FORATOM
THE VOICE OF THE EUROPEAN NUCLEAR INDUSTRY

IMPORTANCE OF LONG-TERM OPERATION OF THE EXISTING EU NUCLEAR FLEET

HELPING TO ACHIEVE EUROPE'S CLIMATE GOALS AT AN AFFORDABLE COST

NUCLEAR

- Is a low-carbon energy source
- Ensures security of supply
- Is environmentally, economically and socially sustainable

NUCLEAR INDUSTRY IN NUMBERS

- Accounts for **25%** of electricity in the EU
- Almost **50%** of low-carbon electricity
- Supports around **1.1Mn** jobs
- Turnover of **102bn** per year

December 2021
Update

EXECUTIVE SUMMARY

An increasing number of experts recognise that decarbonising the power sector cannot be achieved with renewables alone - nuclear must play a role if the world is to reach its carbon neutrality goal by 2050. This paper aims to outline the opportunities provided by the long-term operation (LTO) of the existing fleet of nuclear reactors. Furthermore, it gives an overview of some of the challenges which will need to be tackled and provides a series of EU policy recommendations.

In a nutshell:

- The revised intermediate decarbonisation targets in the transition towards a 2050 carbon neutral economy are more ambitious than before and cannot be achieved without the LTO of existing nuclear power plants (NPPs).
- The costs of electricity produced by nuclear power plants performing LTO are unarguably lower than the cost of electricity coming from the other sources (RES, gas, etc.). This is because LTO of the existing nuclear fleet has clear economic advantages: it requires a much lower capital investment cost, it is a mature solution which leads to low investment risks for investors and capital markets, and it triggers lower and more stable customer costs.
- From a technical point of view, the LTO of nuclear reactors provides a great advantage thanks to the "… timely implementation of reasonably practicable safety improvements to existing nuclear installations" which brings older generation reactors to a level of safety which complies with the amended Nuclear Safety Directive.
- Nuclear operations can improve during LTO. This can be explained by
    I. plant enhancements implemented by operators during LTO refurbishments
    II. growing operational capabilities
    III. governing frameworks that enable best practice sharing and
    IV. maintaining workforce skills across the nuclear value chain / ecosystem.
- LTO will reduce the EU's energy import dependency – mainly fossil fuels – and will also provide reliability and security to the grid and contain electricity prices.
- Low-carbon nuclear generation provides firm capacity to the electricity system and supports the integration of higher shares of variable renewables (VRE) at a lower cost.

CONTEXT

The aim of this position paper is to provide more information about the long-term operation (LTO) of the existing fleet of nuclear reactors and its benefits. This information is provided within the context of the EU's very ambitious target of reducing greenhouse gas emissions by 55% in 2030 and to achieving the EU's carbon neutrality goal by 2050. At the same time, a cost-effective and secure energy transition is essential.

The current document is an update of the position paper published in July 2019, and takes into account the following:

- More ambitious 2030 targets resulting in the increased importance of keeping the existing nuclear fleet running;
- Potential security of electricity supply issues identified in some countries which are pursuing a massive renewable deployment path;
- New information regarding the Levelized Costs of Electricity (LCOE) of nuclear LTO;
- The updated version of the "Pathways to 2050: role of nuclear in a low-carbon Europe" report by Compass Lexecon;
- Brexit and thus consideration of only the EU27 in all policymaker modelling;
- Updates of the Espoo and Aarhus convention requirements relevant to nuclear LTO.

a. More ambitious EU decarbonisation targets for 2030

The strategy, entitled "Stepping up Europe's 2030 climate ambition" , outlines the EU's strategic long-term vision for reaching a climate-neutral economy by 2050. This strategy also acknowledges that a current 40% reduction of GHG emissions target compared to 1990 is insufficient if climate neutrality is to be achieved by 2050 and therefore requires larger reductions after 2030.

One objective, which considers increasing the 2030 GHG emissions reduction target to 55% compared to 1990 levels, has already been adopted within the European Climate Law.

