and Tihange) operated by Electrabel (Engie), the Belgian nuclear reference electricity generation (REG) represents 52 TWh per year, while nuclear energy production only reached ~33 TWh in 2020 (41 TWh in 2019).

The early-2020 utility estimate of nuclear fleet availability forecasted a 13.8 TWh planned-unavailability, whereas, at the end of the year, the actual value was 19.7 TWh (+5.9 TWh). While actual planned-unavailability periods remained in line with the initial Electrabel forecasts during the first half of 2020 (see Figure 15), it was a significant delay in Tihange-1's restart which impacted production during the second half of the year.

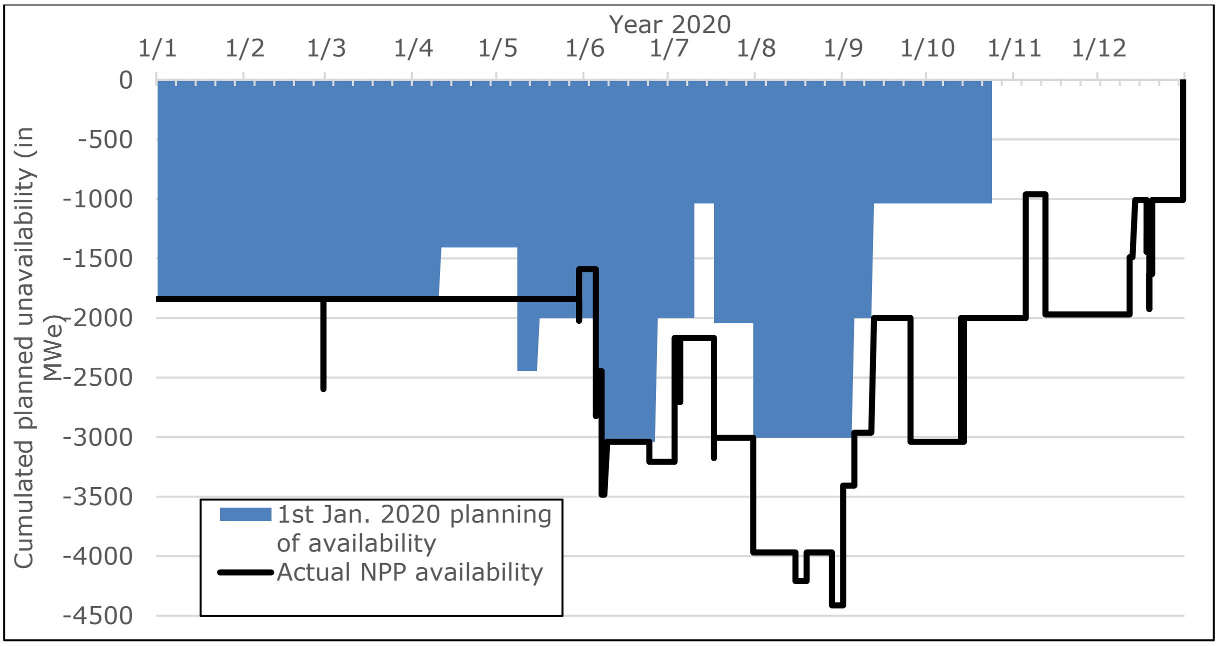


Figure 15: Belgian nuclear fleet cumulated unavailability for 2020 (real and 1st Jan. estimate) – Data Engie transparency data

Several large maintenance operations were underway in Belgium in 2020, for long-term operation considerations. The delays in restarting reactors under maintenance are the cause of the lower performance of the Belgian nuclear fleet, with Tihange-1 delays being responsible for ~60% of the additional losses:

- Doel-1's restart was initially planned on 16th May and was finally postponed to 9th June (20 days' delay, equivalent to 0.2 TWh losses).
- Doel-2's restart was also postponed from 11 April to 30 May (50 days delay, equivalent to 0.5 TWh losses).
- Tihange-1's restart after the fourth ten-years inspection was initially planned on 10th July but finally postponed to 14th December (150 days delay, equivalent to 3.5 TWh losses). The outage extension was due to a failure in a cooling water reservoir tank[10].
- The Tihange-2 maintenance operation initially planned from 12/11 to 25/12 was finally postponed to 22/01/2021 (28 days' delay).

Nevertheless, despite the COVID-19 pandemic, some minor maintenance & refuelling operations were successfully performed on time (Doel-3, Doel-4).

France

Considering the 58 reactors in France (including Fessenheim Units 1 & 2 which were shut down in 2020), operated by Electricité de France (EDF), the nuclear fleet presents an upper capacity of 544 TWh per year (REG), while nuclear energy production reached 335 TWh in 2020 (compared to 379 TWh in 2019).

The early estimate for 2020 was forecasted at 93 TWh for planned unavailability (corresponding to a 451 TWh potential production), whereas the actual value has been 194 TWh (a difference of 101 TWh).

Already, during the first months of 2020, before the first pandemic wave, French nuclear production capacity began differing from the original forecast (see Figure 16). For example, on March 1st, the unavailable daily nuclear capacity was 15.7 GW (for a total capacity of 62 GW), while the initial estimate was 7.3 GW. In terms of energy, the planned losses were originally estimated at 10 TWh, while the actual value was 15 TWh.

This example highlights the fact that all deviations identified from 2020 electricity generation are not necessarily the result of the COVID-19 pandemic, which appears to be an amplifier of other difficulties.

[10] According to safety authority FANC.

At the end of first COVID-19 wave, EDF largely updated its unavailability planning for the eight following months and anticipated total planned losses of up to 190 TWh (as of 1st May), close to the actual end of year result.

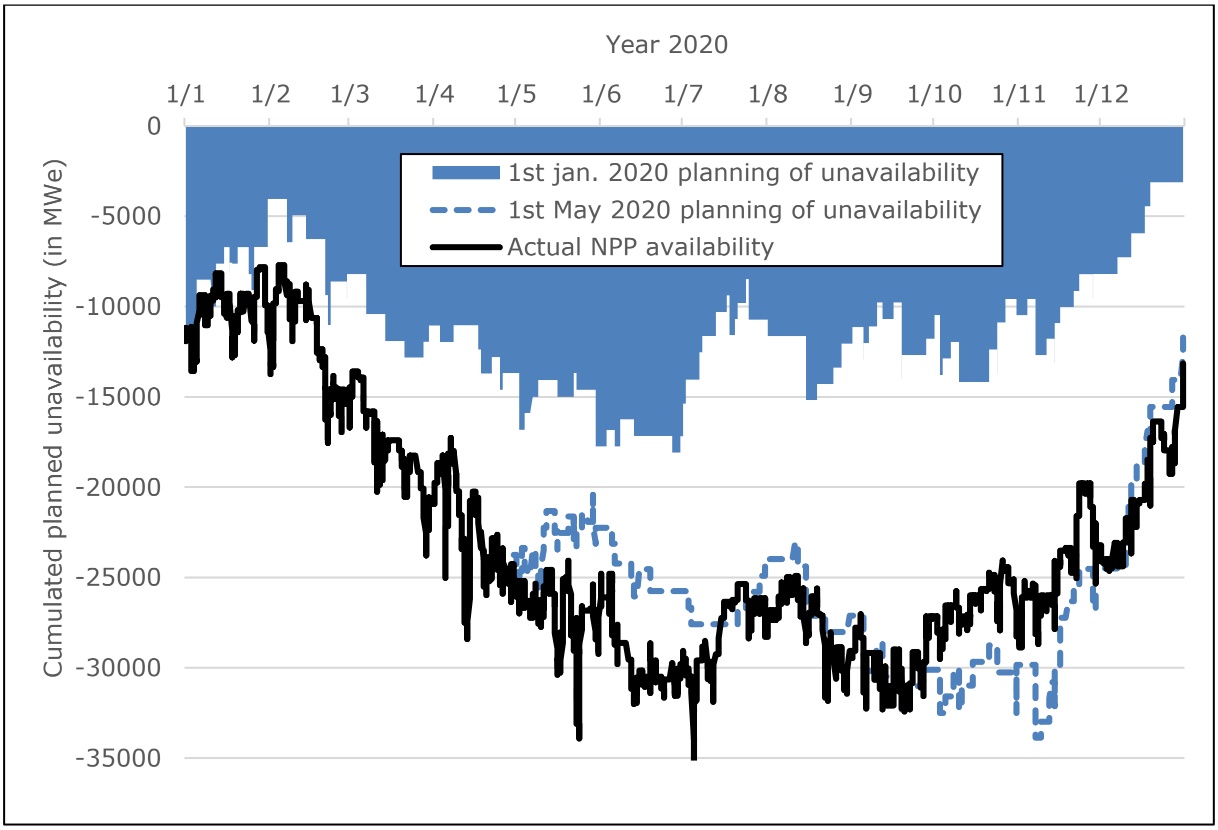


Figure 16: French nuclear fleet cumulated unavailability for 2020 (real, 1st Jan. and 1st May estimates) – Data EDF transparency data

As fuel cycle durations range between 12 and 18 months, all French reactors had planned unavailability's periods during the COVID-19 pandemic. For most of them, the shutdown period was only for refuelling and normal maintenance (about 2 months, standard duration), but for some of them, large upgrade operations were scheduled (6 months or above) and few of them were out-of-line for 1 or 2 years for technical repairs.

During 2020, the shutdown duration was significantly increased, up to a factor 5 in some cases *(e.g., +533% increase of Dampierre-1 unavailability periods, inducing a loss of 4.3 TWh by the end of 2020)*; almost half of the reactors have experienced a doubling in their unavailability periods.

The increase of losses due to planned shutdown of reactors can be attributed to a limited number of installations; out of the 56 French reactors, 10 of them are responsible for more than 50% of the total increase of planned availabilities periods:

Details are provided hereafter for the most-impacted installations:

- Flamanville-1 was shut down is September 2019, following corrosion issues in auxiliary systems (emergency diesel generators, water pumping station, etc.), shortly after its third ten-year inspection (10 months duration, from Apr. 2018 to Apr. 2019). As of Jan. 2020, the restart was planned for Feb. 2020, and finally postponed to May 2021 (+ 15 months, 9% of total PEL increase for 2020). Such a delay being justified by EDF by a priority given to Flamanville-2's restart and the COVID-19 pandemic.

- The Flamanville-2 reactor was shut down in Jan. 2019 for its third ten-year inspection. As of Jan. 2020, the restart was planned for Mar. 2020 and finally postponed to Dec. 2020 (+9 months, 8% of total PEL increase). Such a delay is mainly the result of unanticipated maintenance works[11] (same corrosion issues found in unit 1).

- The Paluel-2 reactor was shut down in late 2019 for refuelling operations, but defects found during maintenance led to unexpected works (need for a full core replacement following fuel integrity issues and issues on water filtration system); finally, the restart took place in Feb. 2021 (+11 months, 8% of total PEL increase), after several postponements. The COVID-19 impact is estimated at 4 months.

- Chooz-1 was shut down twice in 2020, for its third ten-year inspection and for environmental considerations. Inspection lasted longer than expected (until 19/08 instead of 6/07) with delays potentially linked to COVID-19, while, in August, a French/Belgium agreement on the water pumping limits on the Meuse forced EDF to shut down the installation for one month. Inspection delay and environmental shutdown represented in total a 4% increase of total PEL.

- Chooz-2 was shut down twice in 2020, to adapt to the lower electricity demand[12] and for environmental considerations, first for saving fuel and to allow operation during winter 2021, and second, as for Chooz-1, due to constraints on pumping in the Meuse River. These unavailability periods represented a total of 3% of total PEL increase.

[11] https://www.asn.fr/Controler/Actualites-du-controle/Arret-de-reacteurs-de-centrales-nucleaires/Arret-pour-visite-decennale-et-rechargement-en-combustible-du-reacteur-2
[12] https://www.edf.fr/sites/default/files/contrib/groupe-edf/producteur-industriel/carte-des-implantations/centrale-chooz/actualites/2020/MAI/v2choozenperspectiveavrilmai2020.pdf

- The Bugey-2 reactor has been shut down during all of 2020 (18/01/20 to 15/02/21) for its fourth ten-year inspection, initially estimated to last 6 months. The delay was due to both COVID-19 conditions and unplanned technical issues[13]. The delay represents 4% of the total PEL increase in 2020.

- The Bugey-3 reactor shares an effluent reservoir with Bugey-2. Corrosion issues identified during Bugey-2's inspection forced EDF to shut down Bugey-3 during repairs (4% of total PEL increase).

- The Civaux-1 reactor was shut down for maintenance shortly before the first pandemic wave in Mid-March and remained so until end September, while the initial schedule forecasted a 3-month maintenance duration. The full perimeter of the maintenance activity was maintained, but COVID-19's impact delayed operations by 3 months (delays representing 4% of total PEL increase).

- Civaux-2 maintenance activities were cancelled during 2020 and postponed to 2021, because of foreseen COVID-19 delays and in preparation for winter peak demand. This postponement forced the reactor to operate for three months at a lower power level (400 MW instead of 1500 MW) to save fuel. The variation represented 4% of total PEL increase.

A summary of previous developments is given hereafter, in Table 5.

Reactor	Start/end unavailability period		Delay	Share of 2020 PEL variation
	Early 2020	Final		
Flamanville 1	18/09/19 – 15/02/20	10/01/19 – 03/05/21	14.5 months	9%
Flamanville 2	10/01/19 – 31/03/20	10/01/19 – 12/12/20	8.5 months	8%
Paluel 2	26/10/19 – 29/2/20	25/10/19 – 01/02/21	11 months	8%
Chooz 1	21/02/20 – 06/07/20 *Unforeseen*	21/02/20 – 19/08/20 24/08/20 – 28/09/20	1.5 months 1 month	4%
Chooz 2	*Unforeseen* *Unforeseen*	19/04/20 – 19/06/20 21/08/20 – 01/10/20	2 months 1 month	3%
Bugey 2	18/01/20 – 02/07/20	18/01/20 – 15/02/20	7.5 months	4%
Bugey 3	*Unforeseen*[14]	15/05/20 – 11/03/21	6.5 months	4%
Civaux 1	14/03/20 – 08/06/20	14/03/20 – 21/09/20	3 months	4%

Table 5: Main variations of planned unavailability events during 2020

Among the 48 other reactors, 27 out of them had minor variations representing less than 1% each of the total PEL increase, while the remaining ones contributed from 1-3% of total PEL increase.

[13]https://www.edf.fr/groupe-edf/nos-energies/carte-de-nos-implantations-industrielles-en-france/centrale-nucleaire-du-bugey/actualites/4emes-visites-decennales-l-unite-de-production-ndeg2-sur-le-reseau-national

[14] Unforeseen unavailability period combined with planned maintenance activities that started in September 2020.

COVID-19 had a real impact on French nuclear power plants, first on delays of large maintenance operations and then in the overall management of the nuclear fleet, with various updates of unavailability periods (temporary shutdown or limited production level to save fuel, postponement of maintenance operations, etc.). However, COVID-19's impact is often hard to dissociate from standard delays and uncertainties linked to large maintenance operations.

United Kingdom

EDF Energy is currently operating 15 nuclear power plants in the United-Kingdom, 14 of them being advanced gas-cooled reactors, and Sizewell B being a pressurized water reactor. This nuclear fleet of 10.4 GW installed represents a reference production of 78.4 TWh of electricity per year. Nuclear electricity production in the UK reached 47.4 TWh in 2020, to be compared to 52.6 TWh in 2019.

EDF Energy forecasted, in early 2020, a total planned unavailability of production for the coming year equivalent to a loss of **15.7 TWh** (a production of 62.7 TWh), while the cumulated unavailability led to an actual loss of ~**32 TWh**.

As illustrated by Figure 17, EDF Energy initially expected an improvement of nuclear fleet availability during the second quarter of 2020, with different units expected to come back online. Reactor restart was ultimately delayed, and important variations were seen during the last year, with up to 4 GW of installed capacity unavailable as compared to initial forecasts.

Initial forecasts for the first quarter of 2020 were very close to actual NPP availability. Forecasts of UK nuclear fleet availability for the following months of the year were updated during the March/April period, confirming the large production capacity drop of 2020, with a total loss of production from planned unavailability reaching 26 TWh (to be compared to an initial estimate of 15.7 TWh).

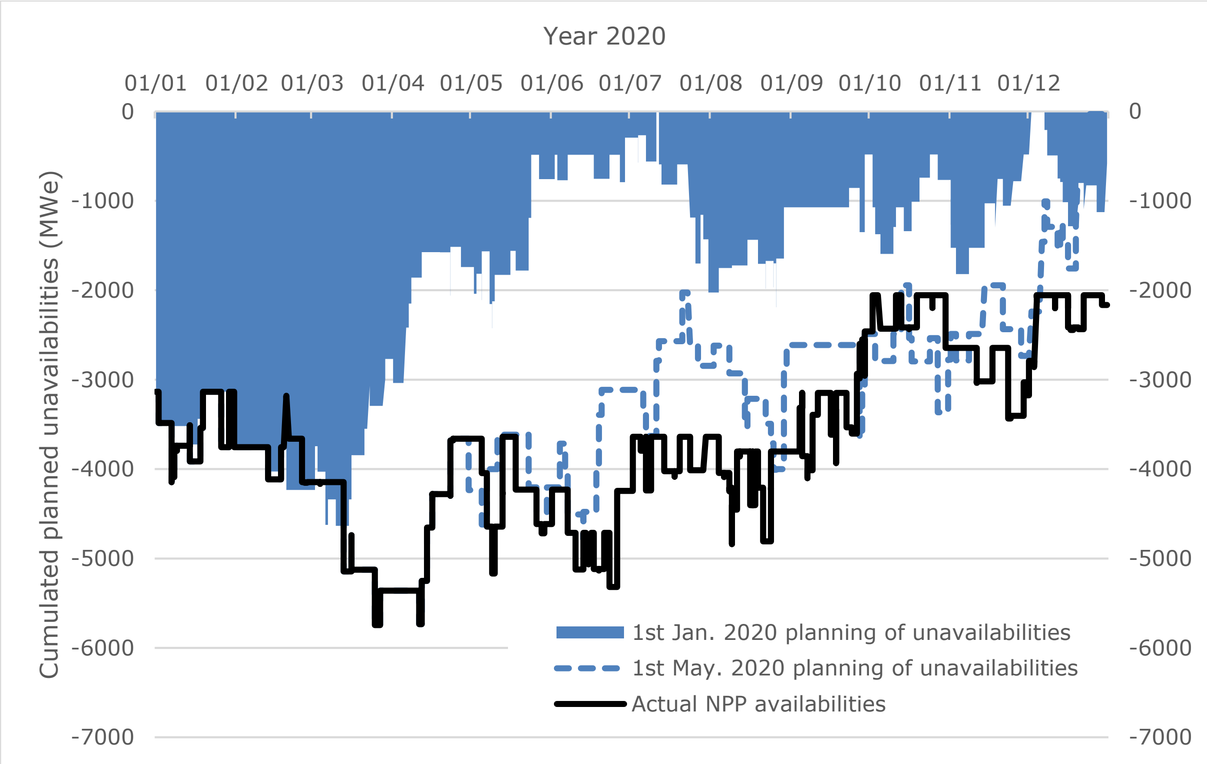


Figure 17: UK nuclear fleet cumulated unavailability for 2020 (real, 1st Jan. and 1st May estimates) – Data Remit BMRS

According to EDF[15], the main availability issues that impacted nuclear fleet performances are quoted hereafter:

"This decline resulted primarily from the outage of Hinkley Point B for a graphite inspection. Hunterston B came back to the grid in September and Dungeness B is still offline. Our output was also affected by the de-load of Sizewell B in May-Sept at the request of National Grid, which was fully compensated."

Details are provided hereafter for the most-impacted installations:

- The two reactors at Dungeness B (1&2) were shut down in 2018, following a decision from UK Safety Authority (ONR) following corrosion of safety-related concealed systems. Inspections performed by ONR demonstrated large corrosion issues on pipework, storage vessels and seismic restraints. The shutdown of both reactors has been extended multiple times during 2020, impacting early 2020 production capacity estimates. Postponements of reactors represented ~33% of total PEL increase of 2020. Such delays are not linked to COVID-19. Ultimately, EDF Energy announced in June 2021 that both reactors would finally move directly to defueling phase with immediate effect.

[15] https://www.edfenergy.com/media-centre/news-releases/edf-group-results-2020-highlights-edf-energy-ltd

- Reactor 3&4 of Hinkley Point B were taken offline on 21 February and 8 June 2020, respectively, for a series of inspections of the graphite core. That was not initially planned in early 2020 EDF Energy fleet unavailability estimates. Restarts of both reactors took place in March/April 2021, but for a limited duration (2 times 6 months for each reactor), followed in 2022 by a scheduled closure. Such shutdown in 2020 represented ~33% of total PEL increase of 2020.

- Sizewell B power output was reduced by half by EDF Energy[16] during 2020 (between May and September) following a request from the national grid operator ESO (Electricity System Operator) to cope with low power demand from COVID-19. The power decrease represented a production loss of ~2.2 TWh (13% of total PEL increase). EDF received an indemnity[17] to compensate for losses caused by the plant's lower output.

- Hunterston B (Units 3 & 4) have been offline respectively from March and October 2018; their restart was postponed during the year 2020 (the restart of reactor 3 finally took place in September, compared to an initial target of early March 2020). The cumulated delays of units 3 & 4 represented 20% of overall PEL increase. The impact of COVID-19 on these delays is unknown.

Aside from these reactors where a part of PEL increase might be linked to COVID-19, most EDF energy NPPs in UK were operated close to initial 2020 projections (Heysham 1-2, Hartlepool).

Sweden

The Swedish nuclear fleet is owned and operated by Vattenfall and different private utilities (Uniper SE, Fortum, MKB AB Group of utilities) and composed of 6 reactors as of 1st Jan. 2021. This represents an installed capacity of 7.1 GW, following the final shutdown of Ringhals-2 (852 MW) in late 2019 and Ringhals-1 (881 MW) in late 2020. The reference electricity generation (REG) decreased in the last two years, because of these shutdowns, from 75 TWh in 2019 to 68 TWh in 2020. Nuclear electricity generation reached 47.5 TWh in 2020.

As illustrated by Figure 18, actual Swedish NPP availability largely differed from initial forecasts. For the whole year 2020, loss of production due to NPP unavailability reached ~18 TWh to be compared to initial forecast of ~8 TWh. Such difference being the results of longer maintenance periods, lower power outputs or temporary shutdowns of Ringhals reactors (Units 1/3/4), accounting for 70% of the variations.

[16] https://www.reuters.com/article/uk-britain-nuclear-idUKKCN2521GZ
[17] EDF group half-year financial report – 30 June 2020

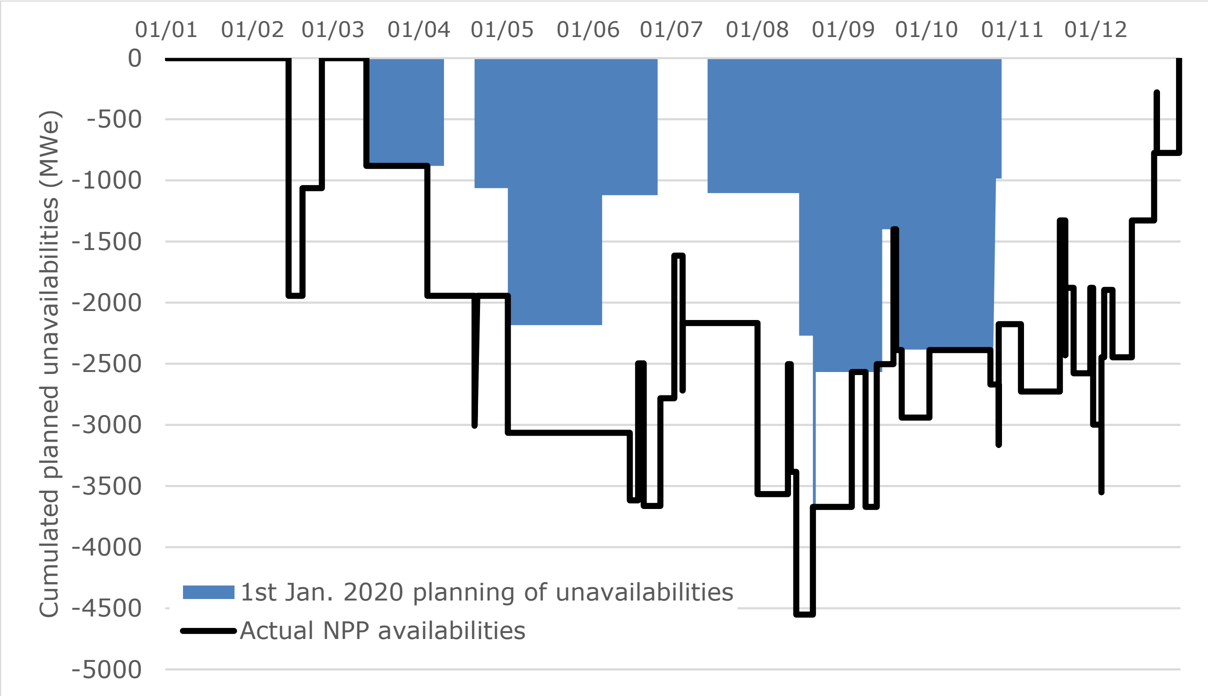


Figure 18: Sweden nuclear fleet cumulated unavailability for 2020 (real, 1st Jan. estimate) – Source Nord Pool REMIT UMM[18]

Main events are highlighted hereafter to estimate COVID-19 impact on the Swedish nuclear fleet:

- Ringhals 1 was shut down for maintenance on 13th March 2020. Unit shall remain offline until after summer 2020. For economic reasons, Vattenfall planned to optimize restart date in line with electricity market prices[19]. The impact of COVID-19 on demand and large hydro production led to low electricity prices during 2nd quarter 2020. Nevertheless, following a request from SvK *(Swedish national electricity system operator Svenska Kraftnat)*, it was decided in mid-June 2020 to restart Ringhals 1 (in exchange for financial compensation by SvK) to secure voltage stability and short-circuit power in the transmission network, since such stabilising effect on the network could not be secured through other production sources, according to SvK[20].

- Ringhals 3's planned maintenance has been progressively extended by 2.5 months (from 1.5 to 4 months long), as a result of both technical issues encountered during maintenance (troubleshooting and repair on main steam valves) and for economic reasons.

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[18] https://umm.nordpoolgroup.com/#/messages?publicationDate=all&eventDate=custom&eventDateStart=2020-01-01&eventDateStop=2020-12-31&status=active&areas=10Y1001A1001A44P&areas=10Y1001A1001A45N&areas=10Y1001A1001A46L&areas=10Y1001A1001A47J&fuelTypes=nuclear&includeOutdated=true
[19] https://www.world-nuclear-news.org/Articles/Outage-management-adapts-to-COVID-19
[20] https://www.world-nuclear-news.org/Articles/Early-restart-agreed-for-Ringhals-1-after-maintena

- Forsmark 1 reactor maintenance went as planned, without duration deviation. However, unit power output was halved from late Oct. 2020 to Feb. 2021, due to vibrations problems in a generator.

- Other reactors (Forsmark 2-3 and Ringhals 4) faced technical issues[21] during the year 2020. Ringhals 4 planned maintenance has been extended, from 40 to 80 days, allowing to expand scope of maintenance activities.