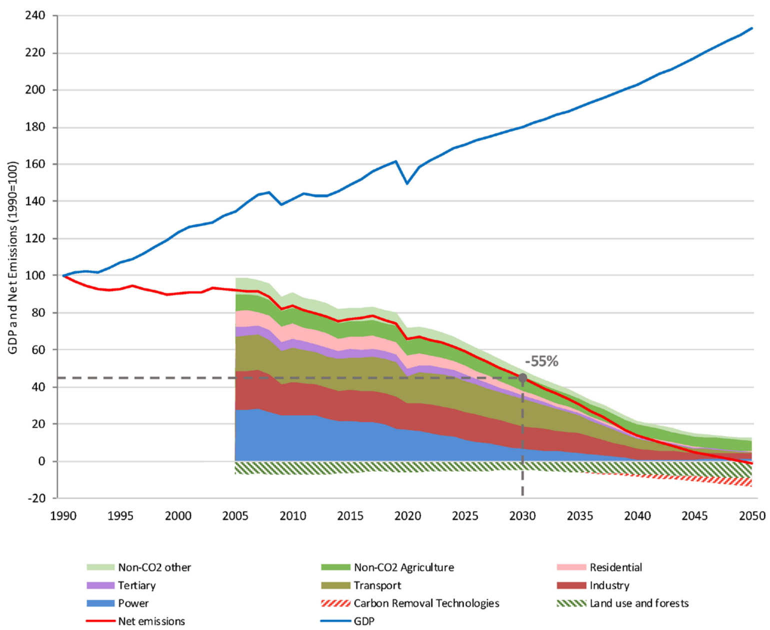

Fig. 1. The EU's pathway to sustained economic prosperity and climate neutrality, 1990-2050

[1] *FORATOM position paper on "The importance of long-term operation of the existing EU nuclear fleet", July 2019.*
[2] *Stepping up Europe's 2030 climate ambition.*
[3] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119*

As shown in Figure 1, there is a lot of pressure on the decarbonisation of the power sector, as it is one of the first to reach carbon neutrality by around 2040.

In order to deliver on the targets, the European Commission (EC) proposed a package[4] of policies which will enable a reduction of net greenhouse gas emissions of at least 55% by 2030.

According to the policy scenarios for delivering the European Green Deal[5], in 2030, the installed capacity of nuclear will decrease from the current 107 GW to around 93.9 GW under all proposed scenarios for 2030 and account for between 16.3% and 17.3% of electricity production depending on the scenario. By 2050, the installed capacity may further decrease to around 50 to 70 GW and will account for between 6.9% and 11.8% of electricity production depending on the scenario. It is important to mention that nuclear power generation currently accounts for around 25%[6]. The expected decrease, compared to 2020, is due to two reasons:

- Nuclear phaseout in some countries (e.g. Germany and Belgium)
- Increase in demand for electricity

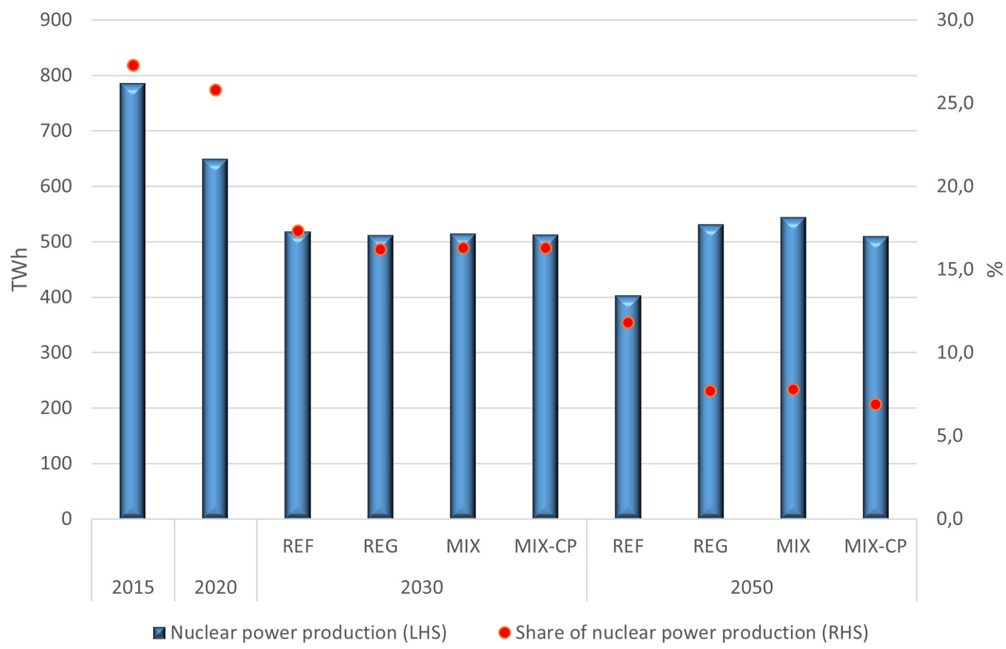

Fig. 2. Nuclear power production and its share in the EU electricity mix according to the reference scenario[7] and the scenarios proposed by the European Green Deal[8]

Regarding the EC's latest scenarios and its predictions for nuclear power, it should be kept in mind that the EU Reference Scenario 2020 is not a forecast but rather a projection built on EU and Member State policies (National Energy and Climate Plans – NECPs). It assumes that national contributions towards the current EU 2030 energy targets on energy efficiency and renewable (respectively 32.5% and 32%) will be achieved and allows policymakers to analyse the long-term economic, energy, climate and transport outlook based on the policy framework in place in 2020.

FORATOM takeaway: most new nuclear build projects are missing from the NECPs that focus on 2030. As a result, they are not considered under the 2050 perspective either. The next revision of NECPs should take into account recent announcements relating to developments in the sector.

[4] *Fit for 55 package.*
[5] *https://ec.europa.eu/energy/data-analysis/energy-modelling/policy-scenarios-delivering-european-green-deal_en.*
[6] *FORATOM calculations using EMBER data.*
[7] *EU Reference Scenario 2020.*
[8] *Policy scenarios for delivering the European Green Deal.*

b. Developments at the international level

The latest Intergovernmental Panel on Climate Change (IPCC) report[9] stresses that our window of action to reach 1.5 C target is rapidly closing. **It also shows the impact of cumulative emissions, which means that every tonne of CO2 emitted adds to global warming.** This strong statement about the carbon budget increase should be a serious warning for the countries that are considering replacing nuclear with fossil fuels during the transition towards 2050.

The IEA has also made several statements lately which emphasize the potential role of the nuclear sector in general as well as LTO in particular. During the 2019 edition of the European Nuclear Energy Forum (ENEF), Dr. Birol indicated that without any policy changes three-quarters of Europe's nuclear fleet would be decommissioned by 2040. In addition, he claimed that whilst an increase in renewables and a phasing out of coal could reduce emissions by 40%, maintaining nuclear could accelerate CO2 emission reductions.

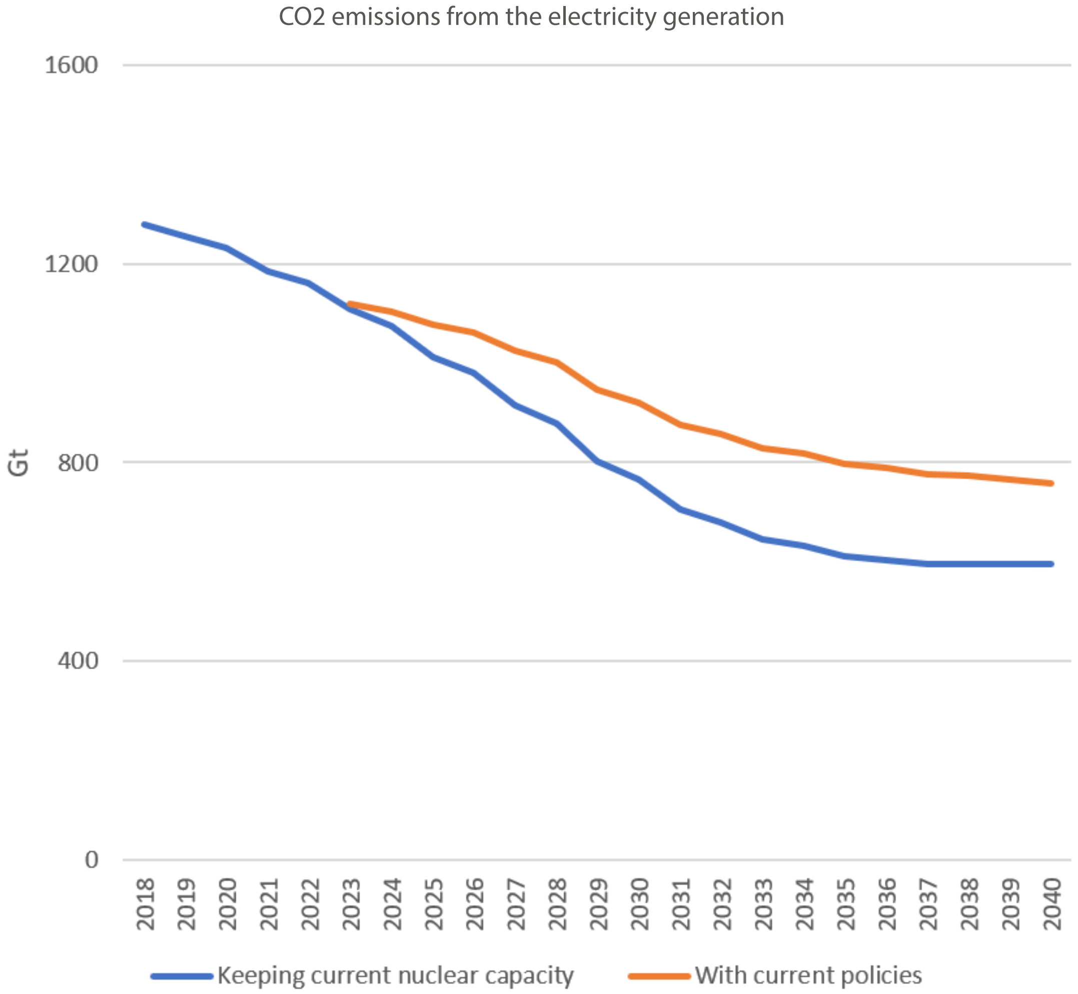

Fig. 3. IEA forecast for the 2040 emission reductions in Europe – presentation delivered by Dr. Birol at ENEF 2019 plenary meeting in Prague

[9] *Climate Change 2021 The Physical Science Basis, IPCC 2021.*

According to its report launched in May 2019 on Nuclear Power in a Clean Energy System report[10] , the IEA has gone even further by stating that a "steep decline in nuclear power would threaten energy security and climate goals" and "lifetime extensions (of existing nuclear reactors) are crucial to getting the energy transition back on track". These conclusions are also reflected in the IEA policy review of the European Union released in 2020[11].