According to Vattenfall[22], Nuclear power generation decreased by 7.2 TWh during the first half of 2020 as compared to 2019, mainly due to the prolonged shutdowns of Ringhals 1 and 3 in conjunction with the yearly revisions and the closure of Ringhals 2 (responsible for roughly 50% of the total power generation difference decrease for 1st semester 2020).

Based on these findings, it seems that COVID-19 impact on Swedish reactor was essentially indirect, with power outputs optimization by Vattenfall to cope with electricity market fluctuations, rather than directly negatively impacting availability.

[21] https://www.montelnews.com/es/news/1126719/unforeseen-incidents-behind-low-nuclear-output--vattenfall
[22] Vattenfall Interim report - January–June 2020

1.3. The COVID-19 pandemic impact on new build construction projects

1.3.1. The status of new build projects in Europe

Like any large construction projects, new build reactors necessitate years of intensive work, mobilizing thousands of workers from tens of companies during long duration to bring the projects to completion. Important variations of manpower can be seen during the standard 10 years reactor construction, from high mobilisation of civil workforce during the first years of the project, to low mobilisation during the handover period of the installation to the operator during the commissioning phase. The following figure highlights the main phases and milestones seen in new build projects and shall be used hereafter to position current EU projects.

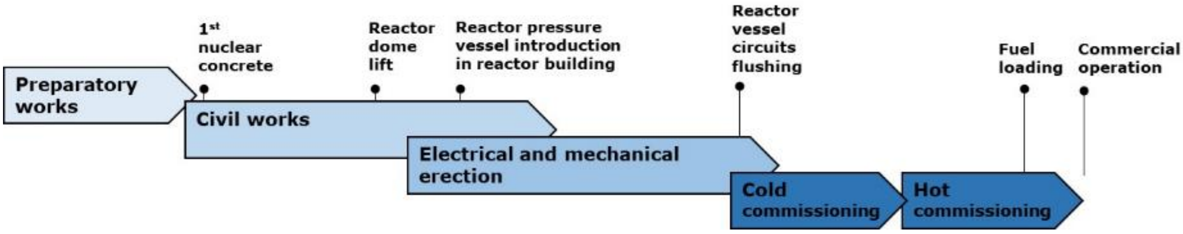

Figure 19: standard timeline for new build reactor project

As these new build projects rely on a wide range of workforce, equipment, and material, through complex coordination and management, their resilience against external threats could be at risk.

Over Europe, there is currently a limited number of power reactors under construction (6 units in total), the different projects are introduced below, providing indications on their progress status in early 2020:

- Hinkley Point C (United-Kingdom) project is composed of two EPR units (2 x 1630 MWe[23]) under construction at Hinkley Point nuclear site. Owned by EDF Energy and financed by EDF (66.5%) & CGN[24] (33.5%), the project's cost is now estimated around £22-23 billion. Commercial operation is now expected to take place in June 2026 for unit 1. In 2020, the two units were under active construction phase: the "J0" milestone[25] was achieved in June 2019 and May 2020, respectively for units 1 and 2.

- Mochovce 3 & 4 (Slovakia) project is the longest running nuclear construction project anywhere in Europe. The reactors were designed by the Soviet Union back in the 1970s, construction began back in 1987 but in 1992, soon after the collapse of the communist regime, it was suspended. Construction of Units 3 and 4 restarted in November 2008. The Unit 3 is

[23] Reference unit power
[24] China General Nuclear Power Corporation
[25] Completion of nuclear island concrete basemate, allowing to start the construction reactor building

expected to be operational in 2021 and unit 4 in 2023, they will be operated by Slovenské Elektrárne.

- Olkiluoto 3 (Finland) project started in 2005, for the construction of a single EPR reactor. After important delays and major price increases, TVO (owner/operator) and Areva (now Framatome) announced a new schedule prior to COVID-19 pandemic, with a start of commercial operation in March 2021. The hot commissioning was further delayed after 1st pandemic wave, in August 2020 a new schedule was presented with a new commercial production date in February 2022.

- Flamanville 3 (France) project started in December 2007, for the construction of a single EPR reactor. After different delays and cost increases, the latest cost estimate (July 2020) is at €19.1 billion, with commissioning planned tentatively at the end of 2022. In June 2019, the ASN requested EDF to repair eight containment penetration welds in which quality deviations had been discovered, justifying the latest delays.

1.3.2. The COVID-19 impact on new build projects under late commissioning stage

Most of new build projects were under late commissioning stage during the COVID-19 pandemic (Olkiluoto-3, Flamanville-3 and Mochovce-3/4). The additional constraints raised by COVID-19 had a marginal impact on the activities performed. Despite the delays announced since pandemic start in Europe, owners and nuclear vendors have not reported any specific COVID-19 impact, these delays being mainly the results of additional technical issues faced during hot commissioning.

Olkiluoto-3 project

In April 2020, shortly after the first pandemic wave, TVO announced that the measures put in place to prevent the COVID-19 spread *"may have significantly added uncertainty to the progress of the project"*.

After a few months (in August 2020) during the presentation of an updated planning including delays, TVO declared that *"issues that have caused delays in the project schedule are: slowly progressing system testing; technical problems*[26] *that have been identified in tests; and the increase in the amount of maintenance work caused by project delay. The lack of necessary spare parts has also caused delays."* Most of these issues are not directly or indirectly related to COVID-19.

[26] Technical problems have been related to sea water system equipment; cracks in the pressuriser safety valves' spring-loaded pilot control valves; faulty components in emergency diesel generators and the pressuriser surge line vibration problem. Faulty cable insulation has been detected in certain automation cabinets and these will be repaired during the autumn."
https://www.world-nuclear-news.org/Articles/Further-delay-in-commissioning-of-Finnish-EPR

One year after this statement, fuel has been successfully loaded into the reactor (March 2021) in line with August 2020 planning, confirming that COVID-19 has not prevented the project to progress according to updated objectives.

Flamanville-3 project

Regarding Flamanville-3 project, COVID-19 first had a direct impact on the progress of onsite activities, as the response to pandemic has been a full suspension of work[27] between mid-March and early-May (corresponding to the 1st French lockdown in response to 1st pandemic wave).

After the lockdown and the restart of the construction activities, the EDF chairman declared[28] that the construction schedule for Flamanville-3 EPR is not being jeopardized by specific COVID-19 measures taken to contain pandemic spread.

Currently the completion planning of the unit is subject to the successful repair activities underway of welding issues on primary circuit which is so far responsible for a three-year delay in the project. The new expected commercial date is now postponed to late 2022.

Mochovce 3 & 4

Regarding Mochovce 3-4 construction, both units are close to completion. The completion progress moved from 99.3% and 87.1% in December 2019 to 99.9% and 88% in April 2021, after roughly 8 million man-hours of work over the period. Construction activities were essentially linked to Unit 4.

No specific COVID-19 impact was reported by Slovenske Elektrarne. The operating licence for Mochovce 3 was finally issued by the Slovak nuclear regulator (UJD) in May 2021, more than one year after UJD's positive draft decision on fuel loading[29]. The commercial start of Unit 3 is now expected to take place in late 2021. Mochovce 4 should begin operation in 2023, according to the latest ministry's projections[30].

1.3.3. Focus on Hinkley Point C project

In January 2021, EDF updated[31] its completion date forecast for the Hinkley Point C project, considering the COVID-19 impact on the construction activities. Instead

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27 https://www.world-nuclear-news.org/Articles/EDF-counts-the-cost-of-coronavirus
28 https://www.ouest-france.fr/normandie/flamanville-50340/la-pandemie-de-covid-19-ne-remet-pas-en-cause-le-chantier-de-construction-de-l-epr-de-flamanville-6827982
29 https://www.seas.sk/article/mochovce-3-nuclear-authority-issued-a-draft-decision-on-fuel-loading/409
30 https://www.world-nuclear-news.org/Articles/New-nuclear-reactor-will-make-Slovakia-a-power-exp
31 https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-medias/cp/2021/2021-01-27-cp-certifie-actualisation-projet-hinkley-point-c.pdf

of a start of commercial operation in late 2025, the Unit 1 is now scheduled to start in June 2026 (6 months delay).

As of mid-2021, the share of responsibility on the specific delays in the Hinkley Point C caused by COVID-19 project remained undisclosed. In May 2021[32], the Low Carbon Contracts Company (LCCC), the government-owned company that acts as counterparty on clean energy subsidy contracts said it was "actively working with Hinkley Point C to establish the impact the pandemic has had, in accordance with the terms of [its contract]". LCCC "anticipate that it may take some time to establish the true impact of Covid-19 on complex construction projects such as Hinkley Point, as it is still unknown when Covid-19 restrictions will cease."

Some public information on COVID-19 direct impact on construction activities is given below:

- As of Sep. 2021, around 6300 workers are mobilised onsite[33], to be compared to the 1500 workers at the height of the pandemic in 2020, and the 4500 onsite workers just before pandemic. While EDF Energy initially planned a peak workforce of 5600 workers at Hinkley Point C, it should increase to ~8500 once COVID-19 restrictions are lifted[34].
- In terms of delays, in January 2021, EDF warned[35] that the Covid-19 pandemic had caused delays of three months in 2020 and was expected to lead a further three-month delay in 2021 too, if a full ramp up begins after quarter 2.

1.3.4. Lessons learned from new build projects

As shown previously, pandemic impacted negatively new build schedules, from minor impacts often indistinguishable from standard technical considerations postponing reactor commercial operation, to major impacts that deeply modified the daily organisation onsite. Yet, as illustrated by the Hinkley Point C project, the recognition of the true impact of COVID will require time and can sometimes be still undisclosed.

The pandemic pushed the new build sector, and more largely the nuclear industry, to adopt flexible approaches (e.g., on human resources). The impact of the sudden evolution of best practices shall be closely monitored to avoid future challenges (e.g. Human and organisational factors).

32 https://www.telegraph.co.uk/business/2021/05/23/edf-warns-delays-hinkley-due-pandemic/
33 https://www.edfenergy.com/media-centre/news-releases/five-years-22000-workers-britain-are-work-hinkley-point-c
34 https://www.itv.com/news/westcountry/2021-01-29/thousands-of-new-jobs-as-hinkley-point-c-to-ramp-up
35 https://www.nucnet.org/news/hinkley-point-c-five-years-after-go-ahead-nuclear-plant-project-is-recovering-from-shock-of-covid-9-3-2021

1.4. The COVID-19 pandemic impact on fuel supply chain

1.4.1. Nuclear fuel cycle specificities

Inside the European Union, there are only four power reactor technologies in use and LWRs are largely dominant (PWR, BWR, PHWR and VVER). In the UK, there are 14 AGRs in operation and in Romania two PHWRs. All these reactors use UO_2 fuel pellets with a zirconium alloy as cladding, for LWR and PHWR, and stainless steel for AGR. Enrichment varies from natural uranium (0.7%) up to 5%.

The fuel cycle of a nuclear power plant is generally considered through three main phases (see figure below): (i) the front-end: from mining up to the on-site delivery of assemblies; (ii) fuel use and storage inside the reactor and (iii) the back-end: from shipment of spent fuel up to final disposal.

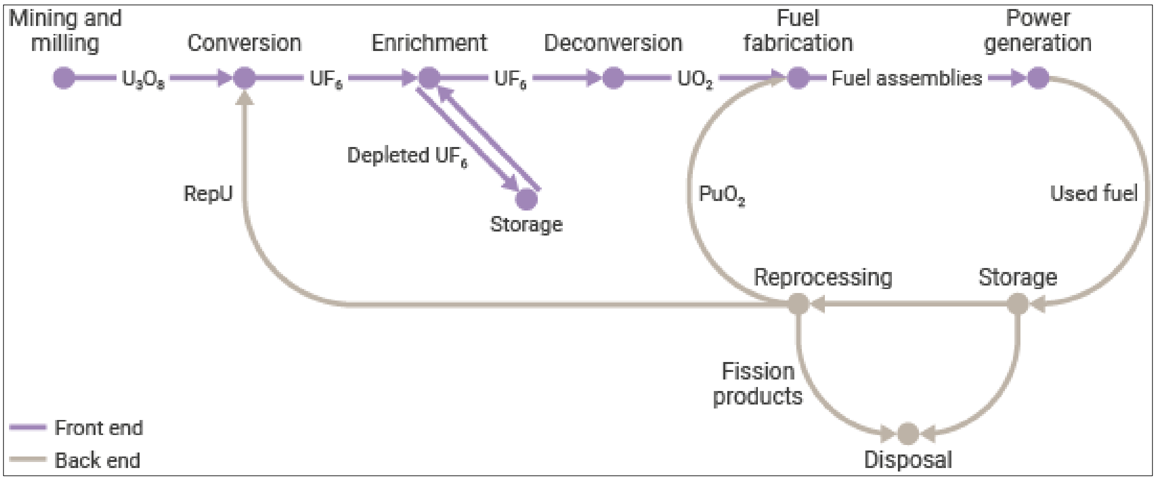

Figure 20: The nuclear fuel cycle – Source: World Nuclear Association

The present study aims at assessing the impact of COVID-19 on the front-end of the fuel supply chain only, which covers the following steps (full process for LWR, partially followed for PHWR and AGR):

- Mining: Uranium ore in its natural form is typically found in very low concentrations and conglomerated in other minerals. The mining process includes mechanical (grinding) and chemical operations required to extract the uranium (milling). This produces a uranium concentrate containing around 70% of U_3O_8 (yellow cake).

- Conversion: The yellow cake is then dissolved in nitric acid and converted into volatile uranium hexafluoride (UF_6).

- Enrichment: naturally occurring uranium contains 0.7% of the U_{235} fissile isotope (99.3% U_{238}). PWR type reactors requires a range between 2.0%-5.0% U_{235}. Gaseous UF_6 is used in enrichment technologies to increase the concentration of U_{235}. The preferred commercial technology for enrichment has long been diffusion through porous membranes. Nowadays, this has been completely replaced by Gaz Centrifuge Enrichment Plants, dramatically reducing the production cost.

- Fabrication: UF_6 is then chemically converted to pure uranium oxide powder (UO_2) which is then pressed into pellets and sintered to produce ceramic fuel. The pellets are sealed in zirconium tubes which are bundled into the fuel assemblies for use in reactors.

It must be noted that utilities own the uranium throughout the entire process, from the time that they purchase yellow cake. All the steps of the fuel cycle for the front-end process are considered as services; the uranium not being a supply, but a material to be treated.

Utilities survey demonstrated no shortage during COVID-19 pandemic, and no long-term impact of the pandemic is expected on the fuel supply chain. As demonstrated hereafter, the temporary closure of mines or installations had negligible impact on the supply capacity, considering both the existing oversupply capacity, the existing stockpiles, and the long timeframe for fuel front-end supply chain.

1.4.2. COVID-19 impact on mining activities

Since 2009 and despite the impact of Fukushima accident in 2011, the global uranium mine production continuously increased, reaching a maximum value in 2016 (62,997 tU). After this period, the uranium market became depressed, major producing countries (Canada, Kazakhstan, etc.) decided to close temporary some of their mines. This resulted in an important production decrease in 2017 and 2018 (from 62,997 tU in 2016 to 53,516 tU in 2018). Market stabilized itself in 2019, prior to COVID-19 crisis, experiencing a slight increase (+1%), with a production accounting for 54,224 tU in 2019[36], as indicated in Figure 21.

[36] Uranium 2020 Resources, Production and Demand – IAEA & OECD/NEA

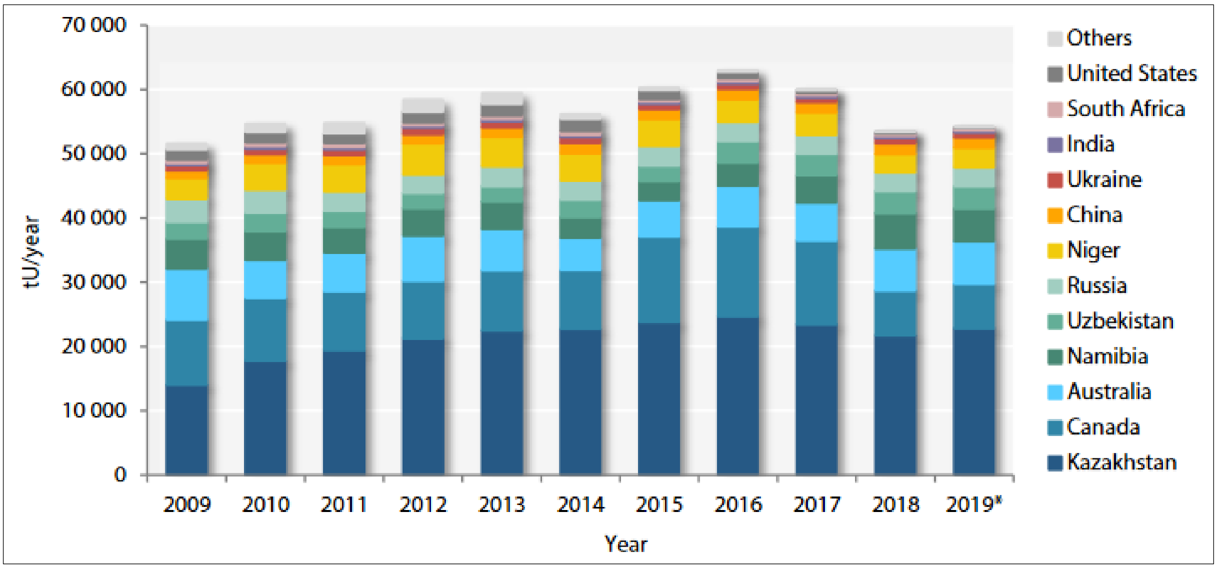

Figure 21: Recent world uranium production (tU/year) – Source IAEA/OECD

Such production must be compared to yearly needs to cope with nuclear power plants' needs. Worldwide uranium requirements to satisfy world installed nuclear capacity of 396 GWe (in 2019) was equivalent to ~59,200 tU.

Demand for natural uranium in the EU represents approximately one quarter of global uranium requirements. EU utilities purchased a total of 12,592 tU in 2020[37]. Following reactors final shutdown and decision to phase-out for some EU countries, the overall EU demand for Uranium is decreasing since 2012, combined with the trend to consume Uranium inventories. The EU demand for 2020 is about 13,124 tU (to be compared to 12,592 tU purchased).

[37] Euratom Supply Agency – Annual report 2020

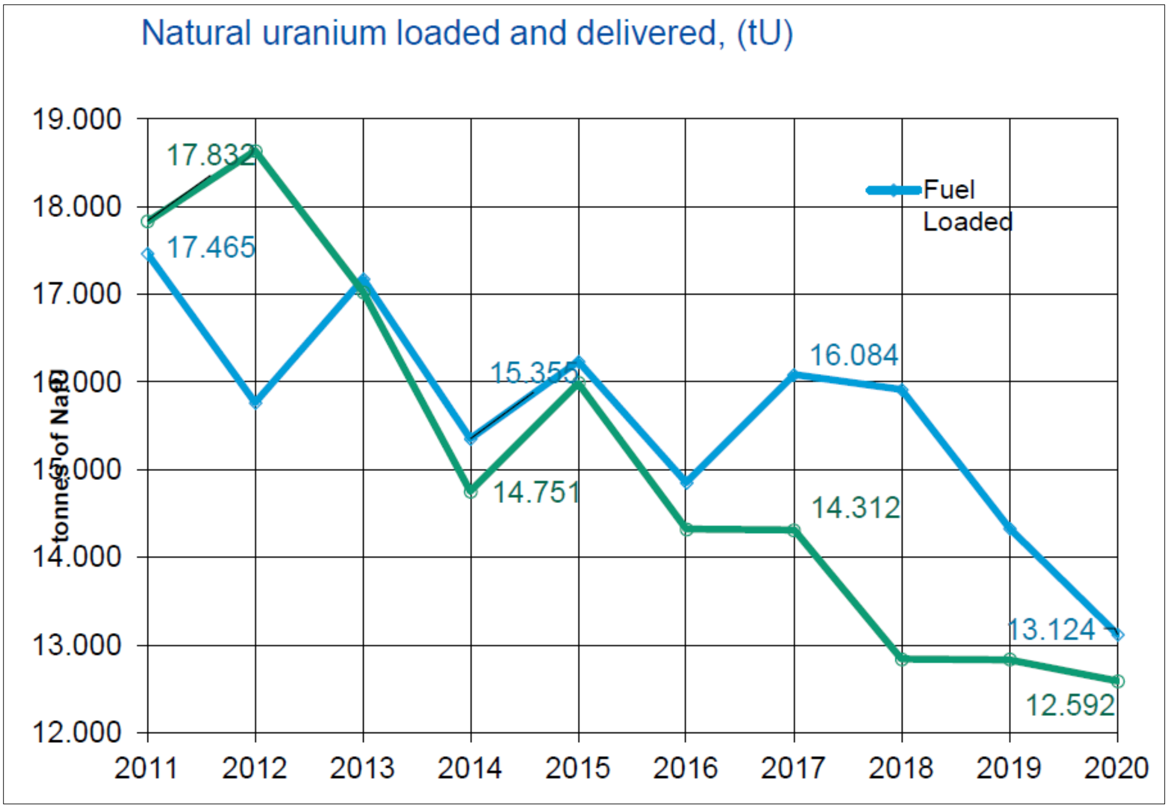

Figure 22: Natural uranium loaded in EU NPPs and delivered (tU) – Source ESA

In terms of Uranium inventories, based on average annual EU gross uranium reactor requirements, EU uranium inventories (42.396 tU in 2020) can fuel EU utilities' nuclear power reactors for 2.5 years on average. This is in line with ESA recommendations utilities to stock a sufficient quantity for, at least, one reload.

Uranium mining industry is controlled by few players, five of them having more than 2/3 of the world market shares[38] (Kazatomprom, CNNC/CGN, Rosatom, Orano, and Cameco), as illustrated by Figure 23. The 2019 world production reached 54.750 tU. There are currently no remaining mining activities within EU, and Orano is the only European player operating uranium mines across the world.

[38] https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx

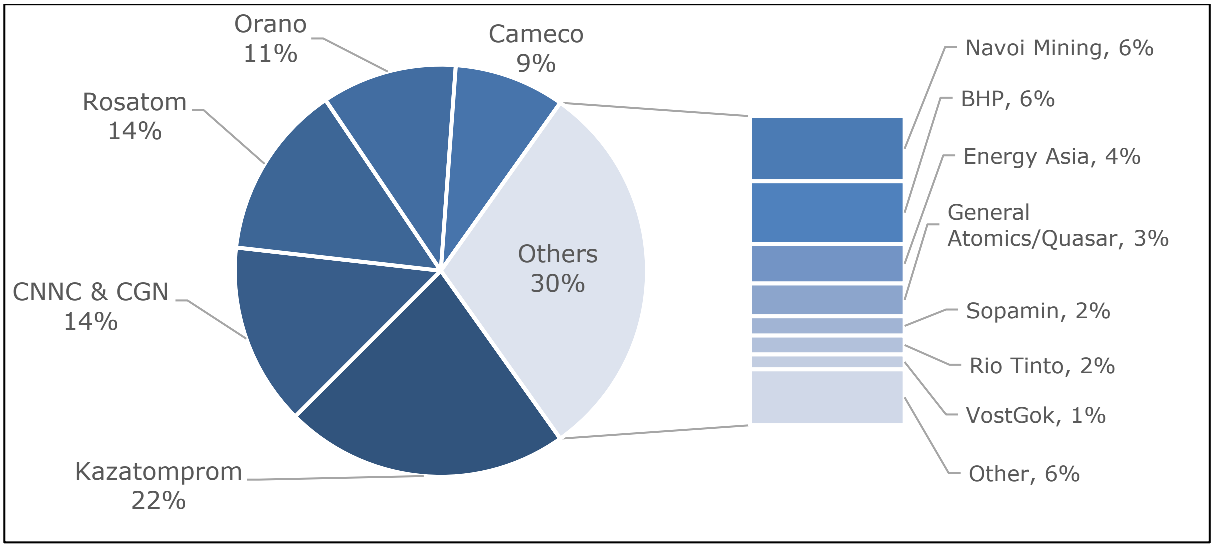

Figure 23: Uranium mining companies world market shares in 2019 – Source WNA

To evaluate COVID-19 impact on uranium mining, the 5 largest industrial players 2020 performances have been assessed:

- Kazatomprom: COVID-19 had a significant impact on Kazatomprom activities in 2020. The production dropped from 22,800 tU (planned production in early 2020, like 2019 production) to 19,477 tU[39] (-15% decrease), following COVID restrictions that significantly decreased on-site staff presence (reduction of onsite workers[40] from April to August 2020). Kazatomprom past strategy to flex down production volumes by 2020 shall continue in 2021 & 2022, preventing to compensate for production losses in 2020, with production objectives up to 22,800 tU.

- CNNC/CGN (Chinese Companies): The COVID-19 impact differs between the various mines under CNNC/CGN control. The Rössing mine (Namibia) achieved slightly higher production[41] in 2020 than 2019 (from 2077 to 2111 tU), despite the direct impact of lockdown that forced the mine to enter into minima mining operations. On the other hand, the production of Husab mine[42] slightly decreased from 3400 to 3302 tU between 2019 and 2020. Impact of CGN joint ventures mines with Kazatomprom is previously discussed.

[39] https://www.world-nuclear-news.org/Articles/Kazatomprom-uranium-output-falls-15-on-year
[40] https://www.neimagazine.com/news/newskazatomprom-to-resume-uranium-production-as-pandemic-restriction-ease-8064679
[41] https://www.rossing.com/cnnc-cnuc_message.htm
[42] https://world-nuclear.org/information-library/country-profiles/countries-g-n/namibia.aspx

- Rosatom (Uranium One & ARMZ): Uranium One production faced a net 7% decrease in 2020 as compared to 2019, with 4,276 tU produced. It must be noted that in terms of revenue the uranium price increase observed in 2020 compensated the consequential loss caused by the drop in production[43]. No production figures could be found for ARMZ[44].

- Orano: COVID-19 impact on production varied among countries of production. The Niger SOMAIR production remained stable over 2020 (from 1912 tU in 2019 to 1879 tU in 2020), In Kazakhstan, the Muyunkum and Tortkuduk mines (operated jointly with KazatomProm) production decreased about 13%, with 2833 tU produced in 2020, as compared to 2019 production of 3250 tU. In Canada the Cigar Lake uranium mine is developed within Cameco (mine co-owned by Cameco/Orano). Orano reported an 87 M€ loss[45] in its mining activities due to COVID-19 effects.

- Cameco/Orano: Cigar Lake uranium mine (co-owned with Orano) production was suspended in 2020, and the facility placed in safe care and maintenance mode during the COVID-19 pandemic. This reduced the workforce on site from around 300 to 35. This had a major impact of production, that dropped from 6900 tU produced in 2019 to only 3878 tU in 2020[46].

At the top of the COVID-19 pandemic (2nd quarter 2020), more than 50% of the world's uranium mining production was shut down[47] (~2500 tU/month of unavailable production). As a result of these production cutbacks, the spot price of uranium faced large increase in the March/April 2020 period, from 24.70 $/lb to 34.00 $/lb in May 2020 (~+40% increase), breaking for the first time the 30 $/lb level of 2016. It should however be noted that COVID-19 had almost no impact on long-term prices (as per Figure 24).

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43 Uranium One sold 11.8 million pounds of U3O8 in 2020 at an average price of $30.5/lb of U3O8 (~360 M$), which is 2% less than in 2019 (12.1 million pounds at $28/lb – equivalent to 338M$).
44 2020 yearly report is not available at the time of writing this report
45 https://www.orano.group/docs/default-source/orano-doc/finance/credit-update/ar/orano-annual-results-2020_credit-update_april-12th2021.pdf?sfvrsn=cc14c29f_6
46 https://www.orano.group/docs/default-source/orano-doc/finance/publications-financieres-et-reglementees/2020/rapport-annuel-d%27activite-2020-orano.pdf?sfvrsn=a7d51139_23
47 https://purepoint.ca/industry_news/covid-19-shuts-down-over-50-of-the-worlds-uranium-production/

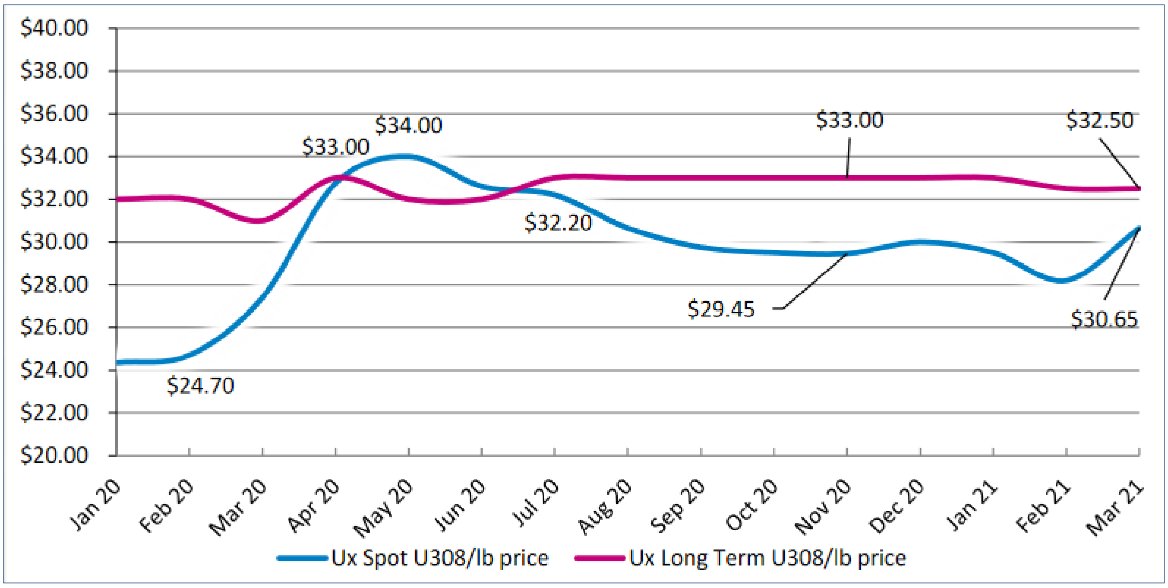


Figure 24: Monthly variations of Uranium spot and long-term prices – ESA/UxC

With these higher prices, many international companies are now resuming extraction operations. Shall the uranium remain above the $30 spot level, this could secure the production increase in the next years. Also considering the potential worldwide nuclear installed capacity increase in the next decades (OECD/NEA[48] forecasts an installed capacity growth that would necessitate between 58 to 79 ktU by 2030), uranium mining production shall increase in the future.

Regarding security of supply, the Euratom Supply Agency (ESA) considers in its latest yearly report[49] (including COVID-19 pandemic impacts) that quantitative analysis of contractual coverage rate for natural uranium shows that EU utilities are covered around 100% and even more under existing contracts until 2024. The coverage rates drop down from 93% to 57% from 2025 until 2029. Latest ESA forecast update (in 2021, including COVID-19 impacts) does not indicate any negative COVID-19 impact (as per figure below).

[48] https://www.oecd-nea.org/jcms/pl_52718/uranium-2020-resources-production-and-demand
[49] https://euratom-supply.ec.europa.eu/publications/esa-annual-reports_en

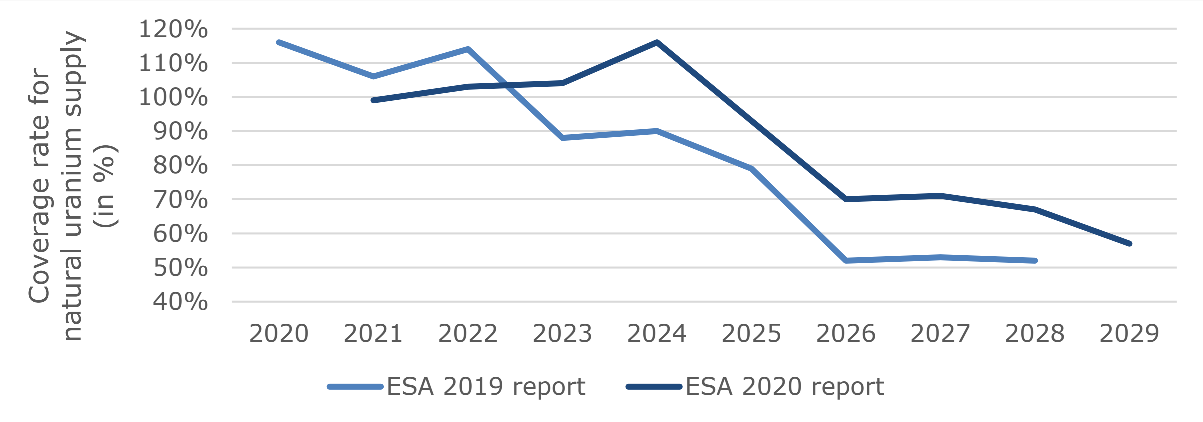


Figure 25: comparison of ESA contractual coverage rate forecast for natural uranium between 2019 and 2020 – Source ESA

1.4.3. COVID-19 impact on conversion

Conversion services purchase are almost systematically made by electrical utilities. The uranium conversion (from uranium ore to UF_6) is composed of a limited number of industrial players, with a large oversupply capacity in the last years due to lower demand and large UF_6 stockpiles available. The current worldwide conversion capacity and origin of conversion services used by EU utilities are given in the table below:

Company	Location	Nameplate capacity (tU)	Production in 2019 (tU)	Prod. For EU utilities in 2019 (tU)	Prod. For EU utilities in 2020 (tU)
Orano	Pierrelatte & Malvési	15,000	~2,500	3,976	3,651
Cameco	Port Hope	12,500	~10,000	2,284	3,993
Rosatom	Seversk	12,500	~12,000	3,115	3,040
Converdyn	Metropolis	7,000	0	2,080	1,970
CNNC	Lanzhou & Hengyang	15,000	~10,000	0	0
Unspecified				1154	196
Total		~62,000	~34,500	12,600	12,850

Table 6: Summary of world primary conversion capacity in 2019, along with respective supply services to EU utilities – Data from ESA and WNA

The worldwide conversion services in the last years have provided less than the necessary UF_6 needed for the front-end of the fuel cycle. The remaining supply came from commercial and government inventories, enricher underfeeding, depleted uranium tails recovery and uranium/plutonium recycle. For EU only and based on ESA data, out of the 12,850 tU supplied to EU utilities, only 9,000 tU were coming from conversion contracts (~70%).

To evaluate the COVID-19 impact on uranium mining, the 2020 performances of 3 largest EU suppliers of conversion services (representing more than 80% of conversion service to EU utilities) are hereunder assessed:

- Orano: conversion activities were pursued without interruption[50] during 2020, only some non-priority activities (e.g., dismantling) were put on hold during the 1st pandemic wave in EU (April 2020). In its latest yearly report Orano states[51] that "The unforeseen events related to the pandemic did not result in any contract terminations, penalties for late performance or significant disputes with customers or suppliers. However, ad hoc agreements were negotiated with some customers to rearrange certain contractual obligations without prejudice to the parties".

- Rosatom: no specific impact reported by Rosatom on its Seversk conversion plant.

- Cameco: after a temporary safe shutdown of the port Hope conversion facility[52] in early April 2020, Cameco restarted in mid-May its production. Since then, a few COVID-19 cases were detected among employees, but without impact to operation.

Regarding security of supply, the Euratom Supply Agency (ESA) considers in its latest yearly report that contractual coverage rate for enrichment services will continue to be more than 100% until 2029. It drops down to 89% in 2029. Same finding than for natural uranium coverage can be seen for enrichment services (as per Figure 26).

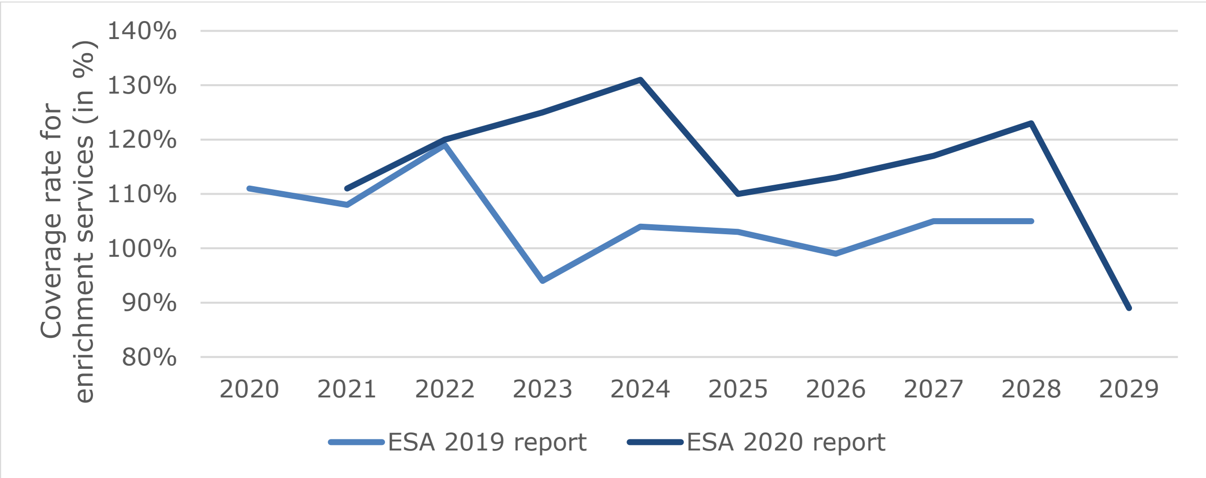


Figure 26: comparison of ESA contractual coverage rate forecast for enrichment services between 2019 and 2020 – Source ESA

Considering the oversupply capacity and the large existing stocks of UF_6, the immediate COVID-19 impact on conversion services can be considered negligible.

50 https://www.orano.group/docs/default-source/orano-doc/groupe/publications-reference/tsn-orano-malvesi_vf.pdf
51 Rapport Annuel d'Activité 2020
52 https://www.cameco.com/invest/strategy/covid-19-response

1.4.4. COVID-19 impact on enrichment

Enrichment services for EU utilities are provided by a very limited number of players. Orano and Urenco providing more than 2/3rd of enrichment services to EU utilities, while Tenex/TVEL (Russia) provides the remaining. The current worldwide enrichment capacity and EU utilities origin of enrichment services are given in the table below:

Company	Nameplate capacity (tU)	Prod. For EU utilities in 2019 (tU)	Prod. For EU utilities in 2020 (tU)
Orano	7.500	8,764	7,955
Urenco EU	14,900		
Tenex	28,660	3,927	2,961
Urenco USA	4,700	0	0
CNNC	>10,700	0	0
Unspecified/Others	~250	220	307
Total	66,700	12,912	11,224

Table 7: Enrichment services origin of supply – Source ESA

As for the conversion services, the COVID-19 did not impact the different players capacity to satisfy contract deliveries, as activity was fully maintained[53].

Regarding security of supply, the Euratom Supply Agency (ESA) considers in its latest yearly report that conversion services coverage rate is- above 100% until 2025, then it fluctuates between 90 and 99% to finally drop to 82% in 2029.

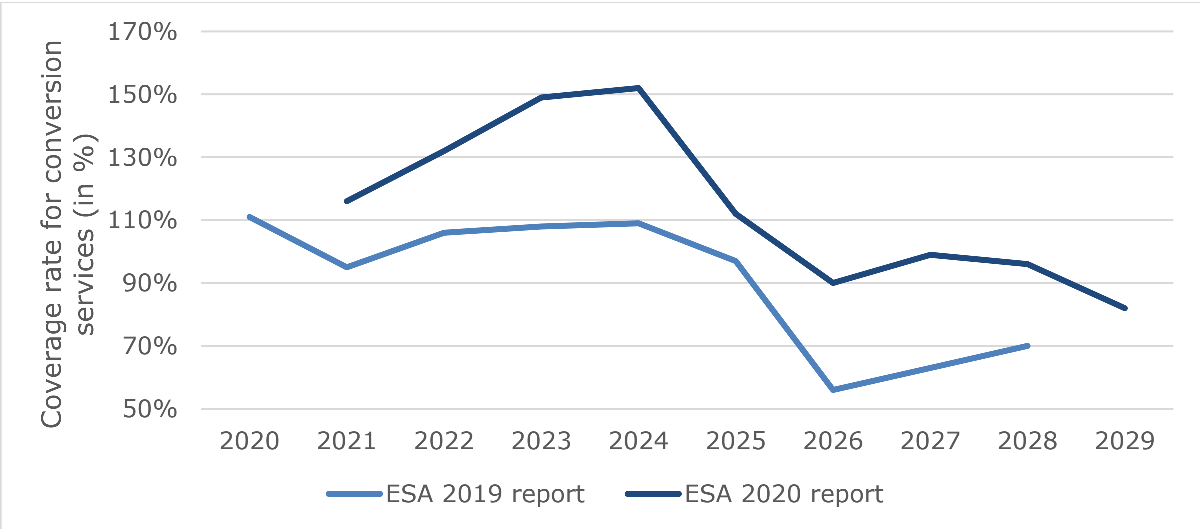


Figure 27: comparison of ESA contractual coverage rate forecast for conversion services between 2019 and 2020 – Source ESA

[53] Urenco "Solid operational and financial performance, despite COVID-19 pandemic, with 100% customer delivery record maintained" https://www.urenco.com/news/global/2021/full-year-2020-audited-financial-results

1.4.5. COVID-19 impact on fuel manufacturing

The fuel manufacturing industry for LWR (PWR, BWR and VVER) is dominated by a few players: Framatome (ex AREVA), Westinghouse, Global Nuclear Fuel (GNF) & TVEL. Currently, fuel fabrication capacity for all types of LWR fuel throughout the world considerably exceeds the demand.

A summary of fuel manufacturing players is given below.

	Manufacturer	Conversion	Pelletizing	Rod/assembly
Brazil	INB	160	120	400
China	CJNF Jianzhong	800	800	800
	CBNF	0	0	400
	CNNFC	200	200	200
France	Framatome-FBFC	1800	1400	1400
Germany	Framatome-ANF	800	650	650
India	DAE Nuclear Fuel Complex	48	48	48
Japan	NFI (PWR)	0	383	284
	NFI (BWR)	0	250	250
	Mitsubishi Nuclear Fuel	450	440	440
	Global Nuclear Fuel – Japan	0	620	630
Kazakhstan	Ulba	0	108	0
Korea	KNFC	700	700	700
Russia	TVEL-MSZ	1500	1500	1560
	TVEL-NCCP	450	1200	1200
Spain	ENUSA	0	500	500
Sweden	Westinghouse AB	787	600	600
UK	Westinghouse	950	600	860
USA	Framatome Inc	1200	1200	1200
	Global Nuclear Fuel – Americas	1200	1000	1000
	Westinghouse	1600	1594	2154
Total (tonnes/year)		**12,645**	**13,913**	**15,276**

Table 8: World LWR fuel fabrication capacity, tonnes/yr – Source WNA

In the EU, only Romania operates PHWR (CANDU) reactor type and relies on its Pitesti Nuclear Fuel plant to produce the necessary fuel for the operation of its two CANDU units (about 250 tonnes years of Rod/Assembly).

No impact of fuel manufacturing capacity was reported during the pandemic. Fuel supply was not impacted, as stated by utilities (See Chapter 2).

1.4.6. COVID-19 impact on the front-end of the nuclear fuel cycle

The COVID-19 impact on front-end of the fuel supply chain appears limited, no immediate or medium-term observable impact is expected. The largest impact observed was in mining activities, with the temporary closure of several installations at pandemic peak, without impacting security of supply. At the top of the COVID-19 pandemic (2nd quarter 2020), more than 50% of the world's uranium mining production was shut down (~2500 tU/month of unavailable production).

The main future risks for the front-end of the nuclear fuel cycle are highlighted by ESA in its latest yearly report:

- the uranium oversupply that continues to unbalance the market,
- the insufficient investments over supply chain,
- transport issues.

Pandemics could exacerbate some of these risks, as investments or transport issues could be directly impacted as seen during 2020 in various industrial fields. However, the nuclear fuel cycle remains resilient and the COVID impact in the last year was very limited. Projections from ESA in terms of contractual coverage for natural uranium, enrichment or conversion services were not impacted negatively by the pandemic.

1.5. The COVID-19 pandemic impact on radionuclide production

1.5.1. COVID-19 impact on radionuclide demand

During the consecutive pandemic wave peaks in Europe, national healthcare systems were put under high pressure to manage the sudden increase of COVID-19 patients. In- and outpatient care capacities were impacted for weeks, drastically reducing treatment and diagnostic capacities for other diseases. In this context, the national Health Authorities and/or nuclear medicine professional associations issued guidelines for organizing and ensuring nuclear medicine activities during this period.

These national guidelines/ recommendations allowed clinicians in the decision-making process to maintain or cancel nuclear medicine appointments, both for diagnostic and therapeutic applications. Decisions were nevertheless taken on an individual case basis, considering patients' specificities (existence of a diagnostic, type and cancer stage, etc.) and the COVID-19 local situation.

Red	Amber	Green
Do not cancel or rebook unless patient at risk	**Discuss with clinician if there is a need to cancel/rebook**	**cancel or rebook as necessary, without need for discussion with a clinician**
Oncology Bones	2 phase bones and non-oncology Whole body bone	Morphine HIDA
Meckels	MPS routine	Sincalide HIDA
GI bleed	Tl-201 hibernation	C13 UBT
GFR	White cell consider FDG	CSF studies
SLN	Platelet	Dacroscintigraphy
Y90-SIRT	Lung VQ	Salivary
Lung perfusion	MIBG heart	Gastric Emptying
MPS acute chest pain	MIBG pheochromocytoma	Small bowel transit
Radium-223	MUGA	Lymphoscintigraphy
Lu-177 DOTATATE	Amyloid DPD	Proctoscintigraphy
F-18 FDG new cancer	Parathyroid	Red Cell Mass
F-18 FDG sepsis	Mag3	SeHCAT
	DMSA	Colonic Transit
	Octreotide/Tektrotyd	DATscan
	Thyroid Tc-99m/ I-123	
	Parathyroid	
	Ga-68 DOTATATE	
	Ga-68 PSMA	
	F-18 FDG follow up	

Figure 28: BNMS (British Nuclear Medicine Society) - COVID-19: Guidance for infection prevention and control in nuclear medicine settings

Similarities can be found among the guidelines issued by the European countries most impacted by COVID-19 (Italy[54], France[55], United-Kingdom[56]) for diagnostic and therapeutic applications:

- Therapeutic procedures were generally theoretically maintained by any means, with adaptations to standard modus operandi (e.g. ^{177}Lu-Dotatate, ^{177}Lu-PSMA or ^{223}Ra-dichloride injections performed as an outpatient procedure). ^{131}I treatments were postponed depending on the thyroid treatment status.

- Non-urgent diagnostic procedures, having no immediate impact on patient care, were systematically postponed (e.g., periodic monitoring examinations, gastric imaging, etc.), while procedures having a direct impact on patient care were maintained (e.g., Myocardial Perfusion Imaging, sentinel node scintigraphy, etc.). Such an approach led to a strong decrease of scintigraphy and SPECT examinations, while PET diagnostics remained less impacted (^{18}F, ^{68}Ga, etc.).

Thus, the prioritization of nuclear medicine activities had a direct impact on radionuclide demand. Different international surveys[57,58] during the first half of 2020 evaluated the overall decrease in radionuclide demand following COVID-19 pandemic. In line with recommendations, thyroid and myocardial scintigraphy faced large demand drops (e.g., up to 80% decrease in Italy and Spain), while at the same time PET/CT examinations and radionuclide therapies were partially reduced (less than 40% decrease).

Radionuclide demand and production are closely linked, as most of the production is realized with a "just-in-time" approach (due to the short radioactive decays).

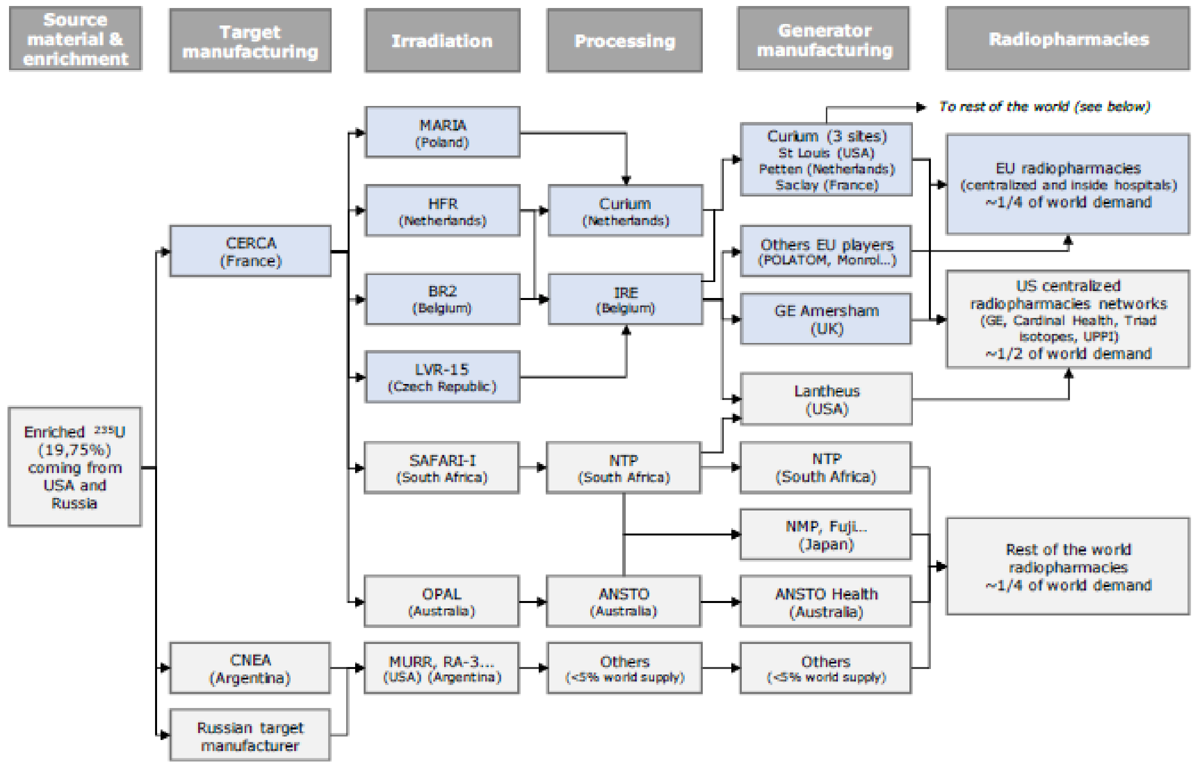
1.5.2. COVID-19 impact on radionuclide production

Before discussing the pandemic impact on production, the main radionuclide supply chains are hereafter briefly introduced, using as examples the production of ^{99}Mo and ^{18}F.

- For ^{99}Mo, targets are irradiated in different research reactors in Europe (BR2, HFR, LVR-15, MARIA), then shipped (by road) to European processing facilities for ^{99}Mo extraction (Curium/Petten or IRE/Fleurus). The ^{99}Mo produced is then sent to generator manufacturers (Curium, IRE, etc.) which ultimately produce generators that are sold in Europe or exported on

[54] Gestione delle Attività di Cardiologia Nucleare durante la pandemia da Coronavirus (COVID-19): documento del Gruppo Italiano di Cardiologia Nucleare (GICN)
[55] Conseil National Professionnel de Médecine Nucléaire - Covid-19 - Recommandations portant sur l'organisation des soins en médecine nucléaire.
[56] BNMS - COVID-19: Guidance for infection prevention and control in nuclear medicine settings
[57] Impact of the COVID-19 pandemic in nuclear medicine departments: preliminary report of the first international survey - https://doi.org/10.1007/s00259-020-04874-z
[58] Global Impact of COVID-19 on Nuclear Medicine Departments: An International Survey in April 2020 - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7456173/

international markets (see figure below). The supply chain is centralised, with a few installations (research reactors, processing facilities, generator manufacturing plant) covering the whole European demand.



Only the main fluxes have been included in the figure (e.g. NTP and ANSTO also supply ^{99}Mo to Curium)

Figure 29: ^{99}Mo/^{99m}Tc supply chain (EU players in blue) – Source NucAdvisor

- The ^{18}F supply chain is adapted to ^{18}F half-life (109 min), with a ^{18}O target irradiation in tens of cyclotrons production site in Europe, with a just-in-time delivery to hospitals. The supply chain is fully decentralised.

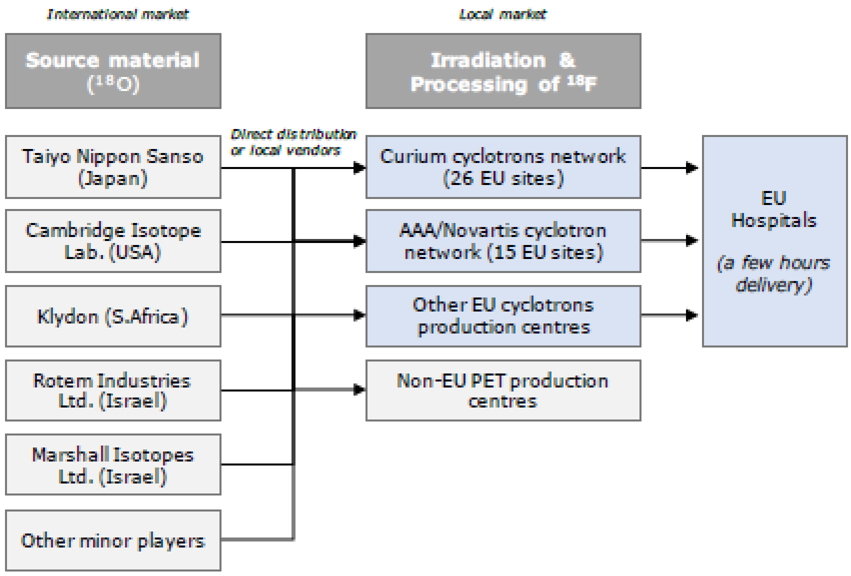


Figure 30: ^{18}F supply chain (EU players in blue) – Source NucAdvisor

Supply disruptions of medical radionuclides have been mainly observed, in the international studies mentioned previously, outside Europe and North America (Africa, Latin America, etc.).