Mr. Birol's statements have been further strengthen by the conclusions of the joint IEA and OECD-NEA report on "Projected Costs of Generating Electricity 2020" that "also finds that prolonging the operation of existing nuclear power plants, known as long term operation (LTO), is the most cost effective source of low carbon electricity." [12]

According to a recent report from the OECD-NEA[13] , long-term operation is one of the safest and most mature solutions available to support ambitious decarbonisation strategies. LTO is key to securing climate targets by 2030. High LTO scenarios could also help bridge the gap toward carbon neutrality by 2050, representing nearly 40% of the total emissions avoided by nuclear.

The role of LTO is not limited to emission avoidance and it could make important contributions in terms of security of electricity supply and its affordability. Key enabling conditions include long-term industrial policies and market regulations that adequately reflect the climate and security of supply benefits of nuclear power plants.

The overall message of all these organisations is that decarbonising the power sector cannot be achieved with renewables alone. Nuclear is the only significant, scalable, low-carbon partner in a future energy mix which is capable of achieving the EU's decarbonisation targets together with renewable energy sources (RES).

FORATOM believes that whilst the European Commission has launched several initiatives to achieve its long-term decarbonisation targets, not enough efforts are being made to ensure proper prolongation of the existing nuclear fleet's lifespan. As a result, in light of the above, the EU may fail to deliver on its decarbonisation objectives, despite huge investments in renewables and energy efficiency.

c. EU legislative and regulatory aspects impacting nuclear LTO

Recently, the Commission has proposed several legislative files which may impact LTO decisions.

- European Green Deal / Fit For 55 package

According to the Commission's work programme for 2021, the revisions and initiatives linked to the European Green Deal climate actions, and in particular the climate target plan's 55% net reduction target, are presented under the Fit for 55 package.

Given the EU Climate Law sets the objective of a climate-neutral EU by 2050, and a collective, net greenhouse gas emissions reduction target (emissions after deduction of removals) of at least 55% by 2030 compared to 1990 initiatives, the EC is showing that it is committed to reaching the targets by drafting legislative proposals as part of the "Fit for 55 package". FORATOM believes that the following legislative proposals might have an impact on the nuclear sector:

- Revision of the EU Emissions Trading System (ETS), including maritime, aviation and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) as well as a proposal for ETS as an own resource
- Carbon Border Adjustment Mechanism (CBAM) and a proposal for CBAM as an own resource
- Revision of the Energy Taxation Directive
- Revision of the Renewable Energy and Energy Efficiency Directives in order to implement the new 2030 climate target ambition and in particular the way low-carbon hydrogen is being considered in policies in general.

[10] *"Nuclear Power in a Clean Energy System" – IEA, May 2019.*
[11] *https://www.iea.org/reports/european-union-2020.*
[12] *Press release of the IEA and OECD-NEA report of the "Projected Costs of Generating Electricity 2020".*
[13] *https://www.oecd-nea.org/jcms/pl_60310/long-term-operation-of-nuclear-power-plants-and-decarbonisation-strategies.*

- Clean Energy Package (CEP)

Whilst the Clean Energy Package adopted in 2019 did have some impact, it failed to incentivise long-term investments in low-carbon technologies, as it picks winners (i.e. renewables or energy efficiency) and leads to an increase in energy market disruptions without addressing the core issue of decarbonising the sector. Its progress is presented in the annual State of Energy Union reports[14].

According to the annex of the last State of Energy Union report[15], renewables remain the most subsidized energy sector in 2019 as they are unable to survive on the market without interventions while for nuclear the figures are the lowest overall, even if the share of electricity production of the two sources is at a similar level (around 25%).

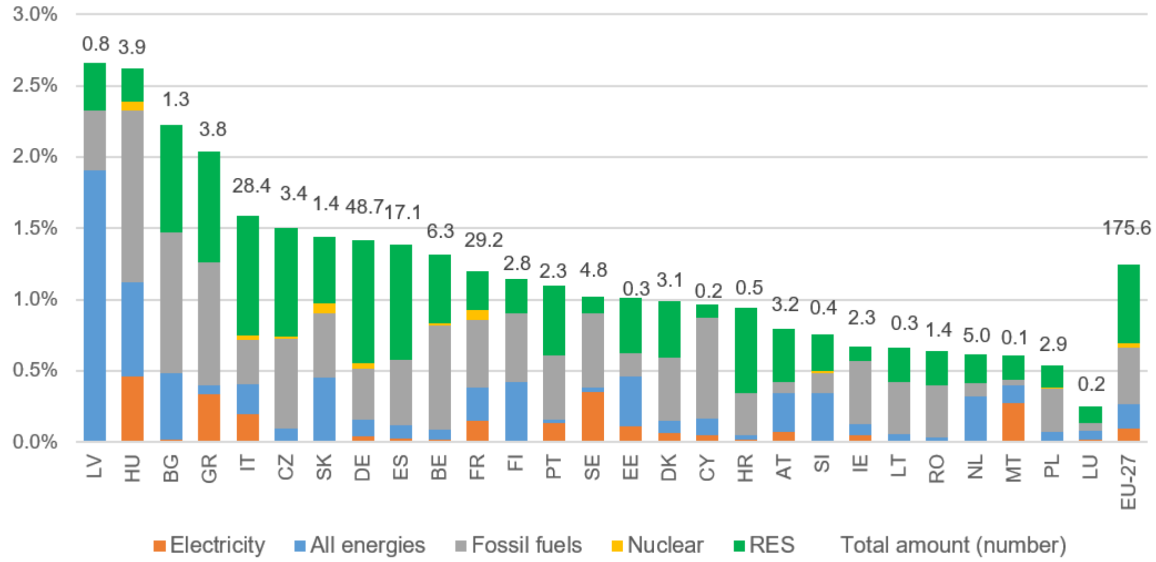

Fig. 4 Subsidies for different energy sources, as percent of GDP and in billion euros in 2019.

It should be mentioned that for nuclear in 2020, an additional €2.7 billion were disbursed as new instruments to compensate for the early closure and decommissioning of nuclear facilities in Germany and France. In the forthcoming years, compensation for the early closure of nuclear, coal and lignite-fired power generation facilities are expected to have an increasing impact on the total amount of energy subsidies in the EU. But this effect can be counteracted by avoiding the closure of the existing nuclear fleet and performing LTO.

The European Green Deal initiative does present a more pragmatic approach, foreseeing a 2050 power system which takes advantage of all potential sources of low-carbon energy, focusing primarily on the most mature technologies – renewables and nuclear power. But it still does not solve the market issues – in fact it deepens the structural problems which arise mainly from the revision of Renewable Energy and Energy Efficiency Directives by proposing even higher targets of 38%-40% and around 37% respectively.

- Energy prices and the toolbox for action and support

The EC released in October 2021 a communication[16] on "Tackling rising energy prices: a toolbox for action and support". Even if it's not a legislative proposal, the proposed measures might influence future decisions on the EU energy mix. In addition to some short-term measures meant to help vulnerable consumers deal with high energy prices, there are also some medium and long term measures proposed, most of which refer to renewables.

[14] *EC State of Energy Union reports*.
[15] *Annex to the State of the Energy Union Report on energy subsidies in the EU*
[16] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A660%3AFIN&qid=1634215984101*.

- Application of the Espoo and Aarhus conventions

Regarding the Espoo Convention, the guidance published in July 2021 following the work undertaken by the ad-hoc working group (established to assess applicability of the convention to lifetime extension [LTE], provides a set of indicators for NPP operators to determine whether or not the LTE to perform LTO of a given NPP falls under the applicability of the Espoo Convention.

Concerning the Aarhus convention, it establishes requirements for public access to environmental information held by the public authorities and the right to participate in environmental decision-making. Thus, when the operating conditions of a nuclear power plant are updated or reconsidered, provisions of the Aarhus convention are deemed applicable.

2. WHAT IS LTO?

The approaches to LTO (or "lifetime extension") differ from one country to another, and it can therefore have a different meaning. In general, most laws or regulations provide for indefinite operation terms, or allow for unlimited licence extensions. According to International Atomic Energy Agency (IAEA), LTO can be considered as an "operation beyond an established time frame set forth by, for example, licence term, design, standards, licence and/or regulation, which has been justified at one point of time, by technical assessment, with consideration given to life limiting processes and features for systems, structures and components".

3. BENEFITS OF LTO

Before starting to describe the benefits of the LTO of nuclear, it is worth mentioning that as of today, nuclear represent the highest single source of electricity in EU with a share of over 25% in the power mix (share of over 50% of low-carbon power sources).

3.1 A driver of decarbonisation

Key message: The intermediate decarbonisation targets in the transition towards 2050 carbon neutrality will be very challenging to achieve without the LTO of existing nuclear power plants (NPPs).

In order to achieve net zero emissions by 2050, the EU has set a 2030 decarbonisation target of at least a 55% cut in greenhouse gas emissions (from 1990 levels)[17] . This represents an increased ambition from the previous targets that aimed for a 40% reduction. The updated scenario requires the deep decarbonisation of the power sector with an expected reduction of CO2 emissions of over 70% by 2030 and reaching carbon neutrality by 2040. This will require a massive reduction in fossil fuel production (over 150% compared to 2015) with a significant impact on the availability of dispatchable sources but also a massive deployment of mature low-carbon solutions, including variable renewables.

a. Comparison of power sector emissions in the low and high nuclear scenarios

In a recently released[18] report by Compass Lexecon - an update of the 2018 report on "Pathways to 2050: Role of nuclear in a low carbon Europe - the findings regarding the impact of nuclear on the decarbonisation of the power system are clear.