To assess the overall impact of COVID-19 on radionuclide production along with the supply chains and the industry's ability to ensure continuity of supply, a questionnaire was prepared by NucAdvisor and shared with European and international players.

Preliminary findings are given hereafter:

- Most of the industrial players were categorized by national authorities as "essential service provider" (~80%) allowing them to maintain their activity, despite lockdowns or restriction decisions taken by states.

- COVID-19 had a minor impact on productivity/production capacity of industrial players (e.g., irradiation in research reactors remained almost unchanged, no variation, or only slight decrease mentioned for more 80% of respondents).

- Even though transportation was less impacted locally than internationally, severe disruptions in the logistics network were observed. Supply chain players highlighted different issues such as:
  - The severe disruption in air routes, following the massive cancellation of passenger flights across the world, coupled with strong uncertainties in the flight schedules, forcing constant adjustment of international exports/imports of radionuclides.
  - The absence of standardized regulation for radioactive material transport (both national and international) was already a constraint before COVID-19 and has been aggravated during the pandemic due to transborder restrictions and borders closing inside the European Union.

- After the end of the first pandemic wave, supply chains gradually came back to normal operation mode, and had time to adjust to new realities and found alternatives. Yet, under the COVID-19 pandemic, the supply chain showed less resilience on the transport side on the international basis, considering the limited restart of air traffic.

2. The nuclear sector resilience against external threats

Resilience represents the ability of organizations to rapidly adapt and respond to all types of shocks/risks – such as natural disasters, cyber-attacks, supply chain disruptions, among others. Besides the ability to face the consequences of a major incident, resilience also includes the capacity of an organization to adapt, recover and adjust to a new environment and new circumstances.

This chapter addresses the overall resilience capacity of the European nuclear sector, based on the specific COVID-19 experience.

2.1. Assessing the industry resilience through European surveys

Whereas the overall COVID-19 impact on electricity production can be accurately assessed in the public literature, the pandemic impact on the internal organisation of the nuclear industry has not been actively documented during the last two years (2020-2021). Thus, to precisely evaluate European nuclear actors' resilience during ongoing pandemic, surveys were transmitted to European nuclear utilities, national safety authorities and industrial players providing goods and services.

These surveys aimed to analyse the near-terms and longer-term impacts of the pandemic, along with the preparedness and recovery actions taken by owners, operators, regulators, national authorities, etc. Different categories of questions were included, according to respondent typology:

- The internal and external threats anticipation;
- The national responses;
- The respondent's response to pandemic (from the first weeks of the pandemic during the 1st pandemic wave until end of 2021);
- The pandemic's impact on human resources, goods and services;
- The pandemic's impact on nuclear safety and security;
- The pandemic's impact on reactor availability and demand;
- The pandemic's financial impact;
- The recovery phase and main outcomes/lessons learned from pandemic.

The different blank questionnaires used in the frame of this study are provided in Appendix.

In terms of European coverage, most nuclear countries participated to this study, either through their national utility or safety authority. Results cover more than 85% of the European nuclear electricity production (including Switzerland and United-Kingdom) across 9 countries.

The following figure provides details on the nuclear countries that participated to the survey, either through their utilities or safety authorities.

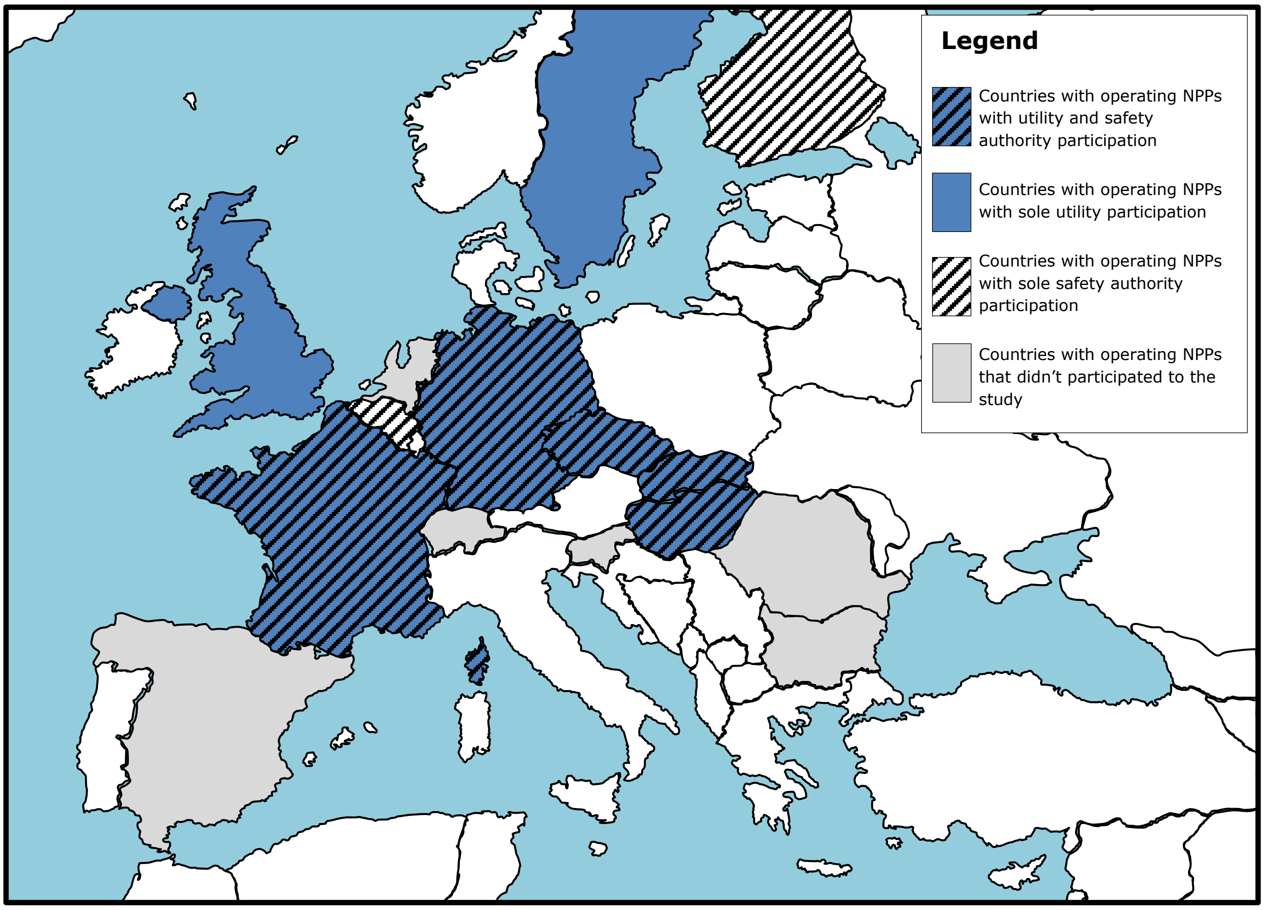


Figure 31: summary of European countries' participation to the study

2.2. Anticipation towards external threats: the pandemic risk

The first pillar of business resilience lies within the anticipation of threats. Through the upstream development of internal procedures, specific national regulations, or simply enough supply reserves, one can better address incoming threats and avoid major disruption of activity.

2.2.1. Impact and limitations of essential services national regulations

In the case of energy, there is an absolute requirement to maintain the supplies without interruption. Electricity generation, like law enforcement or health, medical and social services, is thus referred as "essential services" by national authorities. Such status imposes specific constraints on business activity or workers (e.g., restriction of the right to strike, necessity to establish business continuity plans, etc.) and exemptions to general public rules (e.g. lockdowns, travel restrictions, etc.) to ensure their ability to maintain their activity in case of disaster or state of emergency.

Nuclear electricity production relies on various stakeholders, to ensure safe nuclear power plants operations. The COVID-19 pandemic highlighted the disparity between them from a regulatory perspective:

- Nuclear utilities[59] are systematically considered as essential service providers in Europe, being either the owners or operators of European critical infrastructures (ECI). Following Directive 2008/114/EC[60], it is mandatory for Member States to identify ECI and associated owners & operators. Such status enabled utilities to always maintain their activity during the COVID-19 pandemic, overcoming restrictions put in place by governments (travel restrictions, business closure, etc.).
- In most cases, the utilities reported that their key suppliers of goods and services, directly contributing to the safe operation of nuclear power plants, were not systematically considered as essential services providers[61]. During COVID-19 lockdowns, several EU countries restricted business activity based on such criteria, thus forcing utilities to request specific exemptions to ensure operation (e.g., the cleaning activities at NPP sites, security services, non-safety equipment manufacturing, etc.).
- The regulation and control activities performed by Safety Authorities are systematically considered as fundamental missions to be always

[59] EDF, Vattenfall, Slovenské elektrárne, a.s, MVM Paks Nuclear Power Plant Ltd, CEZ, All German utilities, EDF Energy
[60] Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection
[61] For 5 utilities surveyed out of 7

maintained, justifying the status of essential services for almost all safety authorities.

It is worth noting that in most cases, the "essential service provider" status did not lead to automatic exemptions from national restrictions and stakeholders had to go through specific administrative procedures.

Aside from electricity production, other nuclear installations (fuel cycle, radioactive waste management, medical facilities, etc.) are not always considered as essential services. Each Member State[62] took specific measures regarding the classification of these additional installations.

Finding #5: while electricity production facilities are all considered as strategic installations as per the EU regulation, the industrial players involved in their daily operation are not systematically identified as essential service providers. A better mapping of key NPP operation suppliers could be beneficial to improve coordination with public bodies in the case of emergency situations.

2.2.2. The management anticipation towards external threats

Like other industries with high-impacting consequences in case of accidents, the risk anticipation is deeply rooted in the nuclear industry culture. The anticipation of external (or internal) threats by nuclear actors remains essential to ensure adequate preparedness and to mitigate potential disruptions.

The establishment of "business continuity plans" (BCPs)[63] appears to be a widespread good practice across the nuclear industry. Almost all utilities[64], large suppliers of goods and services and safety authorities had an operational BCP (or equivalent) that has been used to face COVID-19 pandemic. Corporate BCPs are generally developed for utilities and adapted for the nuclear fleet with minor site-specific considerations.

The decision to develop a BCP is motivated by different reasons across Europe:

- For some countries, BCPs are required by law[65], as part of specific regulation against external threats (e.g., in France, Hungary, Sweden, etc.) and generally apply to companies directly contributing to the electricity supply or the nuclear safety.

[62] For example, in Belgium the ministerial decree taken in 18 March 2020 defines the nuclear and radiological sector an "essential sector", thus including NPPs, research facilities, medical isotopes production installations, fuel cycle and waste facilities, facilities under decommissioning, etc.
[63] The International Organization for Standardization (ISO) defines BCP as a "documented information that guides an organization to respond to a disruption and resume, recover and restore the delivery of products and services consistent with its business continuity objectives".
[64] At the exception of German utilities, according to survey.
[65] For example, in Sweden, Hungary, France, Germany.

- Aside from national regulation requirements, insurances, group policy or internal company decision can also lead to the development of BCP.

While, for utilities and safety authorities, the use of BCP is common, such requirement is not shifted across supply chains. Utilities and safety authorities are almost never[66] requiring their key suppliers or TSOs to implement BCP, despite their critical role.

Finding #6: the extension of BCP regulatory requirement to Tier 1, Tier 2 key suppliers of goods and services for nuclear installation operation, along with direct contribution to safety control activities could contribute to improve overall preparedness of the nuclear industry to external threats.

Business continuity management systems remain the property of industrial stakeholders and could not be accessed in the frame of this study. A comparative analysis is nevertheless performed on some specific issues, detailed hereafter.

BCP structure and content generally differ among companies and organizations but shall include standard key items detailed below.

Items	Purpose
Stakeholders' identification	Identification of key services and goods suppliers (external onsite staff, equipment suppliers, etc.) and the corresponding service-level agreements (type of service of products to be provided, contact points, etc.).
Business impact analysis	Identification and evaluation of disruption consequences, to develop mitigation recovery strategies.
Risk assessment	Identification, understanding and evaluation of the potential risks that could impact the activity - identification of external threats and analysis of their respective impact on activity: pandemic, cyber-attack, terrorism, etc. - identification of assets at risks and direct impact.
Identification of critical functions	Identification of critical functions highlighting the processes at risk and mitigation measures to most sensitive issues.
Communication	Definition of the internal and external communication strategy to develop efficient communication channels and good practices.
Testing/exercises	Validation of the BCP. Identification of the critical steps for ensuring the correct application of the BCP through crisis exercises and gathering the correct data for lessons learned, BCP improvement etc.

Table 9: Standard BCP content (not exhaustive)

[66] Only a single Utility declared having implementation a mandatory requirement of a BCP for key supplier, all safety authority declared having to requirement towards BCP existence for TSO or other key suppliers.

Despite the existence of international standards on BCP, like the ISO 22301:2019 on "Security and resilience — Business continuity management systems — Requirements", most utilities, safety authorities and industrial players developed and implemented theirs BCP without relying on ISO standards. In the absence of formal accreditation of the BCP, one could not conclude on the quality or exhaustiveness of BCP.

Nuclear utilities and safety authorities have a strong culture of preparedness, coming mainly from emergency preparedness and response (EP&R) areas dealing with the mitigation of risks and impacts from nuclear and radiological incidents. The vast majority of stakeholders prepared their BCP based on their standard internal practices rather than through international or codified best practices (e.g. ISO standards). The preparation and management of these external risks, despite being independent by nature to nuclear emergency preparedness and response considerations, is almost systematically handled by the same teams and divisions inside nuclear stakeholders (e.g. workers health monitoring being ensured by same team in case of pandemic or accident).

External threats considered in BCP can have very different origins and impacts, in terms of duration, disruption type, operational constraints, etc… Following the different pandemic/epidemic observed during the 21st century (H5N1, SARS-CoV-2, etc.), most of the stakeholders surveyed decided to specifically address this risk in their BCP.

As specified previously, each external risk presents specific characteristics while BCPs remain generic to certain families of threats (e.g., epidemic/pandemic BCP is the generic plan to be used for COVID-19 pandemic). It was therefore necessary for nuclear actors to adapt their BCP to address specific COVID-19 challenges. Most of the nuclear industry stakeholders (utilities, safety authorities, etc.) have developed their COVID-19 specific plans in the weeks preceding the first pandemic wave in Europe (April 2020).

National nuclear regulations define requirements to be respected under any circumstances, including staff number presence onsite. The pandemic risk is not explicitly defined in national regulations. Thus, it is not mandatory for nuclear utilities to address it specifically, but regulatory requirements need nevertheless be met in pandemic situations (including specifically the requirements regarding the minimum workforce volumes in nuclear facilities).

Finding #7: business continuity plan systems appear to be a country or a player-dependent, often relying on existing resources already identified, trained, and mobilized for emergency preparedness and response considerations. The strong nuclear industry culture for handling emergency situations appears to be a significant contributor to resilience in case of pandemic. A specific benchmark analysis of business continuity plans would allow to conclude on the need to improve the uniformity of business continuity plans and related requirements across Europe.

Regarding pandemics, most nuclear actors already considered specifically this risk in their business continuity plans in the last decade, although national nuclear regulation do not require to specifically address such risk.

2.2.3. The operational anticipation to external threats

Nuclear power plants are large industrial installations requiring significant workforce to ensure their safe and continuous operation and maintenance. Each NPP unit directly or indirectly employs around 400 to 700 full-time equivalents[67] (depending on site, regulatory or utility specificities), making workforce availability a major challenge in case of external threats.

A nuclear power plant workforce is composed of different categories of personnel, each category being composed of several teams, working in shifts to ensure continuous electricity production:

- Operators, in charge of the direct control of the reactor from reactor control room under the supervision of a shift manager;
- Technicians and craftspeople, in charge of the physical operating actions in close coordination with the reactor operators;
- Routine maintenance staff, in charge of standard maintenance activities, periodic testing, etc.;
- Onsite engineering staff (or acting remotely in case of NPP fleet);
- Health and environment personnel;
- Security staff;
- Administrative and support staff (cleaning, catering, etc.).

Only a part of this staff is utilities' personnel, the remaining being mobilized by external service providers. Generally, only the core functions are within utilities' staff perimeter (operators, technicians, engineering), while most of the support staff (security, administrative and support staff) belong to external services providers.

[67] According to WNA- Employment in the Nuclear and Wind Electricity Generating Sectors

Among all these categories, "key workers" (i.e., onsite mandatory staff under any circumstances, also referred as critical staff, essential staff, etc.) have been systematically identified inside nuclear utilities own staff. This is also almost systematically the same for Safety Authorities. These key workers are specifically trained to cope with external threats or disruptions. Prior to COVID-19 pandemic, trainings related to epidemic/pandemic were not systematically included in the training programmes.

Key workers coming from external services providers are not systematically[68] identified by utilities. Despite being not directly part of the safe operation of NPPs, most of the support staff remains essential to ensure indispensable operations (security staff granting site access, cleaning staff, etc.). Nevertheless, despite formally identifying key external staff, most utilities have identified their key suppliers of goods and service, essential for safe and sustainable operation of NPP. They are always subject to close monitoring.

The specific supply strategies used by utilities for large equipment, spare parts and fuel supply remain undisclosed for most players. Only generic approach has been communicated. All the spare parts needed for safe operation are stored onsite and stock are generally sized to accommodate the utility needs for a period of several months of operation. For large non-common equipment, they are either purchased through long-term dialogue with suppliers (years in advance) with a delivery on time approach to fit large maintenance activities periods. In the case of unexpected large equipment failures supply strategy for their replacements differs between utilities of large NPP fleet and the others. Spare equipment can be either found at another NPP or inside centralised fleet spare parts stocks or even available in some cases in suppliers' stock (for standardized equipment). A direct dialogue with key suppliers took place to find a solution in urgent cases.

Finally, in addition to standard NPP operating procedures, all European utilities disposed of "degraded modes of operation". Degraded modes of operation are defined as deviations from the standard NPP operating protocols, allowing utilities to cope with limited personnel availability while maintaining electricity production in case of force majeure. Such mechanism allowed utilities to modify their operating procedures during the COVID-19 pandemic peaks (see §2.3 for detailed variations of workforce during pandemic).

On the regulatory side, scenarios in which limited workforce availability could impact regulation and control activities are not systematically defined. Such degraded modes of operation were in some cases never defined in the past, or not applicable to pandemic situations (e.g., in case of military intervention).

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[68] Only half of respondents' utilities declared having identified key external workers, while only a single safety authority declared having identified external key workers.

Finding #8: Securing the workers' availability in the context of a pandemic appears as a major challenge. The selection of key workers by utilities is subject to strict identification process including dedicated training to handle internal, external risks or accident. Management is then responsible to ensure their continuous availability in case of emergency situations, through specific measures taken in line with external threats (e.g. during COVID: physical separation of workers, modified operating practices, etc.)
Despite contractual agreements with service suppliers which include performance requirement under all circumstances, improvements could be done through the systematic identification of key external staff.

The supply of goods and services is generally performed under long-term agreement or with spare parts that allow utilities to cope with a few months' interruption of supply. As the nuclear industry is dealing with long timescale, the impact of a pandemic lasting a few weeks/months appear limited for the nuclear industry.

2.3. The nuclear industry adaptation to COVID-19: from the first weeks of the pandemic to long-term management

Considering the evolution of the COVID-19 pandemic across Europe, the nuclear industry adaptation to the pandemic was done in different successive steps that are summarized hereafter:

- The operational preparation to the pandemic (early 2020), following the progressive increase of COVID-19 incidence in Europe, in a context where only limited restrictions were taken by Member States;
- The adaptation to the first pandemic wave (March-April 2020), where the industry suddenly faced major constraints (lockdowns, borders closing, etc.), leading to important organisational changes within the industry;
- The long-term adaptation to COVID-19, where stakeholders within the nuclear industry implemented or updated their operational structure to maintain activity with a stable pandemic evolution (different "waves" throughout the last year);
- The preliminary crisis recovery, where some stakeholders already started a progressive shift towards pre-COVID operational standards (e.g., employee return to the office, etc.).
- The long-term perspective, with evolution of best practices to cope with future potential crisis.[69]

The evolution of the nuclear industry in the last year, in line with these different steps, is detailed hereafter, with a focus on each type of impact.

[69] Not discussed in the frame of this study, as pandemic is still ongoing

2.3.1. The overall industrial response against COVID-19

Two different approaches could be seen regarding the initiation of pandemic plans inside nuclear industry stakeholders and regulators:

- Either through a graded approach, generally starting in January or early February 2020, where a pre-crisis management allowed stakeholders to prepare to face incoming challenges already observed in China (e.g., lockdowns, need for an increased use of teleworking, etc.) followed by a progressive transition to the highest level of the pandemic plan in line with the pandemic evolution. During this step up, actions were taken to secure activity (e.g., increasing remote connection infrastructures, laptop purchase, etc.) and preparing the internal organisation to face pandemic (e.g. creation of COVID taskforces, preparation of specific COVID-19 procedures, etc.).
- The other response approach is to follow governments' decisions driven by national COVID-19 spreading. This is especially the case for most of safety authorities that introduced their pandemic plan around mid-March 2020.

Most of the crisis plans in application in the early weeks of the pandemic[70] spreading were dedicated to the short-term management of COVID-19 and were expected to be replaced by long-term continuity plans in the following weeks/months.

Finding #9: no systematic approach could be seen in the decision process to initiate the pandemic plan, of which the content differs among stakeholders with more or less consideration to the long-term management.

In addition to the generic workers' protection measures taken by the general public and the professional sector (use of personal protective equipment, teleworking, improved disinfection, temperature checks, etc.), the nuclear industry quickly reorganised itself to pursue electricity production while coping with regulation, safety and health constraints.

[70] Among respondents, only a single safety authority and three utilities declared having developed from the beginning a pandemic plan able to withstand long disruption periods (less than one third of respondents).

Some of the most impacting decisions and modifications done by nuclear utilities are detailed below:

- An overhaul of the internal NPP operating structure was performed by utilities to protect and maintain the availability of key workers, on-call staff and shift crews. This resulted in different adaptations to standard operating practices such as:
  - A decrease in the number of shift crews (e.g., from 7 to 5 for EDF), allowing for home-based back-up operators in each shift, to replace contaminated workers, if needed;
  - An increase of shift durations, to reduce the frequency of workforce interactions when changing shifts (e.g., from 8 to 12 hours shifts);
  - Restrictions on staff transfer among NPPs inside NPP fleets;
  - The workforce physical separation, in pair with workers self-isolation from home, when not under operation. Operating crews were split in different teams (e.g., one team on plant, one team working remotely from home and a third team on standby, with a rotation);
  - The control room or operating crew isolation, preventing contacts with any other categories of personnel, through remote interaction with onsite staff.

- New working habits were quickly implemented by the industry, in line with the spread of teleworking. The monitoring of manufacturing activities inside key suppliers' installations was sometimes performed remotely.

- The outage programme has been rescheduled, impacting specifically utilities with large maintenance activities planned in 2020 & 2021. Such modification led to a global reorganisation of industrial maintenance programme for a few years. Utilities operating a limited number of NPP also postponed, when possible, maintenance activities, avoiding complex management of personnel during outages.

On the regulatory side and during the early pandemic phase, the challenges faced by regulators were similar: workforce availability, teleworking implementation, etc.

Finding #10 : the COVID-19 pandemic had major impact on utilities internal organisation, with modifications headed over workforce. The sudden change of good practices (e.g., switch to teleworking) could raise humans and organisational factors challenges. While NPP operation remained mostly unimpacted, the maintenance and outage strategies were reassessed to cope with COVID-19 constraints, often leading to some maintenance activity postponements.

European and international collaboration within the nuclear sector was quickly established and allowed utilities, industrial players, national regulators to share information, best practices, and COVID-19 continuity plans. From the safety side for example, information was exchanged through ENSREG, WENRA, IAEA IRS database and OECD-NEA, along with direct exchanges, on a bilateral basis, among European Safety Authorities. Such good practice allowed nuclear actors to use existing networks to exchange operational information, coordinating indirectly the COVID-19 responses. There was nevertheless a significant overlapping in reporting and discussions, especially at regulatory level that could be avoided through a better coordination.

Finding #11: International and European collaboration allowed to share a large quantity of technical information to support utilities and regulators in managing COVID-19 pandemic. A better coordination among international and European organisations could improve in the future the transmission of information.

2.3.2. The COVID-19 specific impact on workforce

During the first weeks of the pandemic, utilities set up almost systematically specific communication channels with their different services suppliers, especially those providing the essential external workforce for a safe operation of NPPs. Regular exchanges (daily or weekly) with key suppliers were performed (security services, fire brigade, cleaning services, etc.).

In line with lockdowns, national decisions and the need for physical and social distancing, the onsite workforce decreased significantly during the first weeks of the pandemic, from -40% to -60%, leading to a sudden teleworking need for a few hundreds[71] of workers per nuclear site. Such change shall not be underestimated, especially when teleworking was not particularly considered as widespread practices among nuclear utilities (between 70 to 100% fulltime presence onsite). These reductions of onsite personnel were implemented in line with regulatory operation constraints, never below the limits sets by safety authorities, thus allowing utilities to never operate under the degraded mode.

As of end 2021, the onsite workforce volumes haven't yet reached pre-COVID-19 pandemic level, it is estimated that after the critical March/April period, the utilities onsite organisation stabilized itself at levels in line for a long-term pandemic management (around 75-80% of pre COVID-19 onsite personnel level for most utilities).

On regulatory side, no staff evolutions were reported, the entire workforce from safety authorities remained mobilized during the whole pandemic period, almost fully working remotely from home without staff unavailability issues.

[71] Volumes depending on the number of units on a single site of operation

According to utilities, and despite the constraints developed previously, the staff availability was not disrupted during the pandemic:

- All the categories of personnel were equally impacted by pandemic (key and non-key workers), the non-key workers for which less restrictive actions were taken were identically impacted. The utilities' internal mandatory staff remained available in the required number at all times.

- Regarding external staff, the major challenge was on the mobilisation of international personnel during the first two months of the pandemic, during travel restrictions. Foreign contractors have been generally able to operate onsite, through a complex administrative process for utilities. During the early pandemic, in some cases, several suppliers have been identified for their unavailability to be mobilized onsite, during outages, so their activity has been postponed without negative consequences on safety and operation.

  Such an issue was also seen on regulators side, as travel restrictions impacted IAEA and EURATOM (safeguards) inspectors in the early pandemic phase. As necessary, the regulators supporting staff (e.g., TSO) remained mobilized during pandemic, and no issue has been effectively recorded, in relation with the availability of regulatory bodies.

- The loss of productivity observed by some utilities during outages cannot be attributed to workforce unavailability, but to the overall operational reorganizations imposed by sanitary considerations.

Finding #12: despite the direct consequences of COVID-19 pandemic on personnel, the workforce availability has not been at risk during the period. The mitigation measures taken by the industry enabled to secure internal and external workforce with no major difficulty. No large cluster or contamination inside nuclear industry was reported. The mitigation measures taken by the industry allowed to drastically limit the onsite risks of contamination.

Maintaining the workforce competences through internal/external training has been one specific challenge faced by the nuclear industry. During the first weeks of the pandemic, training activities were cancelled and had to progressively switched to e-learning. Legislative measures had to be taken, in some cases, to extend the validity of some authorisation or personnel certification, as the first lockdown observed in several EU country led to cancel all training activities. For most utilities, priority was given to authority-based training, while non-essential training activities were postponed.