[17] https://www.consilium.europa.eu/en/press/press-releases/2021/04/21/european-climate-law-council-and-parliament-reach-provisional-agreement/.
[18] Compass Lexecon report on "(2021 Updated Results) Pathways to 2050: Role of nuclear in a low-carbon Europe."

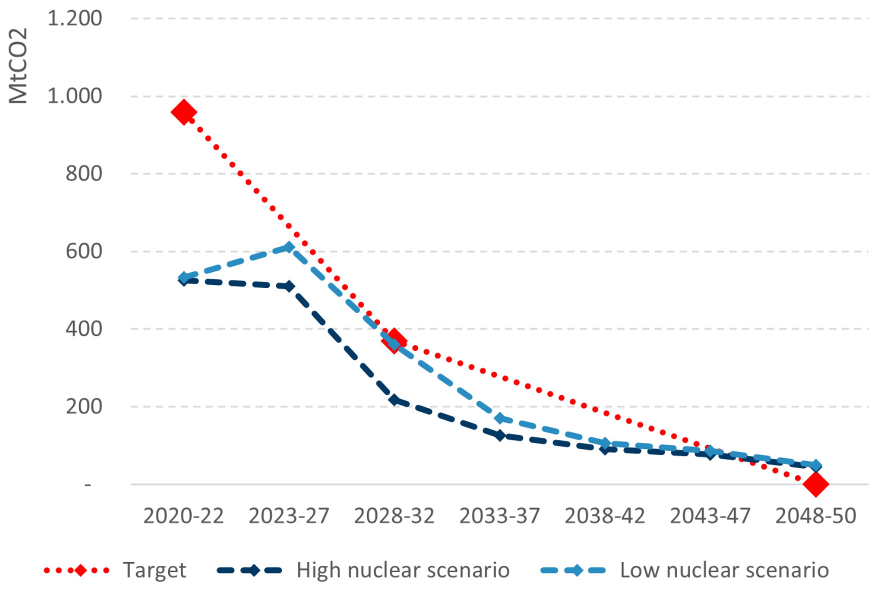

Fig. 5. CO2 emissions outlook for the power sector

While the modelling of the report shows that both scenarios reach the 2030 and 2050 targets, it should be noted that under the low nuclear scenario (which entails no new build and no LTO) there is an increase in emissions in the short-term (2023-2027). This would have an important impact on the overall carbon budget as every tonne of CO2 adds to global warming.

In addition, it should also be noted that for 2023-2032, the low nuclear scenario is very close to the EU's targeted trajectory. This means that there is a low margin of error; each measure that has been proposed to replace nuclear capacity – be it the implementation of renewables or gas projects – must succeed without failure or the EU's climate ambitions will not be met.

b. Nuclear contribution to the additional effort needed to achieve the 2030 climate targets (from -40% to -55% decrease of GHG emissions)

In an internal analysis (see in box 1 the assumption considered for the analysis) FORATOM found that 70% of the additional effort needed for the power sector to reach the new GHG emission targets for 2030 can be achieved using the existing nuclear fleet LTO.

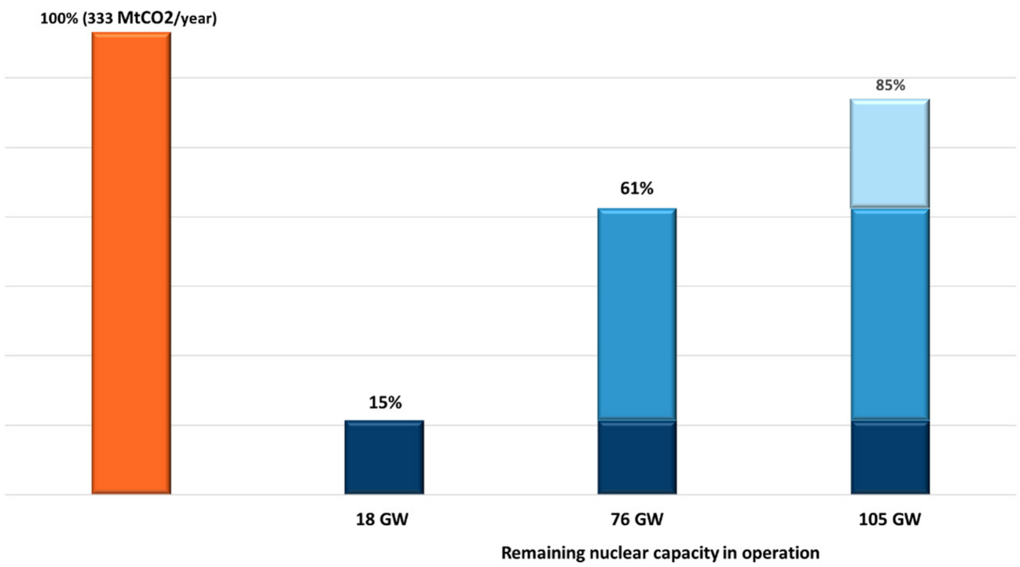

Fig. 6. Impact of the lifetime extension of the existing nuclear fleet on the new decarbonization targets

The low LTO scenario has the highest probability of occurring. For this reason, we will take the results that have been calculated from this scenario. These results suggest that if the entire nuclear fleet is kept in operation, then it can cover over 85% of the additional effort expected for the power sector (70% on top of the low LTO scenario considered as reference).

Box. 1 Assumptions made for figure 6:

a. For emissions targets

From 2005 to 2030 (-40% GHG target), the power sector (GHG 2005 - 1257 million tonnes) shall reduce its emission by 627 million tonnes, therefore the power sector emission would be 630 million tonnes. An average 50% reduction for the power sector.

From 2015 to 2030 (-55% GHG target), the power sector (GHG 2015 – 987 million tonnes) shall reduce its emissions by 697 million tonnes, therefore power sector emissions will be 297 million tonnes. An average 70% reduction for the power sector.

The difference between the two objectives for the power sector is **333 million tonnes.**

b. For technology emissions

The calculation used to identify differences in emission considers life cycle emissions of 12 gCO2/kWh for nuclear and 400 gCO2/kWh for technologies replacing nuclear (mainly gas).

c. Remaining nuclear capacity by 2030

- low assumptions – only 18 GW of nuclear capacity remaining in operation
- medium assumptions – 76 GW of reactors will be in operation
- high assumptions – all the current nuclear capacity (105 GW) will remain in operation

Note: No nuclear new build after 2020 is taken into account for the current calculations.

c. EU's low-carbon power generation forecast

Nuclear power is currently the largest single source of electricity in the EU[19]. Even if power demand increases, nuclear will remain an important component of the system because it is the largest low-carbon, non-weather-dependent source of electricity. Excluding LTO from the portfolio of available low-carbon solutions as shown in figure 6, will lead to an increase in GHG emissions in the short and medium term due to an increased reliance on fossil fuel generation. This will also create a lock-in effect in relation to new fossil fuel production facilities; once built they cannot be phased out after just few years due to financial interests. It will be virtually impossible to achieve the 2030 decarbonisation objectives without LTO given that, even in the case of stagnant electricity demand, the overall share of low-carbon sources will actually decrease if nuclear is removed from the portfolio.

In fact, if the EU were to invest in maintaining a fully operational nuclear fleet over this period, then up to 65% of its electricity would come from low-carbon sources by 2030 (40% RES and 25% nuclear) – making it the global leader on climate change policy.

The decrease in the share of low-carbon capacity resulting from not investing in the LTO of existing nuclear reactors will lead to increased emissions in the medium term. This is due to dependence on fossil fuel sources in order to meet back-up needs. Based on the findings of the Compass Lexecon report[20] the early closure of the nuclear fleet would require additional fossil fuel power production – 3625 TWh (gas) and 525 TWh (coal) over 2020-50.

In FORATOM's opinion, the EU's Emission Trading System (EU-ETS) should be the main tool to reduce industrial greenhouse gas emissions and the current price level of tonne of CO2 should be enough to incentivise the investments in low-carbon technologies. But we see two hurdles:

- Current energy prices that render the price impact of CO2 marginal
- The stability of the current CO2 price level that which has yet to be demonstrated, and which is an important feature required by the investors.

[19] *«Europe's Power Sector in 2020», Ember and Agora Energiewende, January 2021.*
[20] *Compass Lexecon report on "(2021 Updated Results) Pathways to 2050: Role of nuclear in a low-carbon Europe."*

3.2 Economic aspects

Key message: LTO has a clear economic advantage over other power sources. It requires a much lower capital investment cost, it is a mature solution leading to low investment risks for investors and capital markets, and it leads to lower customer costs.

a. Capital costs

According to PINC1, the average LTO investments between 2000 and 2025 are around 630 EUR/kWe, representing the lowest capital cost of all low-carbon technologies. These results are also consistent with the findings of recent IEA and OECD-NEA studies. PINC also estimates a total LTO investment need of around EUR 46,9 billion during the period 2015-2050.

b. Generation costs

According to the IEA[21], the levelized costs of electricity (LCOE) for installed nuclear capacities (LTO) are the lowest among all technologies.