The specific issue of onsite simulator-based training was raised by different utilities. Following lockdowns and limited onsite presence, a backlog on simulator time could be observed in some cases. Recovery plans are still under implementation to catch up accumulated delay.

The pandemic indirectly fostered the development or deployment of several training approaches: e-learning, virtual sessions, self-study, adapted onsite training with sanitary conditions, etc. Most of the onsite drills or emergency exercises were postponed.

Finding #13: training activities were mainly impacted during the early pandemic phase in Europe, being generally implemented through onsite sessions with physical presence. Utilities first focused on maintaining authority-based training and progressively restarted all training activities. In general, the COVID-19 caused only a temporary delay on training activities, that has been quickly recovered.

2.3.3. The COVID-19 specific impact on inspection and control

Ensuring safety follow-up and control of nuclear facilities in pandemic period necessitated regulators maintaining strong interfaces with licensees. Most regulators reported that the frequency of interaction did not change during the COVID-19, with the exception of the initial first days of pandemic or lockdowns where specific assessments of risks and industry's status were performed. Most regulators requested detailed information from licensees in the early pandemic phase to evaluate their capacity to handle the crisis (e.g., preventive measures and plans taken or planned to ensure sufficient staff availability to ensure safety, radiation protection and security functions). The nature of communication drastically changed over the period, standards physical meetings were fully replaced by online or hybrid ones.

New good practices emerged from COVID-19 restrictions. Remote and semi-remote inspections were established to prevent unneeded contacts with licensees:

- Use of photo or video materials taken directly by resident inspectors or licensee itself.
- Use of hybrid inspection approach, with only a part of the inspection team onsite, supported by remote inspectors.
- Remote monitoring systems of essential operational parameters (e. g. reactor power, emergency power supply, position of important valves, radioactive emissions) are transmitted electronically to the office or home office of the supervisory authority.

All the regulators highlighted the efficiency of these new approaches and see interest in keeping these tools in the future.

A specific challenge faced by regulators concerns the electronic transmission of information when supervisory authorities, TSOs and licenses do not have secured communication and information systems, due to teleworking conditions. Some video conference tools were considered as not safe enough and restrictions in their use were imposed by regulators in some cases. Most regulators considered that the communications channels used were reliable and protected against cyber-attack risks. For most of them, secured channels and encryption methods were existing before COVID-19 and the main challenge was to make possible the use of these tools in teleworking conditions. In case of no teleworking possibility, onsite inspections were maintained.

All the safety authorities surveyed reported having been able to maintain their onsite presence for routine (fulltime onsite presence) and specific inspections since the early pandemic phase. With the objective to minimize the travel and onsite presence, some hybrid inspections approaches were implemented, relying more heavily on fulltime onsite presence time, or having a single inspector sent in at the licensees' installations. The most critical inspections were maintained during the critical pandemic phase (March-April 2020), and regulators were progressively able to implement all standard types of inspections.

Finding #14: the regulatory inspection and control activities were maintained during the whole pandemic[72], at levels satisfying regulators expectations and requirements. According to regulators, COVID-19 only had a minor impact on control and inspection activities (i.e., activities maintained but with additional constraints).

The standard approaches used for inspections were modified during COVID-19 with new remote approaches that could be maintained in the future. All the regulators surveyed considered that the way inspections and control activities were performed during the last year is satisfactory.

2.3.4. The COVID-19 specific impact on supply chains

Utilities generally operate NPPs with supply stocks of standard spare parts and material to cope for a few months of operation[73]. Volumes of spare nuclear fuel or heavy components are more limited, being generally delivered to plants according to outage plans[74] (from a few weeks to several months in advance).

As for service suppliers, specific communications channels were quickly secured by utilities with their material and equipment suppliers. Utilities collaborated with

[72] According to Safety Authorities that participated to study's survey

[73] One of the utilities surveyed in the frame of this study declared having specifically replenished its stocks of spare parts and material at the pandemic start to ensure a reserve for 3 months of operation.

[74] In the frame of the survey, utilities did not disclose their detailed supply mechanism for commercial sensitivity purpose. It is not possible to directly conclude on the sizing of utilities spare parts stocks, neither on the standard duration for which a plant could be operated after a major failure of its supply chains.

their supply chains to ensure that strategic stocks were secured in case of future needs or long-lasting pandemic. In some cases, governments were also involved to develop requisition plans in the national interest, such options were finally not required to be exercised.

Despite most of goods and material suppliers being "non-essential service" providers, utilities did not experience any supply issue or tension during COVID-19 pandemic, electricity production has not been impacted by supply of equipment and material. Both European and worldwide supply chains remained functional during COVID-19 pandemic.

Regarding the specific issue of nuclear fuel supply, utilities never experienced issues with fuel supply sourcing during the COVID-19 pandemic and do not foresee any limitation or market tension over the coming year.

Finding #15: The pandemic only had a minor impact on supply chains, activity was maintained, and no tensions or constraints was reported from utilities side[75], the same applies for long-term impact of the pandemic.

2.3.5. The COVID-19 impact on safety

Specific communications channels were quickly implemented between nuclear regulators and licensees. This allowed regulators to be informed in real time of main actions taken at installation level to cope with pandemic impact. Safety authorities specifically monitored the resilience of nuclear industry supply chains (i.e., the availability of goods, equipment, material, services, and workers) to meet safety requirements.

All surveyed utilities declared possessing a defined "degraded modes of operation" to be used in case of force majeure, however they are not systematically developed within the installation safety framework. Communication with safety authorities occurred in the early pandemic phase, to exchange on the practical measures to be taken to address a lack of operations personnel. A close and efficient collaboration was reported by safety authorities and utilities on this topic, especially for utilities that already had pre-defined degraded modes of operation[76]. Thanks to the actions taken by utilities to protect personnel and secure back-up teams, these degraded modes of operation could be avoided.

Despite the various actions taken by utilities (e.g., shift schedule modifications, home office, training adaptations, etc.), no safety framework adaptations or

[75] According to Utilities that participated to study's survey
[76] A typical multi-step approach to deal with decreasing personnel availability, on a 2 units nuclear power site:
- Sufficient critical personnel - nominal output of all power plants
- Limited availability of critical personnel - shutdown of a unit according to the availability of critical personnel
- Insufficient number of critical personnel - shutdown of all units, NPP in cool-down mode

waivers were delivered by safety authorities during the whole pandemic. The installations operational safety frameworks remained unchanged. For almost[77] all utilities, there were no safety framework updates directly related to COVID-19 during the period.

The COVID-19 pandemic led governments to adopt exceptional measures, some of them impacting safety administrative matters. In some cases, authorisation validity durations were extended to cope with the 1st pandemic wave that led to unexpected and sudden lockdowns. On a practical basis, the implementation of some safety actions (e.g., authorisation renewals, maintenance of upgrade activities, personnel accreditations, etc.) were postponed by a few weeks beyond due date.

The electricity production has not been impacted by COVID-19 safety concerns, according to all surveyed utilities, as no deviations from safety standard operating procedures took place. Moreover, utilities experienced no specific operating incidents linked to COVID-19, while their radiation protection and safety performance remained unimpacted by the pandemic. In some cases, the actions taken by utilities even had a positive impact on safety KPI (Key Performance Indicators). The new practices that were developed during COVID-19 pandemic enhanced rigour towards existing good practices.

As detailed previously, the largest impact for the nuclear sector has been in the first weeks of the pandemic. From regulators side, all surveyed authorities considered that:

- The safety level in NPPs has not been lowered during the first wave of the pandemic.
- The regulators visibility over nuclear facilities was sufficient over the first weeks of COVID-19 pandemic.
- The licensees and operators had adequate resources and competencies to maintain safety and security over the last year.
- The new working practices seen through the nuclear sector have not contributed to weaken the nuclear installations safety.

Finding #16: the COVID-19 pandemic hasn’t negatively impacted the safety and radiation protection standards levels within NPPs. Due to the modified operational organisation onsite, an improvement of safety indicator was even observed in some cases. NPPs were operated under standard safety frameworks and no deviations or agreed adaptations were reported.

[77] At the exception of a utility that specifically updated its safety framework to define the modus operandi to be used in case of lack of key personnel progressively leading to the safe shutdown of the NPPs.

Even though operational safety was deemed unimpacted by Safety Authorities and Utilities reorganizations during COVID-19 pandemic, the Emergency Preparedness and Response (EP&R) was considered negatively impacted by a few of the surveyed safety authorities[78]. As detailed previously, the staff availability was never at risk, either for operating personnel or emergency workforce, but the sanitary considerations prevented in some cases utilities to have emergency exercises and drills for their key personnel.

To reduce infection risks, the licensees and regulators of a few number of Member States decided jointly to abstain from performing normal, full-scope emergency exercises during the pandemic while most of the countries developed adjusted EP&R procedures, to cope COVID-19 constraints (reorganisation of crisis room, use of teleworking, hygiene and organisational specific provisions against pandemic, etc.).

The applicability of EP&R procedures under external threats situation was not assessed neither reported through the survey.

Finding #17: the pandemic had a limited impact on EP&R activities. There was a need to adjust EP&R procedures to cope with pandemic constraints, which has been partially done across Europe. The pandemic had a negative effect on organising emergency exercises in some Member States (some were delayed or even cancelled). No conclusion can be drawn on the effective applicability of EP&R procedures under a pandemic situation. Yet, some countries were able to maintain EP&R exercises without reporting specific issues related to COVID-19.

2.3.6. Impact on reactor availability

The direct impact on reactor availability has been extensively described previously. Utilities nevertheless confirmed previous findings: NPPs without important maintenance activities planned during 2020 were not impacted by the pandemic, while units for which major maintenance or revamping activities were expected have faced delays.

[78] 2 Safety Authorities out of 7 respondents

2.4. The post COVID-19 resilience and lessons learned

At the time of writing, the COVID-19 pandemic is still underway in Europe. The business continuity plans implemented in the early pandemic phase are still under use and shall be maintained at least until early 2022. The post-COVID-19 can only be outlined through the preliminary conclusions and lessons learned shared by nuclear actors, while formal COVID-19 outcomes will only be known in a few years.

The establishment of COVID-19 recovery plans[79] is an essential condition to shift towards standard operational procedures safely and progressively. Such plans were generally developed by the nuclear industry and regulators as part of their pandemic plans but remain closely linked to national pandemic situations and state decisions.

2.4.1. Utilities' experience

According to utilities, the pandemic is expected to have short/medium-term impact on their activity, in different fields:

- Regarding maintenance and revamping activities, some non-priority works were deferred during the first pandemic wave and will have to be rescheduled during future outages.
- Cancelled or delayed emergency drills/exercises will need to be conducted as soon as possible.
- Delayed personnel training activities will have to take place through adapted training tools (e-learning, home-office training, etc.) to cope with accumulated delays.

Different lessons learned were highlighted by utilities:

- The protective personnel equipment (masks, hygiene materials, filters, etc.) shall be stored on a strategic manner, at utility or at Member State level, this would improve the responsiveness of nuclear industry against pandemic external threats.
- The successful resilience to external threats necessitates to set objectives in a mid-term perspective: the more scenarios are foreseen the more efficient will be the response to the crisis.
- A strong cooperation between the industry, the regulators and the governments are needed to ensure sufficient coordination at all levels. An early set-up of internal crisis management teams at executive level, with correspondents at operation level, will benefit to stakeholders on preparing

[79] to support the transition from high to residual virus circulation allowing a progressive restrictions lift

progressively their activities against the pandemic consequences while allowing an efficient transmission of information.

- The existing nuclear safety structures and processes have been a strong frame for managing an unpredictable external event, such as the COVID-19 pandemic. The emergency preparedness and response culture within nuclear industry also largely contributed to the quality of the actions taken in the first weeks to cope with the pandemic. There are actually several similarities in procedures used in EP&R and in pandemic crisis management. Finally, the strong medical culture within the nuclear industry, due to the radiation protection concerns also largely contributed in setting the right mitigation actions against pandemic-type external threat.

Utilities do not foresee any major modifications of their organisational structure or production process based on these findings, their business strategy regarding nuclear energy shall remain unchanged. Regarding the specific issue of external threats management, surveyed utilities confirmed that their BCPs were considered adapted, and no major modifications shall be expected.

2.4.2. Regulators' experience

Different lessons learned and good practices were highlighted by safety authorities:

- There is a potential for the use of new/innovative approaches to control licensees' activities. A large part of the regulatory inspections could be performed by remote or semi-remote way, supported by the development of electronic documentation, digital signature use, teleworking, improved teleconference equipment and software, etc.
- In order to efficiently and quickly implement Business Continuity Plans, the establishment of specific crisis cells in the early pandemic was a key success factor.

Aside that, regulators do not expect major modifications of their organisational structure following COVID-19 pandemic.

3. The COVID-19 immediate and long-term economic impact for the nuclear industry

3.1. The pre-COVID-19 pandemic economic status of the nuclear industry in Europe

During the last 20 years, the environment for developing their business changed drastically for the European Utilities. First, there was the progressive electricity market liberalisation, and then the 2009 economic crisis. So, before analysing the impact of the COVID-19 pandemic on Utilities, it is necessary to present the context in which they are developing their activities and their present situation.

In this section, the economic environment of the electric nuclear sector since 2008 is presented based on the following two effects:

1. Long-term macroeconomic trends,
2. the consequences of the current set of EU energy policies on nuclear business and the necessity for a EU nuclear policy.

The impact of each of these elements will help understanding the changes that have been introduced by the new pandemic situation.

3.1.1. The macroeconomic trends: European net electricity generation reached a ceiling in 2008

For the EU, 2008 is the year with the absolute maximum reached in terms of net electricity generation, due to the consequences of the economic crisis, which was never fully recovered before the current COVID 19 crisis.

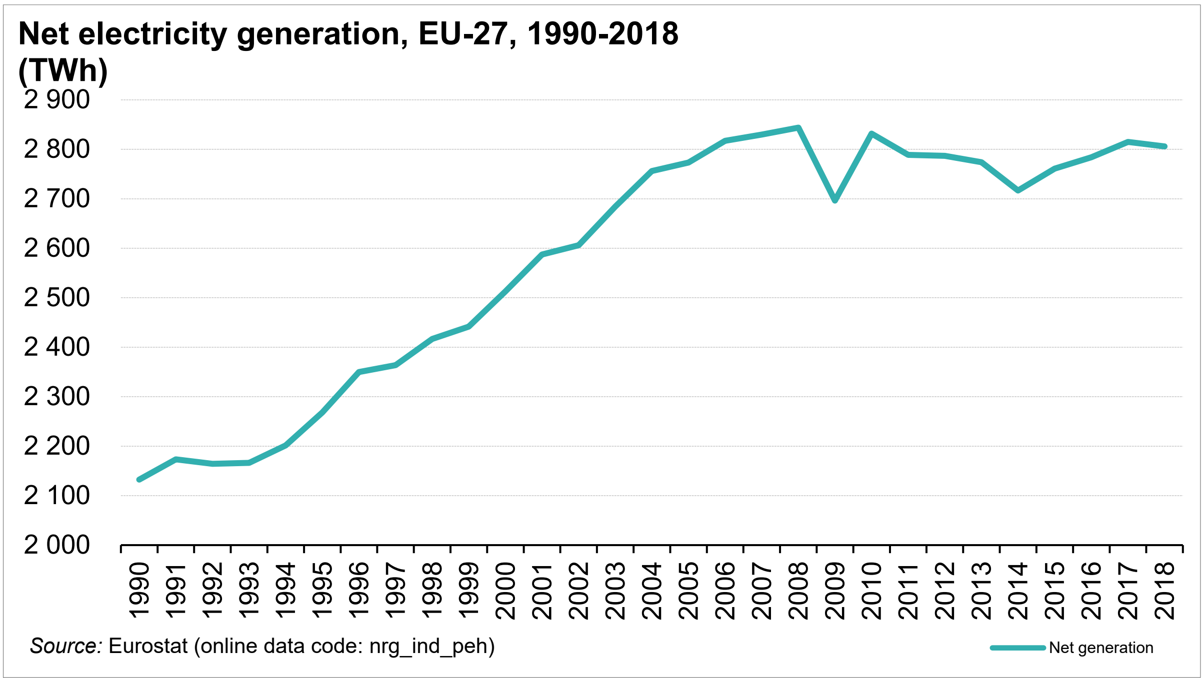

Figure 32: Net electricity generation in EU-27 - Source: Eurostat

Many factors may explain this long-term impact of the 2008-2009 drop in electricity demand. Among them, the reduction of consumption coming from the industrial actors is very significant. This economic crisis had created incentives for delocalisation of many industrial activities outside the EU.

The second factor in the reduction of electricity demand is the digitalisation of the economy, which is less energy-intensive than industry, construction, or the agricultural sector[80].

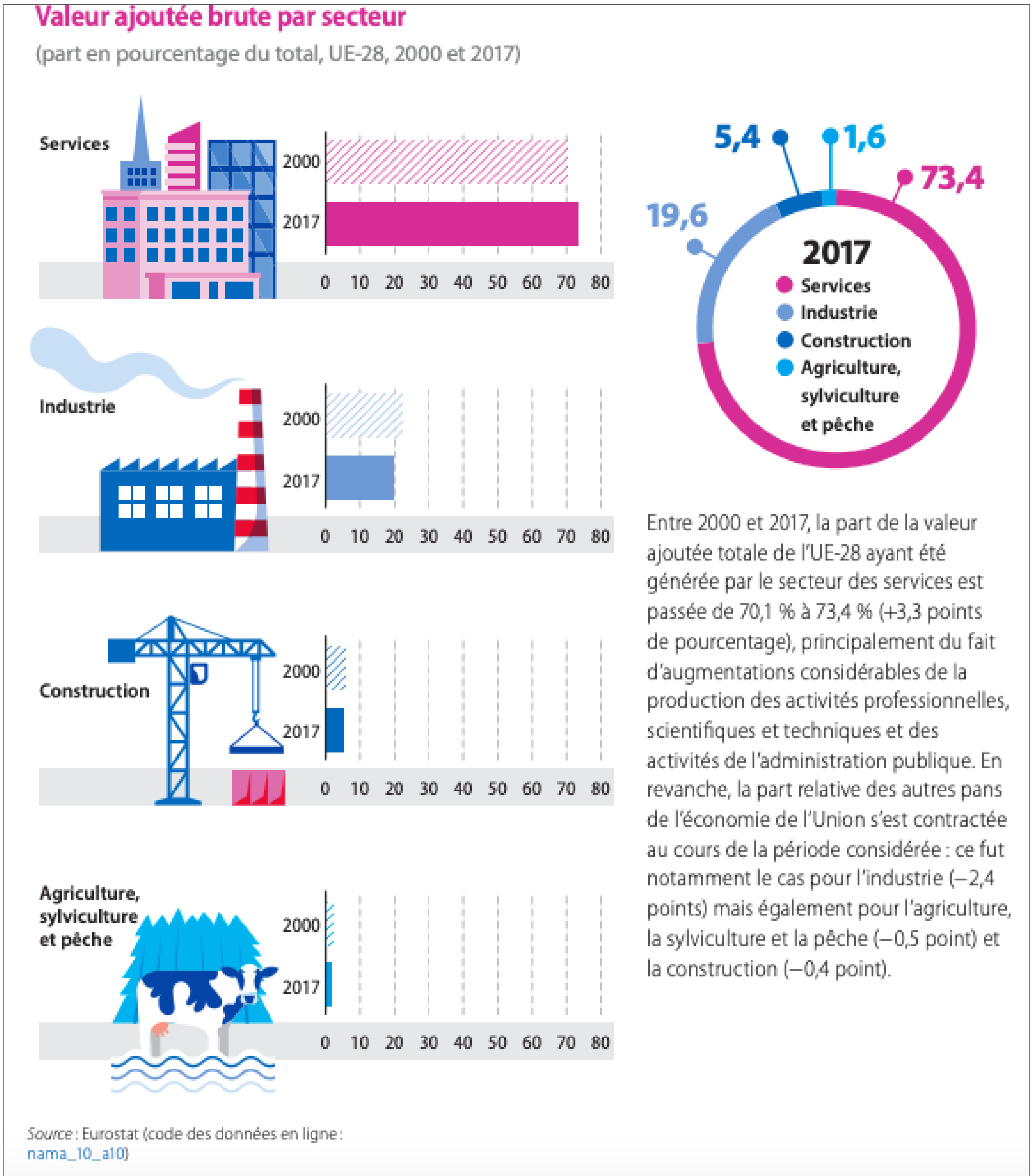

Figure 33: Value added per economic sector - Source: Eurostat

80 https://ec.europa.eu/eurostat/documents/3217494/9376693/KS-EI-18-101-FR-N.pdf/29b27e18-c1b3-45b2-bc40-ae96ea6b80d1?t=1544526697000

What has been the impact of COVID in terms of net electricity generation?

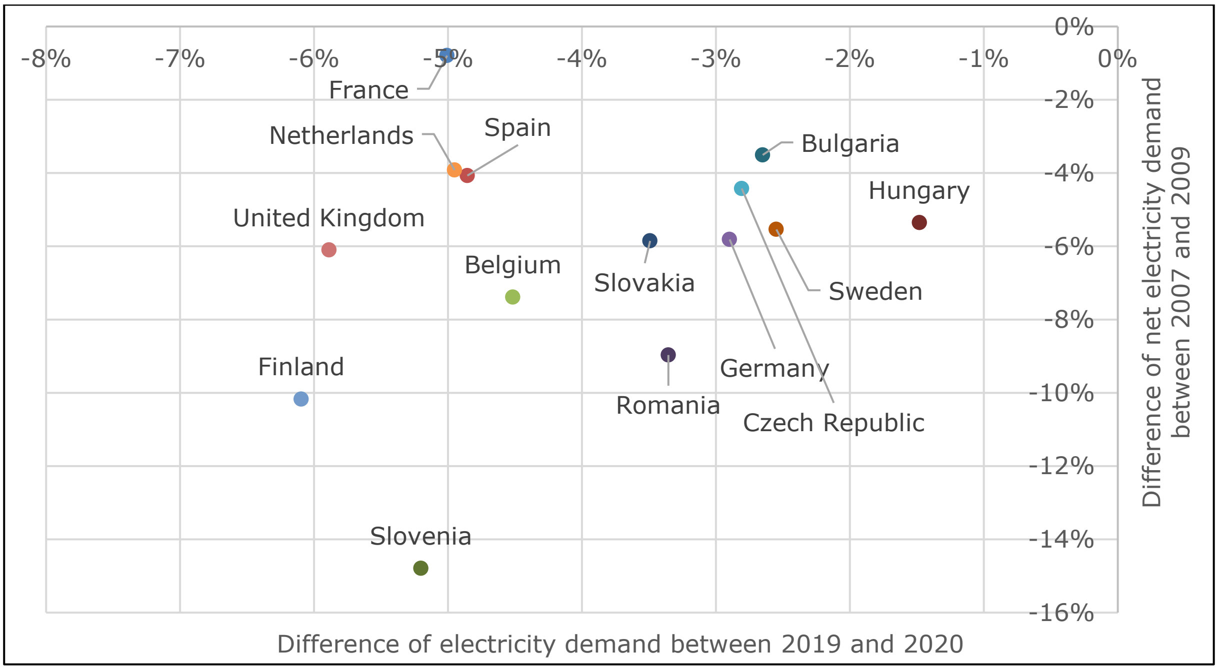

Figure 34: Comparative electricity demand impact between 2008/2009 crisis and COVID-19 pandemic

Figure 34 compares the drop in electricity demand for European countries having nuclear power plants between 2007/2008 and 2019/2020:

- The 2008/2009 financial crisis had a major impact on the European economic activities during the following years and resulted in a net decrease of electricity demand over the period. When comparing pre-crisis demand (2007) to the worst moment of the financial crisis (2009), electricity demand drops of up to 15% were observed in Europe[81], while most countries experienced an overall 4-8% demand decrease.
- A similar situation was observed between 2019 and 2020, when assessing COVID-19's overall impact over the year on electricity demand. Within one year, electricity demand fell in all European countries, from 1.5% in Hungary down to 6.1% in Finland. On average, this represented an overall 4.2% decrease for the year 2020 for nuclear countries.

Finding #18: the success in terms of electricity demand recovery will largely depend on the EU Green Deal and national investments. If the EU Green Deal works as a tool to modernize and boost the re-industrialization of the EU, energy consumption to feed the economic growth would probably allow the level attained in 2019 to be recovered.

[81] Eurostat dataset « electricity available for final consumption"

3.1.2. Impact of EU energy policies

The EU has many policies having an impact on the economics of nuclear. Some like energy efficiency and renewable development, pushing wind and solar deployment, induce difficulties for nuclear industry. In contrast, the evolution of CO_2 prices in recent years, if they persist at a reasonable level, can be seen as favourable to the nuclear industry. A last important point in the EU policy, that is complex to handle for the nuclear industry, is the absence of a clear EU common vision on nuclear energy.

The role of EU energy efficiency policies.

As underlined by some analysts, the net electricity demand decrease, since 2008, can also be explained, aside as consequence of the deindustrialisation and the economic crises, by a successful EU energy efficiency policy, aimed at promoting less energy consumption for final consumers, industries, and transport, thanks to more efficient goods, appliances, and processes[82].

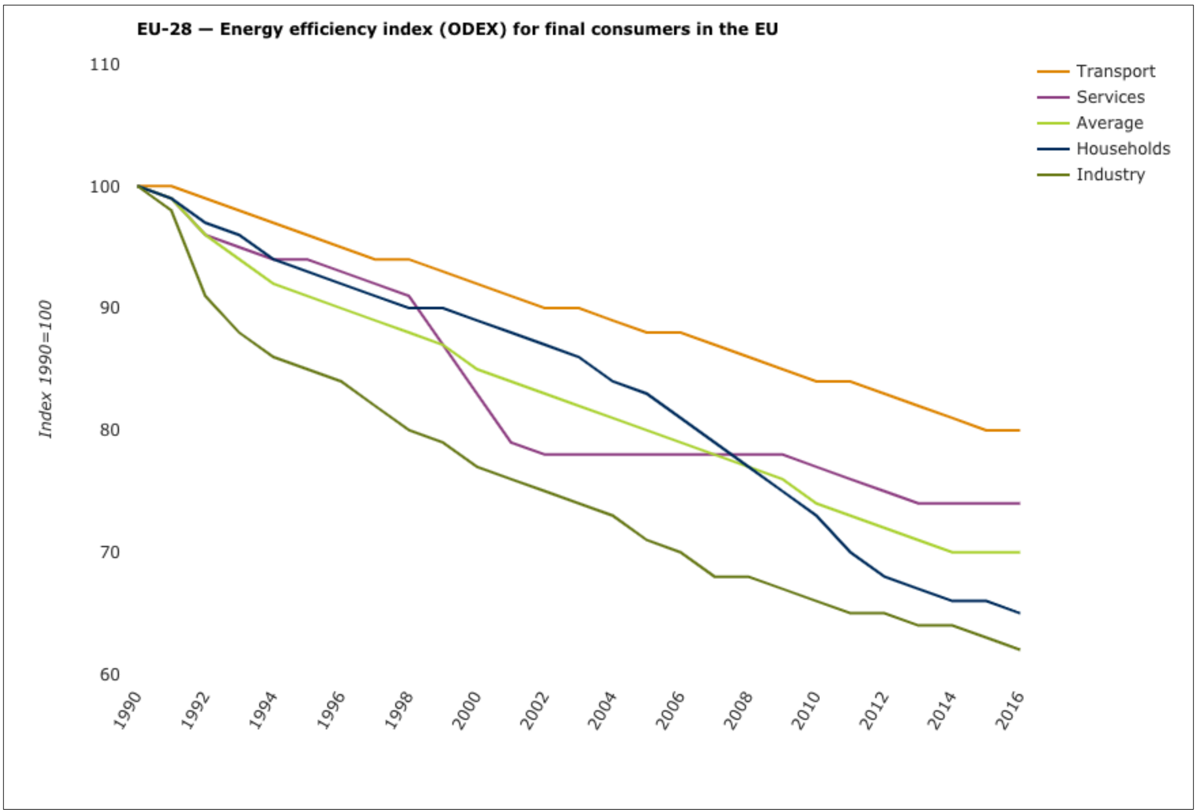

Figure 35: EU-28 Energy efficiency index (ODEX) for final consumers in the EU

82 https://www.eea.europa.eu/data-and-maps/indicators/progress-on-energy-efficiency-in-europe-3/assessment

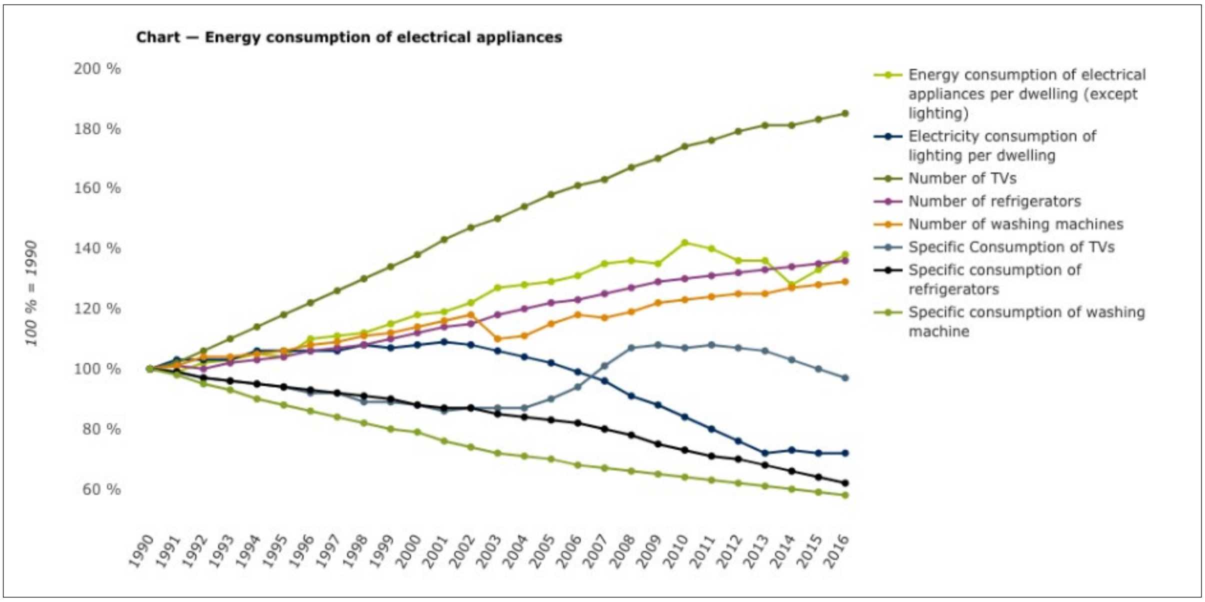

Figure 36: Energy consumption of electrical appliances
Source: Enerdata Research Service

The role of Renewable energy policies.

Aside from the impact of energy efficiency policies discussed earlier, the last factor to be emphasized is the large development in Europe of renewable energy sources like wind and solar. Before the COVID crisis, these technologies have been financed "out of the market" with a large political consensus and a variety of public financial support mechanisms across the EU as shown on the following map.

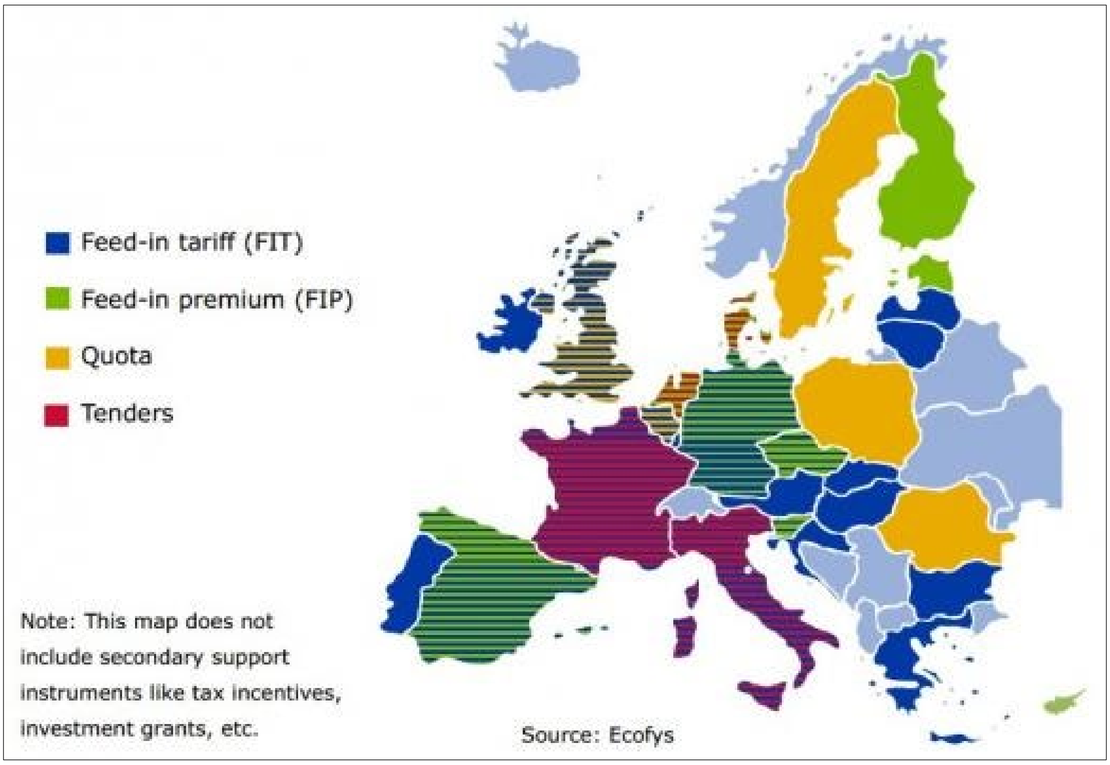

Figure 37: Experience with renewable electricity (RES-E) support schemes in Europe. Status and recent trends. Source: Klessmann C. 2014

Many mechanisms have been used to promote renewable energy sources among them the most often used were Feed-in Tariff[83], Feed-in Premium[84], Exchangeable Quotas[85] and tenders[86]. All these mechanisms have differences and some of them, like FIT and FIP, are known to boost investment in the technologies[87].

For many years, Member States have used and pushed a very large diffusion of Wind and Solar in the EU, as the following table shows[88].

Maximum electrical capacity, EU-27, 2000-2018

(MW)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total capacity	613 221	620 965	634 362	643 788	657 278	675 657	693 041	709 448	730 253	755 885	790 329	830 107	855 056	866 579	880 750	889 830	895 669	907 426	929 461
Combustible fuels	340 088	342 896	348 549	353 033	359 149	370 324	379 790	387 048	394 726	402 193	414 835	421 597	426 573	419 926	419 551	412 248	401 930	398 301	404 216
Hydro	134 729	135 058	135 438	135 861	137 713	139 271	139 516	140 305	140 972	142 247	143 113	144 459	145 060	146 165	146 323	148 311	149 838	150 483	150 826
Pure hydro power	95 932	96 100	96 423	97 127	98 019	98 361	98 168	98 922	99 273	99 948	100 848	101 967	102 099	103 055	102 879	103 707	104 315	104 733	105 201
Mixed hydro power	18 321	18 346	18 331	18 381	18 758	19 246	19 690	19 669	19 992	20 194	20 360	20 580	20 919	21 050	21 238	21 561	22 504	22 948	22 960
Pumped hydro power	20 476	20 612	20 684	20 353	20 936	21 665	21 659	21 715	21 707	22 104	21 905	21 912	22 043	22 061	22 206	23 043	23 019	22 803	22 665
Geothermal	604	587	682	723	658	686	697	700	700	727	761	776	785	797	839	839	841	848	862
Wind	12 297	16 845	22 603	27 253	33 156	38 773	45 612	53 445	60 142	70 883	78 989	87 407	97 146	105 725	115 631	127 171	137 998	148 930	157 292
Solar	175	272	355	588	1 295	2 268	3 224	4 985	10 435	16 999	30 617	53 287	71 215	79 786	83 658	87 677	91 410	96 220	103 892
Solar thermal	0	0	0	0	0	0	11	11	61	284	734	1 151	2 002	2 306	2 306	2 306	2 306	2 306	2 306
Solar photovoltaic	175	272	355	588	1 295	2 268	3 213	4 974	10 374	16 715	29 883	52 136	69 213	77 480	81 352	85 371	89 104	93 913	101 586
Tide, wave, ocean	213	215	218	219	218	216	215	215	218	216	216	215	216	223	226	223	225	224	223
Nuclear	124 851	124 882	126 297	125 416	124 555	123 142	122 837	121 850	122 152	121 684	120 866	121 424	113 237	113 065	113 578	112 470	112 554	111 524	111 240
Other sources	263	210	220	695	534	977	1 149	900	907	936	933	942	824	891	944	890	873	897	910

Table 10: maximum electrical capacity in EU-27 – Source: Eurostat

More precisely PV panels diffusion starts to create small "duck curves" as in the famous CAISO chart, with a net consumption decrease when the sun is shining and an increased need for electricity when the sun declines[89]. In the following graph, the evolution of the duck curve phenomena from 2012 to 2020 in California is displayed.

Aside from the technical challenge of managing the new load curve every day, this situation has two consequences:

- During the day, traditional generators see the net demand being negatively impacted by PV generation.
- At evening time, the need of fast ramping up flexible generation is more and more needed.

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[83] FIT guarantee retail prices for RES plant operators for a given period. FIT provide predictability and stability for the individual producers and investors.

[84] In an FIP, generators must sell energy to the market and receive an additional payment on top of the electricity market price. The revenue risk is increased in a FIP compared to a FIT.

[85] In comparison to FIT / FIP EQ fix quantities and the market decides price. A minimum share of the electricity supply must be from RES, and this share is increasing over time. Suppliers may trade certificates for electricity from RES (RES-E) if they cannot reach the minimum share with own production.

[86] tender or auction schemes can be used to allocate financial support to different renewables technologies and to determine the support level of other types of support schemes.

[87] For an extensive discussion of the merits and limits of the different RES support see Finon Dominique and Perez Yannick 2007, *Transactional Efficiency and Public Promotion of Environmental Technologies: The Case of Renewable Energies in the Electric Industry*. Ecological Economics 62, pp 77 – 92

[88]https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_and_heat_statistics#Installed_electrical_capacity

[89] https://www.aurorasolar.com/blog/the-duck-curve-a-review-of-californias-daily-load-predictions/

These two specific periods of the day induce new complexities to handle for nuclear operators. The first one raising a risk in terms of volume and prices reduction, and the second in terms of flexibility requirements for which nuclear plant are not always ready to technically address.

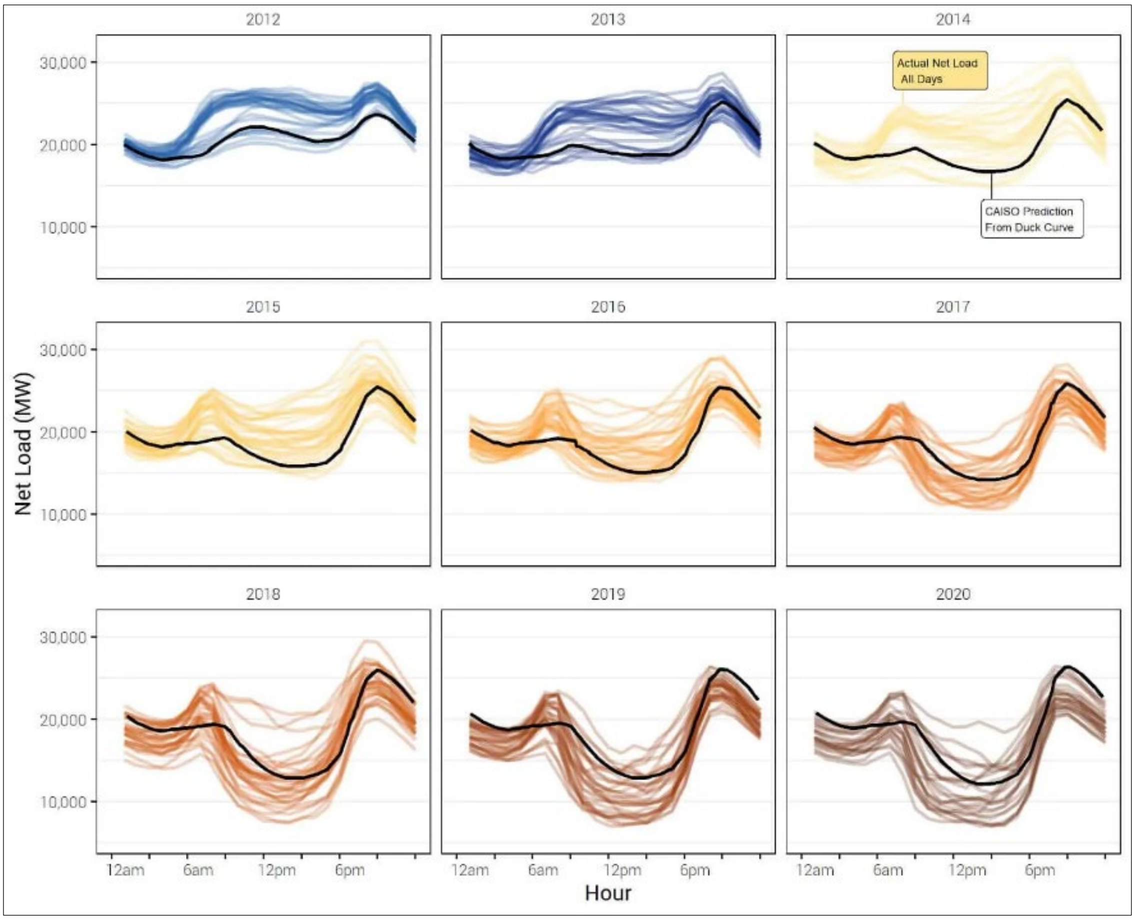


Figure 38: Duck curve: predicted net load vs actual net load for all days between March 15 and April 15

In the California case, this technical challenge is also mixed with an economic one. When PV is working during the day, it decreases the market price of the marginal technology used to set the price for the given hour, which in turn reduces the inframarginal profitability of the other technologies used to generate electricity. This reduction is important for nuclear technology largely used as a baseload one and using the marginal cost of the other technologies to recover their fixed costs.

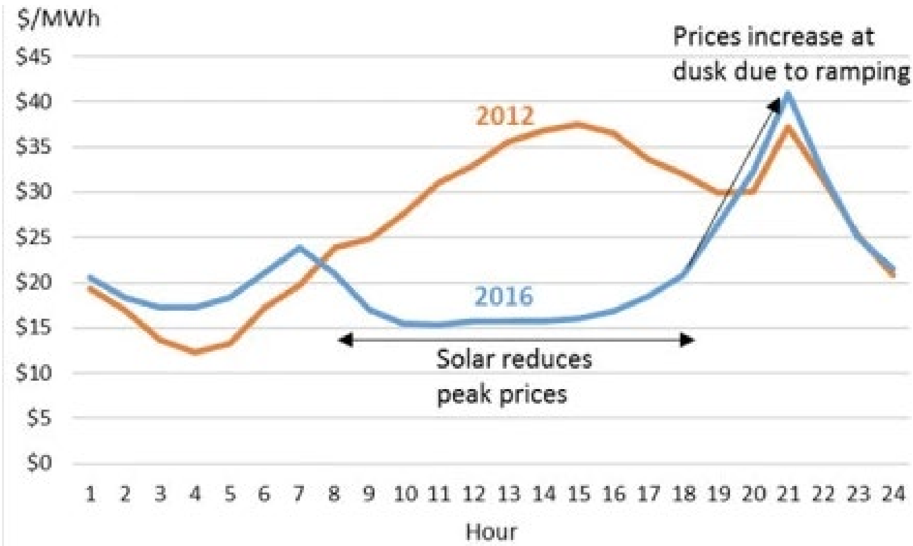


Figure 39: Day-ahead average hourly electricity prices at SP-15 (CAISO), May 2012 versus May 2016 – Source Sparklibrary, based on data from CAISO

This Californian situation is also to be expected with the development of PV panels in the EU. In the following chart, the evolution in the UK's load curve is displayed and the transformation of the camel curve to a duck curve[90] seems to be at stake.

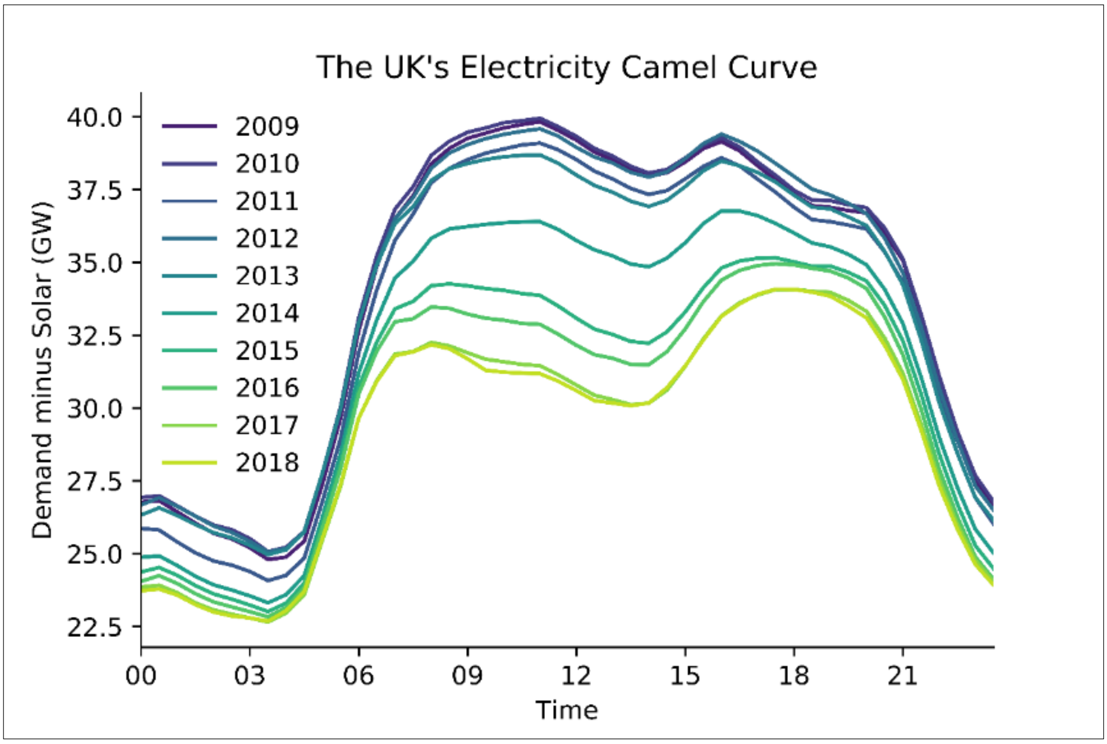


Figure 40: The UK's electricity camel curve

This volume effect is also reinforced by the market price effect. Renewable Energy Sources (RES) causes two different impacts on electricity market price: first impact is an annual mean reduction of a few euros per MWh sold in the market, because RES reduces the net demand that the other technologies must generate. In some

90 http://energyjournal.co.uk/Blog

very specific situations, electricity markets are also facing a negative price for producers (i.e., producers have to pay consumers for increasing their demand in order to save the opportunity cost of shutting down, then restarting their facilities). In the following chart, we displayed one month in Germany in 2020 to exemplify this phenomenon.

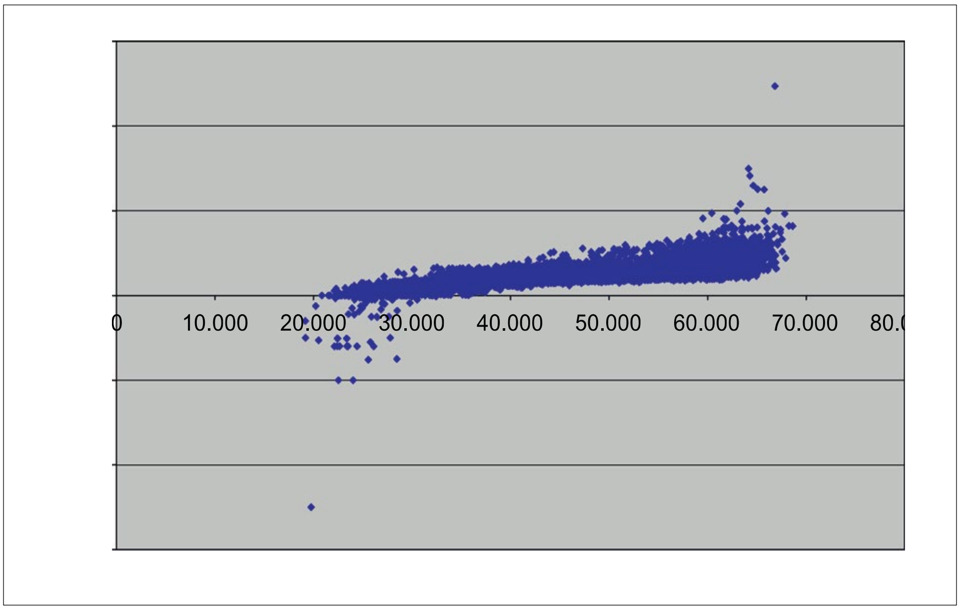


Figure 41: EEX (2010) spot prices and residual load (10/2008 – 12/2009) – Source: Author, based on data from EEX, BDEW and ENTSO-E

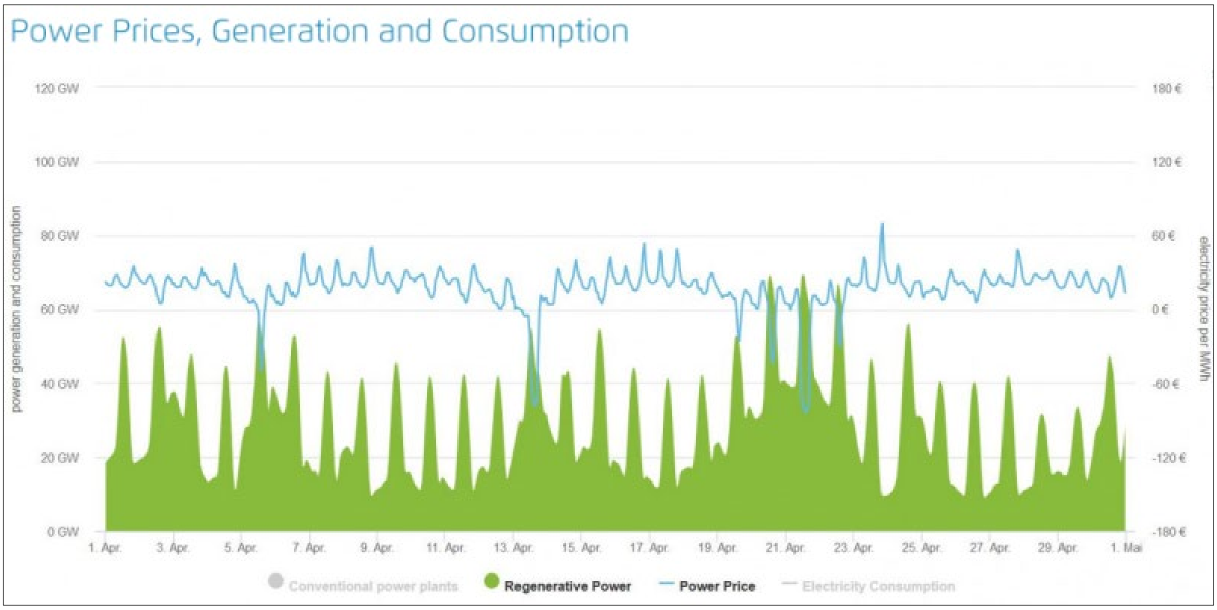


Figure 42: Power prices, generation and consumption – Source: https://energypost.eu/negative-electricity-prices-lockdowns-demand-slump-exposes-inflexibility-of-german-power/

The new role of CO_2 prices

As an almost totally CO_2-free technology, nuclear utilities, in the European electricity market, have seen, during the recent years, an increase in the allowance from a few euros per ton in 2011 to more than 45€ in May 2021; as potential financial good news for their industry.

1. If the nuclear companies have some allowances, they will have the opportunity to sell them at a high value (direct revenue effect of CO2 allowance price increase).

2. As the CO_2 price increases the cost of thermal competitors and their marginal cost, the nuclear industry will get more inframarginal rents revenues when thermal generation sets the marginal price (indirect revenue effect of CO_2 allowance price increase)

If we compare the two crises in terms of CO_2 price management, the actual situation is a major strategic change as the following chart recalls.

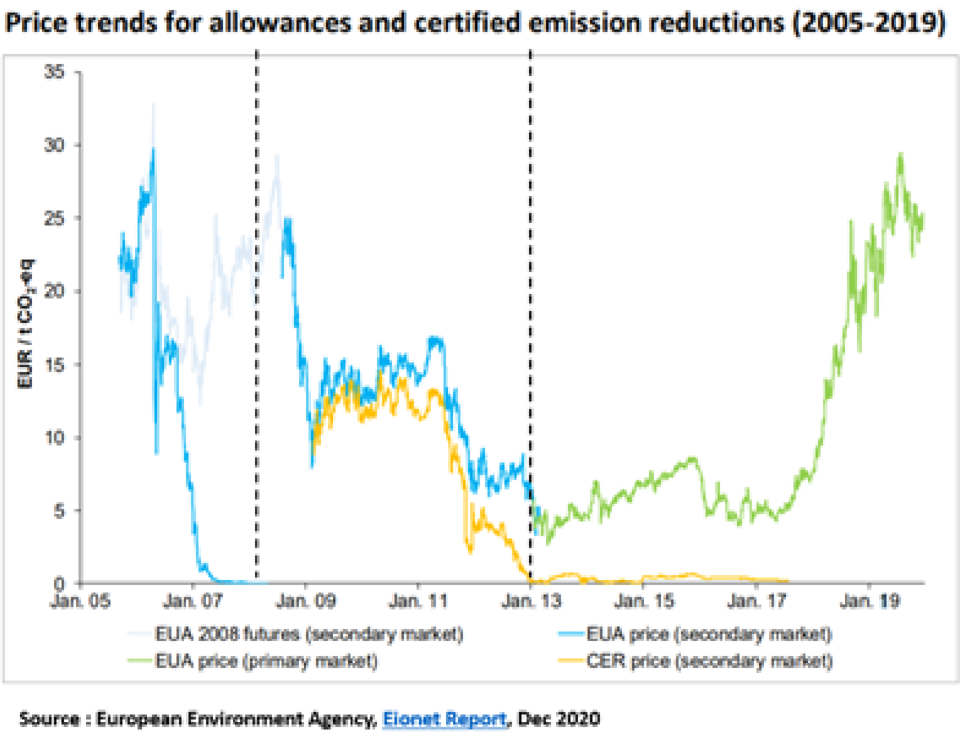


Figure 43: Price trends for allowances and certified emission reductions (2005-2019)
Source: European Environment Agency, Eionet Report Dec 2020

In the former crisis, the CO_2 price has been massively reduced, from around 20 euros to 5 euros per ton, to help the industry to recovers without the hurdle of the CO2 constraint. It seems that in 2021 and the increase of the CO_2 price the message is that re-industrialisation will not be done at the expense of CO_2 emissions.

This strong CO_2 policy implies that the increase in the production cost for CO_2-emitting firms will somehow be managed internationally at the EU borders. Otherwise, this strong increase in manufacturing costs will reduce the competitivity of EU industries in the current competition with countries without CO_2 regulation.

The nuclear energy policy in the European Union.

Several recent nuclear safety directives were adopted by EU MS during the last decade, but several other important topics would benefit from agreed policies at EU level, such as unified safety regulation, common construction standards, wastes and decommissioning management solutions, etc. Nuclear is a capital-intensive energy, and the lack of a clear European frame generates legal and regulatory uncertainties on costs.

The result of the on-going process to define the position of the various energy sources in the European Green Deal will shape the future of European utilities in Europe and drive their investments toward appropriate technologies.

To reach the EU's climate and energy targets in 2030 and the objectives of the European Green Deal, direct investments towards sustainable projects and activities are required. The COVID-19 pandemic calls for direct capital flows towards sustainable projects and more resilient projects against climate and environmental shocks and risks, with clear co-benefits for health.

To achieve this, a common classification for sustainable economic activities is required at the EU level. This effort of definition has been called "EU taxonomy" since 22 June 2020 (Taxonomy Regulation). The EU taxonomy will be a classification system establishing a list of environmentally sustainable economic activities to be funded and supported. It is then crucial for technologies to be in it if they want to be supported by the EU Green Deal.

In 2020, the Commission launched in-depth academic work to define the role of nuclear energy in the EU taxonomy of environmentally sustainable activities. At the date of the present report writing, the final conclusions have not been released, and nuclear energy may be in three possible situations:

- Option A: Nuclear is included in the taxonomy and its future is made economically safer, its risks are reduced, and profitability is structurally enhanced.
- Option B: Nuclear is defined in the same basket as gas technologies as transition technologies. Short term operation of the technology is not negatively impacted but the development of the technology will not be secured and supported by the EU Green Deal.

- Option C: Nuclear is not included in the taxonomy and its future will only rely on the financial capabilities of the companies and Member States willing to finance it at their own costs and risks.

The consequences of the choice will shape the future of Nuclear Utilities; the nuclear energy can only be handled effectively with a long-term vision and strategy. So, the decision on the taxonomy will be among the major factors shaping the resilience of the nuclear sector during the next decades against potential crisis, as new pandemic.

Finding #19 :
It is not in the scope of this report to precisely measure the impact of each of the economic factors we have highlighted, but four trends are shaping the economics of the nuclear industry:

1. The trend that deep decarbonisation, hybrid market designs and energy efficiency requirements tend to increase the complexity, the price and volume risks faced by the business of nuclear operators.
2. The second trend is a cumulative negative impact on the revenues of the baseload technologies like nuclear resulting from EU policies and investment aiming at promoting renewables.
3. Positive economic signals for nuclear are coming mainly from the evolution of CO_2 market allowance prices since 2018.
4. Inclusion of Nuclear in the taxonomy for the EU Green deal plan of investment is a crucial decision on the economics of the future of the nuclear sector in EU, in particular to secure its resilience.

3.2. Financial situation of nuclear utilities, COVID-19 impact

Before the COVID-19 Crisis hit Europe, for the reasons explained above, the financial position of many nuclear utilities had been weakened during the last decade. As a result, their financial capacity for realizing large upgrades on their ageing operating reactors or for constructing new ones could be more limited and the purpose of this chapter is to analyse whether the COVID-19 pandemic has added any significant stress in their financial account.

The evolution of their credit ratings, as published by specialized agencies (Fitch, Moody's, Standard & Poor's…), clearly show the degradation trend since 2010[91]. Credit rating gives an estimate of ability to fulfil their financial commitments, based on an in-depth analysis of strengths and weaknesses of the companies.

	2010	*Variation (2010-2020)*	*2020*	*Variation (2020-2021)*	*2021*	*Credit rating Agency*
CEZ	A-	=	A-	=	A-	Fitch
E.ON	A	-2	BBB+	=	BBB+	Fitch
EDF	A+	-2	A-	=	A-	Fitch
EnBW	A	-2	BBB+	=	BBB+	Fitch
ENDESA	A-	=	A-	=	A-	Fitch
ENGIE	A	-2	BBB+	+1	A-	S&P
Fortum	A-	-2	BBB	=	BBB	Fitch
IBERDROLA	A-	-1	BBB+	=	BBB+	Fitch
RWE	A+	-4	BBB	+1	BBB+	Fitch
Vattenfall	A	-2	BBB+	=	BBB+	S&P

Upper medium grade
Lower medium grade

Figure 44: Credit rating evolution for several European Utilities during the last decade

For several reasons, as developed above, (demand decrease, digitalisation of the economy, development of non-dispatchable renewables capacities…), most of them have seen a drop in their rating level of 2 grades since 2010, putting them globally from "upper medium grade" into "lower medium range", with, as consequences, higher interest rates and reduced options for their loans.

Originally, European utilities operated on their local or national markets; after the market liberalisation (around 2000), they started developing business outside their usual practices and the models they follow now vary greatly, in terms of size, operational exposure to regulated and non-regulated framework, horizontal diversification and vertical integration.

In line with the European policy, they also developed electricity and gas trading, and enlarged their activities to new services by internal and external growth. For most of them, nuclear generation is just a part of their business, and their financial

[91] For an analysis of the financial situation before 2010 see Eurelectric report 2010 The Financial Situation of the Electricity Industry – A View to the Future Challenges.

results are less dependent to the electricity production and their nuclear assets than they were in the past. In some cases, nuclear plants are co-owned by several Utilities which share electricity output.

Since the pandemic, there were few variations in the credit rating grades (only two upgrades in the above sampled list). This may be seen as an indication that the Rating Agencies are not considering COVID-19 pandemic to have significantly weakened Utilities. Some of the sensitivity parameters used in their 2020 annual reports are based on:

- EBITDA and debt variation (difference between the revenues and the operating costs)
- And the ratio of the net financial debt to the EBITDA.

Company	Nuclear Operator Country	2020 Nuclear generation	Revenues	EBITDA 2020		Net financial debt			Long term ranking
			b€	b€	variation /2019	b€	variation /2019	ratio debt/EBITDA	
Engie	Belgium	36,5	55,800	9,300	-10,6%	22,500	-13,5%	2,4	Upper medium grade
Bulgarian Energy Holding	Bulgaria	16,6	2,854	0,458	-14,9%	1,081	-10,2%	2,4	Non investment grade, speculative
CEZ	Czech Republic	30,0	8,300	2,500	7,7%	5,600	-11,0%	2,2	Upper medium grade
FORTUM (Nordic generation)	Finland	21,0	49,015 (elec. 2,006)	2,434 (elec. 0,886)	Not pertinent (perimeter change)	7,023	Not pertinent (perimeter change)	2,9	Lower medium grade
TVO		14,6	0,275	0,500	not published	4,078	-0,1%	8,2	Uncertain: lower or speculative (delays on OL3 start-up)
EDF	France UK	335,4	69,031	16,174	-3,3%	42,300	2,9%	2,6	Lower medium grade
EnBW	Germany	10,4	19,694	2,663	18,6%	14,406	12,1%	5,4	Upper medium grade
EON			60,944	6,905	Not pertinent (perimeter change)	23,956	Not pertinent (perimeter change)	3,5	Lower medium grade
RWE		20,7	13,688	3,235	30,0%	4,432	-36,0%	1,4	Lower medium grade
MVM	Hungary	15,2	4,110	0,608	-7,9%	*No data*			Lower medium grade
PZEM	Netherlands	3,9	0,549	0,041	-36,0%	0,121	-9,9%	3,0	Credit withdrawn, 2021 Feb. non investment grade speculative
S.N. NUCLEARELECTRICA S.A	Romania	10,6	0,500	0,263	11,1%	0,265	-10,2%	1,0	Not rated
SLOVENSKE ELEKTRARNE	Slovakia	15,4	2,898	0,363	6,0%	1,954	-3,5%	5,4	Rating withdrawn, 2021 May: on investment grade speculative
HEP Group	Slovenia	3,0	1,855	0,568	16,1%	0,094	27,1%	0,2	Lower medium grade, if S&P or Fitch
ENDESA	Spain	25,9	17,579	3,783	-1,5%	6,899	8,2%	1,8	Lower medium grade
IBERDROLA		24,3	33,145	10,010	-0,9%	35,142	-7,0%	3,5	Lower medium grade
VATTENFALL	Sweden Germany	39,3	15,700	4,600	9,6%	4,808	-25,0%	1,0	Lower medium grade
ALPIQ	Switzerland	5,3	3,630	0,273	74,4%	0,249	20,9%	0,9	Lower medium grade
AXPO		19,2	4,471	1,087	0,9%	1,098	-6,0%	1,0	Lower medium grade

Legend
Upper medium grade
Lower medium grade
Non investment grade, speculative

Figure 45: list of Utilities owning and operating nuclear plants

Previous figure indicates:
- The country in which the utility operates nuclear reactor.
- The nuclear generation in 2020.

- The 2020 total revenues, an indicator of the company size, in a range from few hundred million euros to several tens billions.
- The 2020 EBITDA and its variation to the previous year.
- The net financial debt and its ratio to EBITDA.
- The current credit rating of the company.

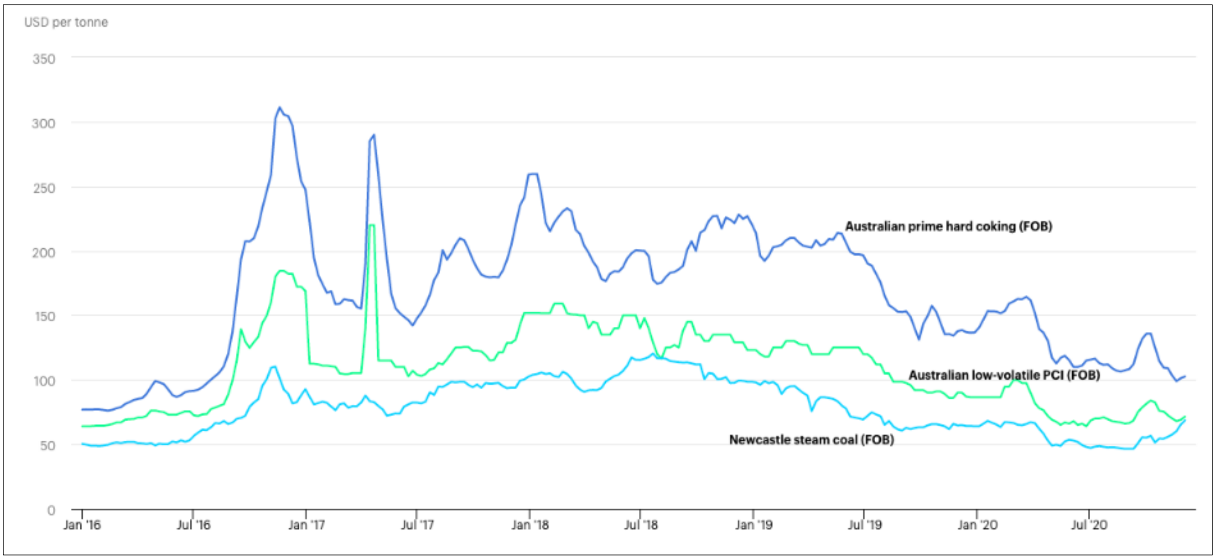
Several factors are driving the 2020 utilities financial results, some are negative, and others are positive. They impacted differently the various companies depending on their geographical locations and operations.

Among the negative effects, the COVID-19 pandemic is the obvious one, mainly through its large impact on the economy with a reduced industrial demand, mostly during the second quarter. It had also consequences on the operating costs, but this is not explicitly expressed in the Utilities Annual Reports as a major effect. The second large negative contributor to the financial result is the weather, mostly during the first quarter of the year; 2020 started with a mild winder in Europe, notably in the Nordic region, but not only, with, therefore, a less call for electricity than usual.

It must be underlined that the weather, with renewables deployment (hydraulic, solar, wind), is now a major parameter shaping the Utilities financial results, as driving not only demand, but also generation, and consequently the electricity prices. As an example, a high level of rains filled hydraulic reservoirs in Nordic countries and contributed to a low price of electricity with direct impact on Nordic utilities incomes.

Besides, there were also several positive factors, in favour of nuclear utilities, counterbalancing the negative effects, such as the rise of price for allowance during 2020, from 15.7 €/t.C in March up to 33.4 in December, which pushed up the wholesale electricity price in the Central market, where coal and gas plants are dominant. Moreover, the coal price increased significantly by the end of 2020[92].

[92] https://www.iea.org/reports/coal-2020



The same evolution applies for gas in European hubs price in the Netherlands (FIF) and in England (NBP) and in Japan and Korea (JKM).

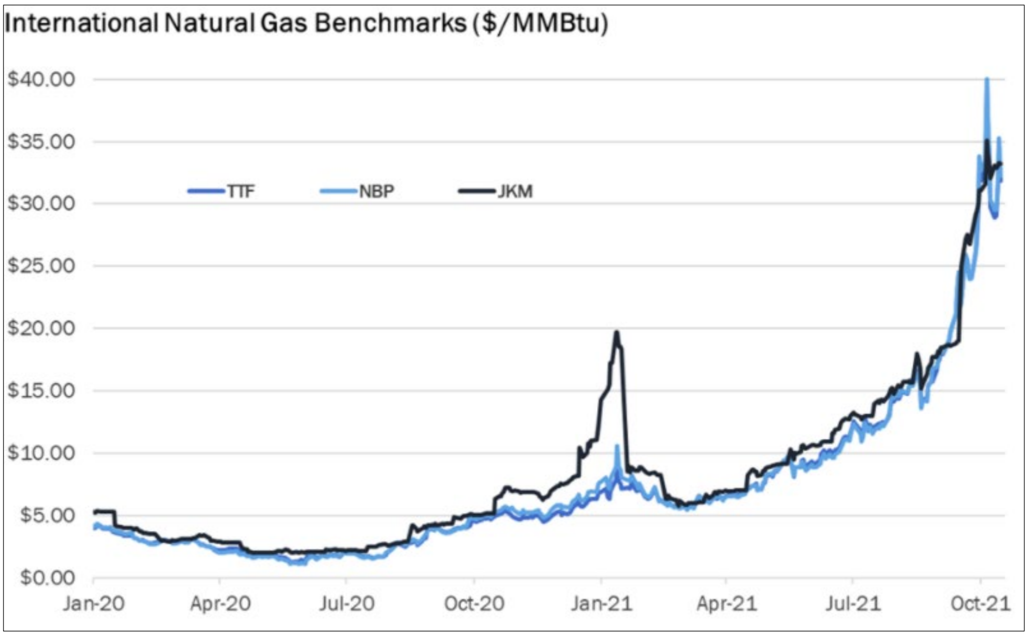


Figure 46: International natural gas benchmarks ($/MMBtu) – Source: https://www.europeangashub.com/european-gas-prices-no-relief-in-november.html

Financial results are also impacted by other factors (e.g., acquisition, losses or benefits in business not directly linked with electricity) that contribute to the various changes of the EBITDA between 2019 and 2020 (positive for some utilities, negative for others).

Finding #20 :
The main financial findings that can be drawn from the table are:
- All Utilities have seen limited variation, positive or negative, in their earnings, showing that COVID-19 pandemic had not significantly disturbed their business. The largest decrease on EBITDA was for ENGIE, Bulgarian Energy Holding, Hungarian MVM and Dutch PZEM for reasons not directly linked to the pandemic.
- TVO and Slovenske Elektrarne are in a particular situation after high investments, and consequently large debts associated with new nuclear reactors construction Olkiluoto 3 and Mochovce 3-4 that are now very close to completion. EDF, with Flamanville 3 is in a similar position.

3.3. Utilities with in-front forecasted investments in nuclear reactors

Several utilities, currently operating nuclear plants, have forecasted to invest for upgrading their ageing reactors and/or build new ones.

- In 2014, EDF has launched a large programme ("Grand Carénage") planned till 2025 for upgrading safety and operation of its French nuclear fleet. The last estimate of the total cost was 49.4 b€. The COVID-19 had slowed down the pace of the work during a part of 2020.
- Since 2018, several British AGRs are suffering of ageing problems and are shut down for safety reasons or repairs. Large investments do not seem foreseen. Due to the reactors age, return of investment is not obvious, and large investments are not expected.
- EDF plans to construct 6 new reactors in France and is expecting governmental approval.
- Vattenfall forecast implementation of independent core cooling system on Forsmark and Ringhals during the next years (0.2 b€).
- CEZ had completed upgrades of its nuclear plants; the next large nuclear investment should be the construction of a new reactor at Dukovany.
- MVM is developing a project of construction for 2 new nuclear power reactors in Hungary (Paks-II)
- PZEM plans to build new nuclear reactors in the future.

3.4. Some specific examples

After a first development phase in the sixties and seventies, most nuclear countries in Europe are now facing an "energy policy crossroads":

i. Should the actual reactors be retrofitted, or should they be decommissioned?
ii. Should new reactors being build, and if yes how many?
iii. The last question is related to the finance issues needed to build new reactors, to retrofit a part of the actual fleet and to manage the decommissioning of the too old reactors. Will the future investments be fund by loans, by stocks or by internal growth (profits made with the generation units)?

In front of this new set of choices, not all the companies react in the same way. Different strategies with associated risks can be explored:

- CEZ is an electricity producer, with coal plants and hydraulic capacities. It operates the 6 Czech nuclear reactors and is preparing the construction of a new one.
- EDF, the largest nuclear operator in the world, with a fleet of 56 reactors in France and 15 in the United Kingdom; it has one reactor under construction and plans to build 6 new reactors in the future. EDF is a diversified producer with renewables capacities (hydraulic, wind) and fossil plants.
- ENGIE is a diversified energy group, with large electricity capacities, mostly gas and renewables (hydraulic, wind, solar); it owns and operates the 7 Belgian reactors. Under the Belgian law, all nuclear reactors must be permanently shut down before 2025.
- Vattenfall is a large European electricity producer; the largest part of its capacity is nuclear, with ownership or co-ownership of 6 reactor in Sweden and 3 in Germany. It has also renewable energy facilities (hydraulic, solar) and fossil plants. Germany has phased out the use of nuclear energy. In Sweden, nuclear energy has been phased out, but the decision was repealed in 2010; nevertheless, Vattenfall, due to Swedish nuclear taxes, does not plan the construction of new reactors.

3.4.1. Electricité de France (EDF) - looking for new reactors, expending the lifetime of the fleet and decommissioning. All to be funded

Nuclear power history

In France, the actual fleet of reactors was launched in 1969. A batch of six reactor of 900MWe was ordered (the CP0 batch) and their construction started in 1971. But the 1973 oil embargo triggered a more ambitious nuclear program. In early 1974, 18 identical reactors of 900MWe were ordered (CP1 batch). They were followed in late 1975 by 18 new reactors: 10 reactors of 900MWe (CP2 batch) and 8 of 1300MWe (CP4 batch). 12 additional reactors of 1300MWe were ordered in 1980 (P'4 batch). Finally, in 1984, 4 reactors of 1450 to 1500MWe (N4 batch) concluded this nuclear policy (Boccard, 2014)[93].

[93] Boccard, N., 2014. The cost of nuclear electricity: France after Fukushima. Energy Policy 66, 450–461. https://doi.org/10.1016/j.enpol.2013.11.037.

Current situation

Nuclear has a central place in the French electricity industry and remains an important energy source in the French energy strategy:

1. with a mix of new reactors under construction (one under construction at Flamanville, 6 are conditional to the completion of the Flamanville project - for a budget of 46 billion € in France, plus the UK Hinkley Point C investment – around 22 billion € and in China),
2. 32 reactors to be retrofitted in France (48 billion Euros for "Grand Carénage" expending their lifetime from 40 to 50 years),
3. 2 reactors decommissioned in 2020 in Fessenheim[94] (14 more are in the same situation before 2035 for a total of around 50 billion €[95]).
4. Cumulative numbers seem to give a global envelope of a minimum of 150 billion € to be invested in the field over the next years by EDF or/and by the French State.

The financial challenge seems to be large for EDF, considering its financial capacities and its actual objectives, requiring, in some ways, support from the French state (owning 87% of the company).

The following figure displays the euros per share given to EDF's shareholders since 2006. This very low level of revenues – and decreasing one- did not allow a large funding by the financial markets.

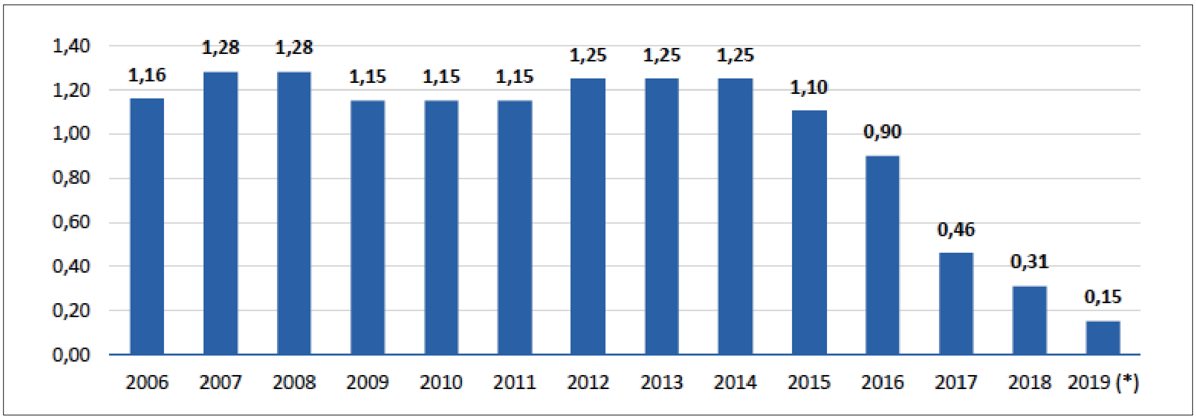


Figure 47: Revenues per EDF share evolution

[94] The decommissioning project is scheduled over the next 15 years.
[95] https://www.lemondedelenergie.com/nucleaire-cour-des-comptes-cout-fermeture-fessenheim/2020/03/05/

EDF debts has continued to increase in 2020 and is now at a level of 42 billion €, which is quite high.

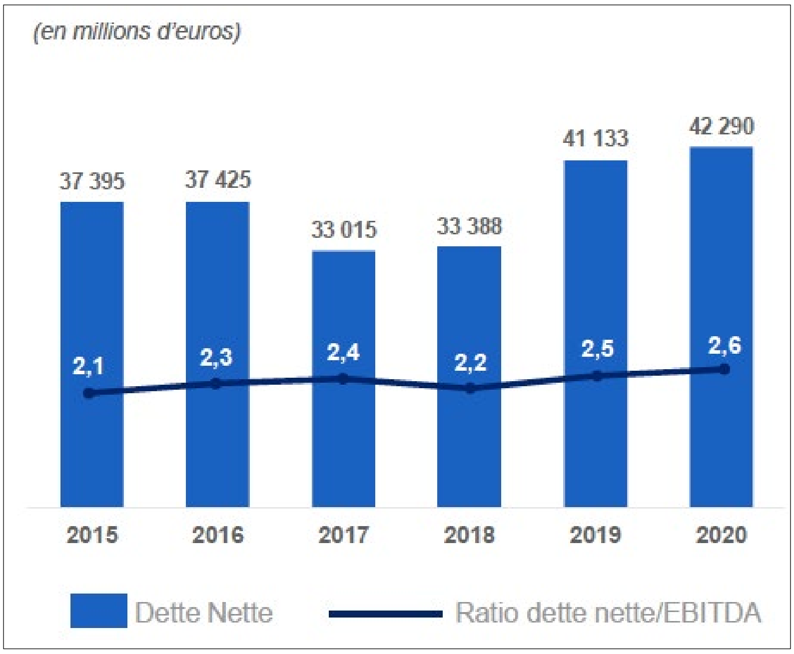


Figure 48: EDF debt and radio debt/EBITDA evolutions between 2015/2020 – Source EDF

COVID-19 impact

The 2020 EDF financial report shows decreases in the group turnover, EBITDA, and net profit, compared to the previous year.

Billion €	2019	2020
Turnover	71.3	69.0
EBITDA	16.7	16.2
Net Profit	5.2	0.65

Concerning France, the report estimates at - 33 TWh (out of the 44 TWh in total) the effect of the COVID-19, and a decrease of 1.5 B€ in sales, half of it coming from nuclear reactors availability and the other half from less demand from customers.

In UK, the EDF-Energy EBITDA has seen an increase (+3%), driven higher nuclear electricity prices and other improvements, offsetting the COVID-19 impact (-182 M€).

In both countries, spot and future sale prices of electricity have been reduced significantly, in a range between -10% up to -20%.

3.4.2. ENGIE – Electrabel – All reactors shutdown in 2025

Nuclear power history

In the late 1960s, Belgium chose nuclear power to produce part of its electricity. Therefore, the government decided to build 4 nuclear reactors in Doel and 3 in Tihange. In 1968, Doel-1&2 were ordered. Construction started in 1969. The Doel-1 reactor was commissioned in early 1975 and later that year Doel-2 followed. Doel-3 went online in 1982 and in mid-1985 Doel-4 was fully operational. Doel-1&2 are fully owned by Electrabel. Doel-3&4 are largely owned by Electrabel (89.8%) and partly by EDF.

In 1968, Tihange-1 was ordered. The power station was commissioned in 1975, just in time to reduce Belgium's dependence on oil. Tihange-2 went online in mid-1983 and Tihange-3 followed in 1985. Tihange-1 is owned 50/50 by EDF and Electrabel. This cooperation between France and Belgium started with the construction of the Chooz nuclear power plant in France. Tihange-2&3 are largely owned by Electrabel (89.8%) and partly by EDF. Electrabel ensures the operation of the power stations.

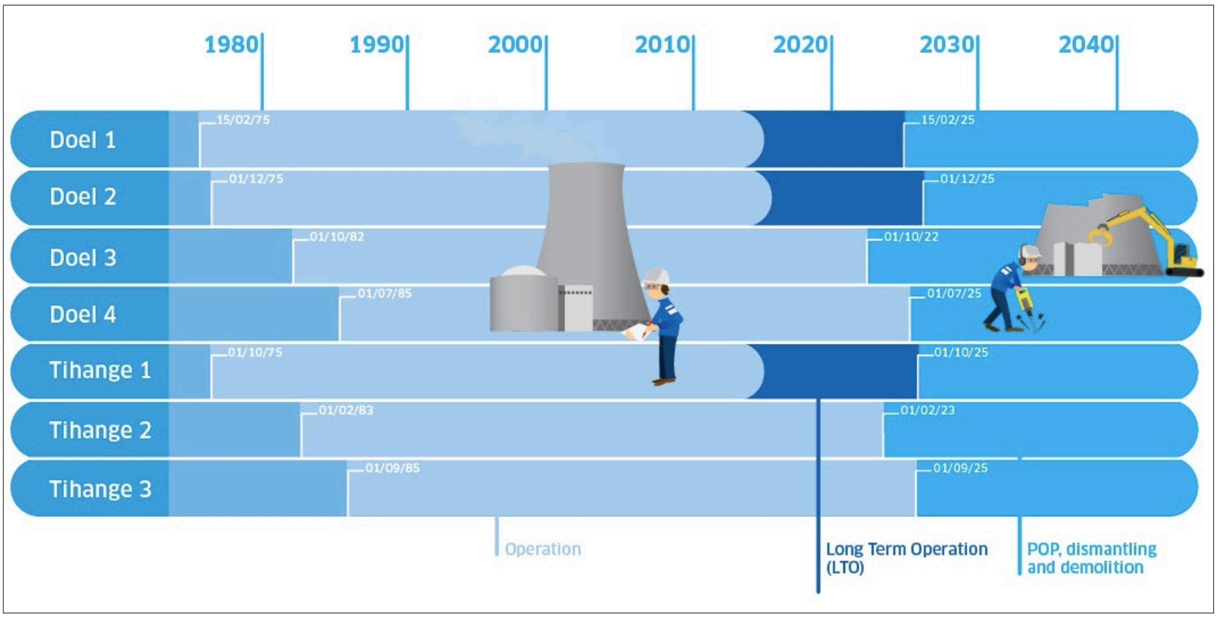


Figure 49: Current Belgian nuclear power plants lifecycle

Current situation

Engie's Belgian subsidiary Electrabel operates the seven PWR nuclear reactors in the country - Doel 1-2-3-4 and Tihange 1-2-3 reactors - which accounted for 47% of power generation in 2019.

1. Doel-1 and Doel-2 and Tihange-1 have secured 10-year lifetime extensions, while Tihange-2 will reach its 40-year lifetime limit in 2022, followed by Doel-3 in 2023 and Doel-4 and Tihange-3 in 2025.

2. The government has been hesitating concerning those two reactors to continue operations after 2025. However, Engie estimates that €500m to €1bn would be necessary to extend their operation and invited the government to accelerate its decision on Tihange-3 and Doel-4 from 2019 to March 2021.
3. New CEO decided that Engie will stop Doel-4 and Tihange-3 extension plans and preparation and will close the plants in 2025.

The strategy of Engie group has been impacted by Covid (loss of revenues due to demand restrictions and energy prices decrease) and its position toward nuclear seems to be explained by alternative to develop other technologies (renewables and hydrogen) and infrastructures investments has the new future of the company.

COVID-19 impact

The 2020 Engie financial report shows decreases in the group turnover, EBITDA and net profit, compared to the previous year.

Billion €	2019	2020
Turnover	60.1	55.8
EBITDA	10.4	9.3
Net Profit	1.0	-1.5

Electrabel is a part of Engie-group, and its financial results are not appearing per se.

Engie decided the impairment of its nuclear assets (2.9 Bn€), accounted as non-recurring), and 1.3 Bn€ in nuclear funding, because of a shorter lifetime assumption for Belgian nuclear reactors and changes in the commodity price scenario for nuclear assets.

The direct COVID impact is estimated at 60 M€, for adjusted maintenance operations.

3.4.3. Vattenfall: Managing the assets, no new reactors are planned

Nuclear power history

In the late 1950s, Vattenfall faced increased electricity consumption and fewer expandable hydropower resources.

In 1968, Vattenfall ordered Ringhals-1, a 750 MWe BWR from ASEA, and Ringhals-2, an 800 MWe PWR from Westinghouse, to compare the technologies. Two further Westinghouse PWRs were built at Ringhals, becoming operational in 1981 and 1983.

In 1969, OKG ordered Oskarshamn-2 and Sydkraft ordered Barsebäck-1 with an option for unit 2, all from ASEA Atom. In the 1970s Vattenfall cooperated with other utilities to build the Forsmark nuclear plant. Six reactors entered commercial service in the 1970s and six in the 1980s. The 12 reactors were at four sites around the southern and eastern coast. Barsebäck-1 closed in 1999 and unit-2 in May 2005.

Reactors operating in Sweden

Reactor Name	Model	Reactor Type	Reference Unit Power (MWe)	Construction Start	First Grid Connection
Forsmark 1	ABB-III, BWR-2500	BWR	990	1973-06	1980-06
Forsmark 2	ABB-III, BWR-2500	BWR	1118	1975-01	1981-01
Forsmark 3	ABB-III, BWR-3000	BWR	1172	1979-01	1985-03
Oskarshamn 3	ABB-III, BWR-3000	BWR	1400	1980-05	1985-03
Ringhals 3	W (3-loops)	PWR	1072	1972-09	1980-09
Ringhals 4	W (3-loops)	PWR	1130	1973-11	1982-06

Table 11: Reactors operating in Sweden – Source World Nuclear Association

Current situation

Vattenfall is a major owner of nuclear power with experience of nuclear operations, decommissioning and management of radioactive waste and spent nuclear fuel. Vattenfall owns ten nuclear reactors, five of which are in commercial operation. Seven reactors are in Sweden (four at Ringhals, three at Forsmark), and three in Germany (Brunsbüttel, Krümmel and a minority stake in Brokdorf).

In Germany

As German government has made the decision to phase out nuclear power, Vattenfall's nuclear assets in Germany will be wound down in accordance with this decision[96].

In Sweden

Eight power reactors – Ågesta, Marviken, Barsebäck 1&2, Oskarshamn-1&2 and Ringhals-1&2 have been permanently shut down and at various stages of decommissioning. In 2015, Vattenfall decided to close the two oldest reactors at the nuclear power plant Ringhals. Ringhals-2 was decommissioned according to plans at the end of 2019 and Ringhals-1 at the end of 2020.

Reactor	Type	Net capacity MWe	Commercial operation
Ågesta	Prot HWR	10	1964 - 1974
Barsebäck 1	BWR	600	1975 - 1999
Barsebäck 2	BWR	600	1977 - 2005
Oskarshamn 2	BWR	638	1974 - 2013
Oskarshamn 1	BWR	473	1972 - 2017
Ringhals 2	PWR	852	1974 - 2019
Ringhals 1	BWR	881	1976 - 2020

Table 12: Reactors at decommissioning stage – Source WNA

Over a period of ten years, Vattenfall has invested in modernisation programmes so that Ringhals 3 and 4 and Forsmark 1, 2 and 3 are well prepared to operate for decades ahead.

New nuclear reactors are not planned to be built in the coming year by Vattenfall.

COVID-19 impact

The 2020 Vattenfall financial report shows decreases in the group turnover, EBITDA and net profit, compared to the previous year.

Billion €	2019	2020
Turnover	16.6	15.8
EBITDA	4.2	4.6
Net Profit	1.4	0.8

"Vattenfall's generation volume in 2020 was considerably lower compared with the preceding year. This is due above all to the situation for Swedish nuclear power,

[96] The German Constitutional Court has confirmed that Vattenfall, according to the understanding, would receive a compensation of EUR 1,425 million. https://group.vattenfall.com/press-and-media/pressreleases/2021/understanding-to-terminate-disputes-on-german-nuclear-phase-out

where we are phasing out older reactors, performed more maintenance and periodically cut back on production when prices were at their lowest."

The Vattenfall-group nuclear generation, in 2020, was reduced of 14.0 TWh (at 39.3 TWh). On average, the sales price in Nordic countries was similar to the previous year, at 31 €/MWh, against 32 in 2019.

3.4.4. CEZ Group – keeping current fleet and building new ones

Nuclear power history

In 1978, construction commenced on the Dukovany plant – the first nuclear plant in what is now the Czech Republic. The four VVER-440 model V-213 reactors were designed by Russian organizations and Energoprojekt and built by Skoda Praha. These entered commercial operation in 1985-87 and have been upgraded since.

In 1982, work started on the Temelin plant, designed by Russian organizations and Energoprojekt and built by VSBc with engineering by Skoda Praha. Planned as a four-unit VVER-1000 model V-320 plant, full construction on units 1&2 commenced in 1987. However, following the Velvet Revolution of 1989, the new democratic government decided in 1990 to suspend construction on units 3&4. Then, with the splitting of Czechoslovakia, the new government of the Czech Republic formally decided in March 1993 to complete units 1&2.

The reactors started up in 2000 and 2003, with the upgrading having been financed by operator CEZ with a loan from the World Bank. Commercial operation was in June 2002 and April 2003, respectively.

Reactor Name	Model	Reactor Type	Reference Unit Power (MWe)	Construction Start	First Grid Connection
Dukovany 1	VVER V-213	PWR	468	1979-01	1985-02
Dukovany 2	VVER V-213	PWR	471	1979-01	1986-01
Dukovany 3	VVER V-213	PWR	468	1979-03	1986-11
Dukovany 4	VVER V-213	PWR	471	1979-03	1987-06
Temelin 1	VVER V-320	PWR	1027	1987-02	2000-12
Temelin 2	VVER V-320	PWR	1029	1987-02	2002-12

Table 13: Czech Republic NPPs in operation – Source: WNA

Current situation

In June 2020 CEZ stated that it expects to invest about $2.3 billion over the next 27 years to extend the operating lifetime of the four reactors at Dukovany by a further 20 years to a total of 60.

Earlier in March 2020 CEZ announced that it had submitted a license application for two new PWRs up to 1200 MWe each at Dukovany. In June 2021 it applied for a zoning permit for up to two new units. In July 2020 the Czech cabinet approved a proposed new law which would allow the government and CEZ to agree a minimum 30-year power purchase agreement (PPA) for Dukovany 5[97]. Negotiations of the state with the European Commission have started within the prenotification process on the compatibility of the public support proposal with the rules of the European Union's internal market, a mechanism has been prepared to support the construction of low-carbon facilities in Czechia by the state, and a proposal to finance new nuclear facilities in Czechia has been discussed to avoid artificial increase of electricity prices.

Reactor	Model	MWe	Construction start	First power
Dukovany 5	?	1200 assumed	2029	by 2036
Total planned (1)		1200 approx		
Temelin 3&4	MIR-1200 or AP1000	1200 approx each		by 2040
Dukovany 6	?	1200 assumed		

Table 14: Planned and proposed Czech power reactors

COVID-19 impact

The 2020 CEZ financial report shows increases in the group turnover and EBITDA, and decrease in net profit, compared to the previous year.

Billion €	2019	2020
Turnover	8.0	8.3
EBITDA	2.3	2.5
Net Profit	0.6	0.2

The nuclear generation in Czechia remained stable between 2019 and 2020, at 28.4 TWh, with maintenance and refueling outages on schedule.

Wholesale prices of electricity in the Central Europe market are mostly driven by hard coal and gas generation that fuel costs and emissions allowances were pushing up.

[97] The price should allow CEZ to recoup the investment cost and make a profit. The state would sell the electricity into the wholesale market. Electricity consumers would be faced with surcharges on their bills to make up for losses if wholesale power prices are lower than the guaranteed price or benefit from lower electricity bills if the prices are higher, as with the UK contract for difference system. There would be a cap on the possible surcharge.

3.5. The COVID-19 economic impact on the radionuclide production sector

As described previously, the radionuclide production remained largely unaffected in Europe by the pandemic, thanks to the large European network of production means, with limited reliance on international supply. Consequently, the COVID-19 only had a limited economic impact on the European industry.

The main players in Europe can be divided in two categories: the commercial players and the public-funded stakeholders, that were differently impacted during the pandemic.

- As the radionuclide production is partially relying on research installations (research reactors, cyclotrons in universities or research installations, etc.), the financing of such installations is mainly coming from national and international research funding which remained unimpacted by the pandemic (SCK.CEN, Nuclear Research Institute REZ Plc, National Centre for Nuclear Research, etc.).
- Industrial stakeholders involved in the radionuclide sector are of all size, from small and medium-sized enterprises to large international groups (Curium, AAA/Novartis, etc.). Not all these players publish detailed yearly reports make it difficult to specifically conclude on the pandemic impact on their activity.

  When figures are available for private players involved in this field, as the nuclear medicine remains a relatively small market within the health sector, the specific figures of radionuclide/radiopharmaceuticals business lines cannot be extracted and do not allow to conclude on the specific impact of COVID-19.

  Examples of Belgian companies are taken below to highlight such issue.

Turnover	2020	2019
IRE-ELIT[98]	11.34 M€	8.14 M€
Isotope service international	6.63 M€	6.15 M€
Transrad	0.49 M€	0.91 M€

  - IRE-ELIT (radiopharmaceutical manufacturing) experienced an important rise of its turnover in 2020, despite COVID-19 pandemic.
  - Isotope service international (international delivery of radiopharmaceuticals products) experienced a small turnover increase in 2020, while Transrad, (transport company specialized in medical applications but also fuel cycle and radioactive wastes) experienced a sharp decrease of its turnover in 2020.

[98] https://www.companyweb.be/societe/ire-elit/sa/826980032

Regarding new investments and due diligence activities. The nuclear medicine sector was partially impacted by the pandemic. The CURIUM pharma buyout initiated in late 2019 has been interrupted by the pandemic, while new build irradiation projects have been progressing over the period (PALLAS, SHINE, etc.).

Finding #21: considering the importance of nuclear medicine in diagnostic and therapeutic applications, the activity has been maintained during the pandemic, and only reduced in periods where healthcare was overloaded by COVID-19 patient. This allowed the industry to maintain its activity, explaining the limited impact experienced by radionuclide manufacturer stakeholders.

4. Recommendations towards a better resilience of the nuclear industry

4.1. The concept of resilience

Since the 1st quarter of 2020, the COVID-19 pandemic has had a substantial impact on the functioning of our societies and economies. Like any other sector, the nuclear industry had first to adapt to these sudden new constraints and then implement strategies to cope with long-term pandemic consequences.

In essence, the nuclear industry must cope with fundamental constraints: always ensuring nuclear safety for its workers and the general public, along with guarantying electricity generation (or radionuclide production) and being an essential service provider. These constraints directly and indirectly contribute to develop the resilience of the industry towards external threats, including pandemic risks.

All organisations, of any size or type, face a wide range of risks that could cause short to long-term harm to their activity. Resilience is a wide term which encompasses crisis management, business continuity, and responds to all types of risk an organisation may face, as well as addressing the consequences of a major incident, adapting itself to a new environment and circumstances following that incident (as described in figure below).

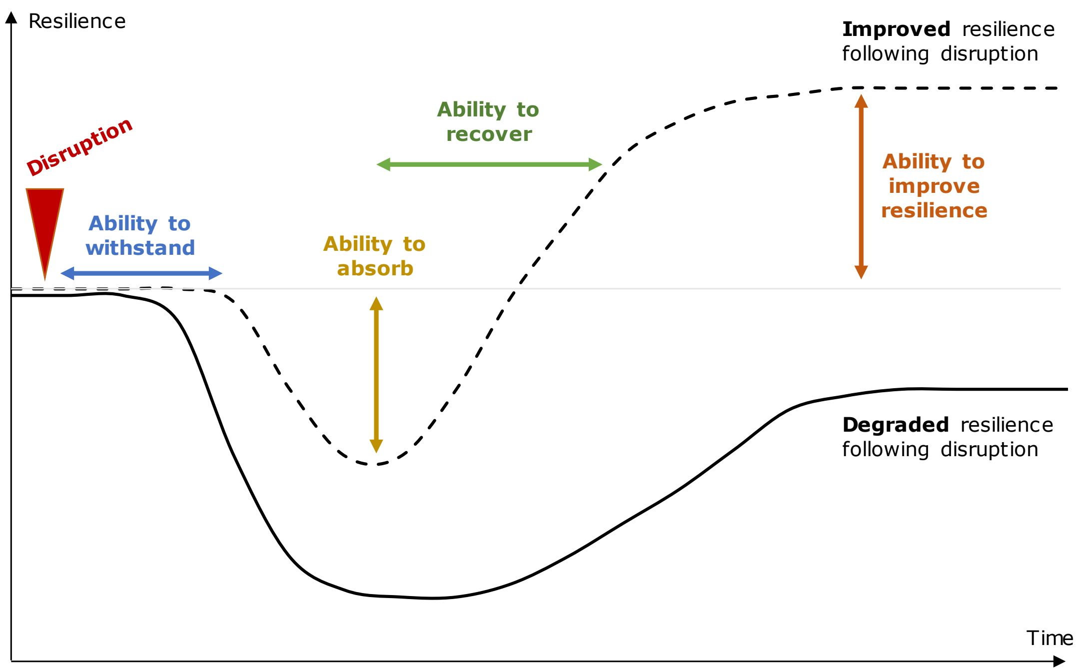


Figure 50: Concept of resilience, from disruption to recovery

Thus, the nuclear sector resilience is the combination of preparatory and mitigation actions taken at different stages following a disruption, that directly impact a stakeholder's ability to withstand, absorb and recover from disruption, along with its capacity to improve its overall resilience.

4.2. Lessons learned on nuclear sector resilience during COVID-19

During the last two years, for most nuclear countries, nuclear installations remained operational without any COVID-19 specific safety concerns, contributing to satisfy electricity and radionuclide demand. At the same time their supply chains and service providers remained mobilised and contributed to support their safe and continuous operation.

The human element remains one of the most challenging parameters for the resilience. Individuals must be trained and managed efficiently against external disruptions to ensure coordinated and efficient responses. The overall workforce availability was never at risk due to the virus itself. The health protection measures taken by the nuclear industry effectively prevented the COVID-19 spreading on working places. In such uncertain times, the real challenge for the industry was to secure workers' confidence in their work environment.

As detailed in Chapters 1 & 2, the nuclear industry has been able to withstand the early pandemic phase, and then absorb the disruptions through the successful modification of operational best practices to cope with a long-term pandemic. At the time of writing, the recovery phase only started for a few Member States and it's still too soon to conclude on the nuclear industry ability to fully recover from the pandemic (e.g., impact on maintenance activities in the next few years, as some minor maintenance works were delayed).

Yet, even if at first sight the nuclear industry demonstrated its resilience and capacity to cope with the COVID-19 pandemic, areas for improvements were identified throughout this study that could contribute to improve the future resilience of the industry against external threats.

These recommendations both come from different lessons learned and good practices identified during the pandemic that could be generalised to the whole nuclear industry.

#1 Nuclear Power Plants and their associated utilities are systematically identified and considered as essential services providers in Europe (Directive 2008/114/EC). Thus, Member States are closely monitoring the status of these services in the frame of large disruptions events, granting in some cases exceptions to restrictions taken for the public. Yet, the service suppliers and key equipment and material suppliers are not formally identified as essential service suppliers. A better mapping of key suppliers to essential services providers could be beneficial to Member States to improve the coordination with public bodies in the case of emergency situations.

(See §2.2.1 for more details)

#2 The availability of Business Continuity Plans (BCP) to face more efficiently external threats is considered being a key success factor in securing business resilience. Considering that external service suppliers or key supply chain players are essential in the safe operation of nuclear installations, it is recommended to evaluate the interest of fostering the use of BCP or equivalent, for utilities' and safety authorities' key suppliers.

Business continuity plan systems appear country or industrial player-dependent, with close connection with emergency preparedness and response considerations, culture, and spirit. A specific analysis of business continuity plans across the nuclear industry would allow to conclude on the need to improve uniformity and business continuity plan requirements across Europe.

(See §2.2.2 for more details)

#3 International and European collaboration allowed to share a large quantity of technical information to support utilities and regulators in managing COVID-19 pandemic. Coordination between the industry and international and European organisations is crucial during crisis to ensure the efficient transmission of information. It is recommended to assess the feasibility of setting a dedicated exchange forum for external disruptions, that would gather European nuclear industrial players, to improve the efficiency of information exchanges across Europe.

(See §2.3.1 for more details)

#4 The COVID-19 pandemic forced the nuclear industry to adapt its day-to-day operational practices, with an increased use of teleworking and electronic exchanges among stakeholders. This led to the development of innovative approaches in several fields such as training, safety control & inspections, etc. The coordinated development of such good practices across the European nuclear industry could be beneficial to all stakeholders, thus it is recommended to launch, in relation with European international professional organisation, a strategic action plan to support the industry in setting new standards of operation.

(See §2.3.3 for more details)

#5 Whereas operational safety was deemed unimpacted by Safety Authorities and Utilities during COVID-19 pandemic, the Emergency Preparedness and Response (EP&R) was considered negatively impacted by a few of the safety authorities surveyed (cancelling of emergency exercises, limited practicality of Emergency Preparedness procedures under pandemic constraints, etc.). Only the operational resilience has been evaluated in this study, thus, it is recommended to specifically evaluate to what extent EP&R procedures are applicable in the frame of external disturbances, to conclude on the resilience of the nuclear sector in emergency situations.

(See §2.3.5 for more details)

#6 Centralised production of radionuclides generally necessitates complex intra-European and international logistics, with radioactive materials being shipped between irradiation, processing, and manufacturing facilities across Europe. The lack of standardised transportation regulation among EU Member States had historically complicated the administrative logistics management (e.g., different standards, forms and authorisations are needed for each Member States). Such an absence was already an issue before COVID-19 but became aggravated during the pandemic, due to additional constraints taken by Member States. Working towards a more harmonised approach for radioactive material could be beneficial to the radionuclide industry, easing transborder logistics administrative procedures.

(See §1.5 for more details)

#7 As the pandemic is still underway at the time of writing, it is recommended to implement an overall evaluation of the definitive ability to the nuclear industry to recover from the COVID-19 pandemic. At this stage, it is expected that no specific concern shall be expected, but such a finding shall be reassessed in a few years.

(See §2.4 for more details)

#8 The pandemic led the industry to adapt to COVID-19 specificities, to consider new sanitary standards by modifying (sometimes in-depth) the standard good practices. While entering the 3rd year of the pandemic in Europe in early 2022, it seems that these adaptations had no negative impact to date, but the question remains on their long-term impacts. Measures taken in 2020/2021 that have proven to be efficient at that time could lead to deficiencies later (delayed maintenance, remote inspection or more weight on the use of informed risk from regulators, etc.). Thus, it is suggested to continue monitoring these potential long-term effects.

(See §2.4 for more details)

#9 The COVID-19 pandemic had undeniable short/medium term impacts on our European economies, nuclear industry being directly touched by the general decrease of electricity demand during the period. Yet, through all the measures taken at Member States level to support the economy, a long-term fall of electricity demand that would have negatively impacted European utilities was prevented. Utilities have seen their financial health weakened during the last decade, while having at the same time to prepare and take an active part in the energy transition, through large investments to secure future European electricity supply. Member States shall then ensure that the future needed investments, both inside and outside nuclear sector, will be deemed possible by their utilities.

(See §3.2 for more details)

4.3. How to improve resilience for the future?

The COVID-19 disease is still spreading, but after the first shock, last year, the situation has stabilized with new working processes, which have not been disturbed by the successive waves. The different variants were more and more contagious, but new tools, as vaccines, helped to keep the epidemy under control. Only a drastic mutation of the virus, more invaliding or lethal, may change the pattern we have seen during the last one and half year.

The pandemic is global and heavily impacted societies, economies, and infrastructures. Among infrastructures, the European nuclear sector held and was able to continue producing electricity and medical isotopes. Basically, nuclear industry personnel are continuously trained to face crisis, and organizations were ready to implement stringent rules, as they have been decided by governments.

Nevertheless, several weaknesses have shown up, mostly due to generic factors, as:

- The age structure of the European nuclear fleet is unbalanced, with most of them being older than 30 years. Consequently, significant revamping operations were on-going on sites, and works have been significantly disturbed by social distancing rules. In addition, several reactors saw simultaneously ageing defects and were shut down for repairs.
- The heterogeneity of rules for transportation of nuclear materials makes always complex the process of distribution of medical isotopes. During the first wave of the pandemic, the organization of shipments was aggravated.

Aside, the first wave of the virus induced severe disturbances in reload, maintenance and repair operations, disturbances from which the recovery is not yet fully complete and may still raise some constraints during the coming winter (2022).

Among recommendations presented in the previous chapter, many of them propose to strengthen the share of individual returns of experience among the various European stakeholders, in a coordinated way, and with a close follow-up.

Different European and International organization already contributed to shape initiatives aiming at gathering and/or facilitating information exchanges inside the industry, either through the organisation of webinars, setting up communication channels or through the production of reports.

A few examples are given below (description coming from organizations webpages provided in footnotes):

- The IAEA COVID-19 NPP OPEX Network "provides a limited access platform for peer-to-peer sharing of COVID-19 related mitigating measures and impact on nuclear power plant performance: operation, maintenance as well as the implementation of refuelling and maintenance outages. Intended users include plant operators and related organizations".

- WANO (World Association of Nuclear Operators) "facilitated the exchange of information from member plants and facilities worldwide. WANO members were actively sharing their COVID-19 plans and were encouraged to work with their WANO regional centre to share information and good practises with their global peers throughout this pandemic".

- The NEA "is examining the regulatory and operational impacts of the COVID-19 crisis and working closely with its members to enable exchanges of policy approaches and best practices around the world. As part of these efforts, the NEA has launched a set of policy briefs and is hosting a series of discussions that explore the role that nuclear energy can play in the post-COVID-19 recovery, whilst also supporting the path towards a truly sustainable and environmentally responsible energy future". Different activities are already foreseen for the next years (Workshop in June 2022 on regulatory approaches to managing inspection programmes during pandemic, Workshop in report over period 2022-2024 on the nuclear sector response to COVID-19 from an organizational and human perspective – how to manage the unexpected?).

Such types of actions are expected to continue in the future and will be of great interest to continue capitalizing all the lessons learned and good practices under COVID-19 pandemic.

Each major pandemic having its own characteristics (lethality, transmission pattern, etc.), the relatively good resilience of the nuclear sector to COVID-19 pandemic does not allow to conclude on its capacity to overcome new or different sorts of pandemics. The workforce availability, which was never at risk during COVID-19 pandemic within the nuclear industry, could become a challenging issue under different circumstances (more common long-lasting health impacts following contamination, high lethality, etc.). Nevertheless, in a certain way, the present pandemic may be considered as an effective "crisis exercise" for a more invalidating or lethal pandemic. The Business Continuity Plans of the various stakeholders will be adjusted accordingly.

But the resilience of a system relies on several types of assets: physical, human, financial and political. On physical and human assets, nuclear industry has a strong leverage; based on the numerous lessons learned, the industry will strengthen its overall resilience (from utilities to regulators) and improve its capacity to overcome future pandemics.

On financial assets, its leverage is more limited and on political assets non-existent. The European utilities have seen their financial capacity degrading during the last decade, reducing their capacity to invest or to face unexpected crisis. If there is continuation of this trend, it is not obvious that they will be able to face a large new pandemic the same way they did at the present time. And specifically, for nuclear utilities, the political decision on the European taxonomy will shape their future, opening room or not toward new build, and consequently development of their human resources and competencies and resilience.

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