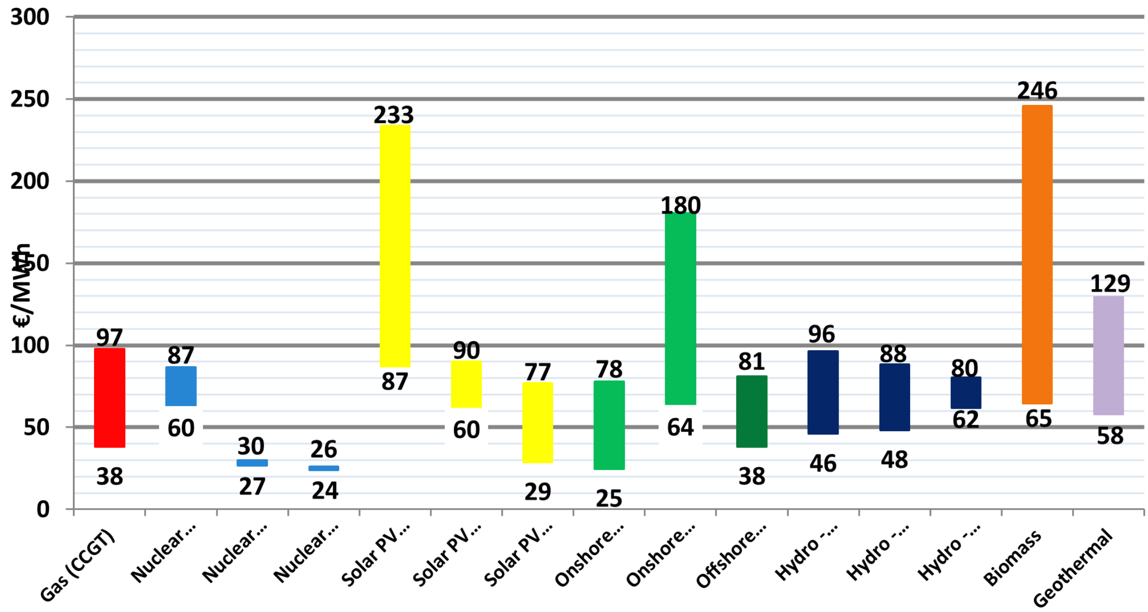

Fig. 8. Comparison of LCOE (levelized cost of electricity) for different technologies in Europe (7% discount rate)

But to understand LCOE better, recent developments and their impacts on generation costs should be taken into account:

- Carbon price

It should be noted that the IEA report considers a price 30 $/tonne of CO2. Under the current EU carbon market, the price of CO2 is more than 70 $/tonne (over 60 €/tonne of CO2)[22]. That substantially changes the gas (CCGT) LCOE

- Fossil fuels and uranium prices

Another significant impact on LCOE is fossil fuel prices. In September-October 2021 gas prices more than doubled in comparison to the first half of 2021. At the same time, uranium prices and thee nuclear LCOE remain very stable.

[21] *IEA report on "Projected Costs of Generating Electricity 2020".*
[22] *EMBER Daily Carbon Prices viewer.*

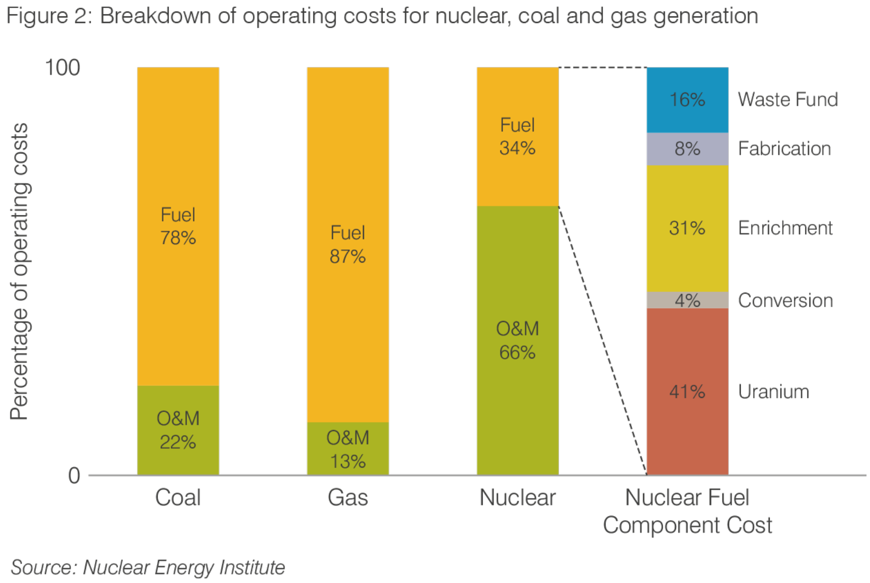

Fig. 9. Breakdown of operating costs for nuclear, coal and gas generation

As highlighted in figure 9, the impact of the uranium price in the overall costs of nuclear operation is less than 15%. As result, nuclear power operating costs are very stable, and even with high fluctuations in uranium prices, the impact is marginal.

- Is LCOE the right metric to compare different power sources?

In 2018, the IEA considered the need to evaluate the relative competitiveness of power generation technologies. An important factor was to consider not just the cost of the electricity produced, but also its value. Therefore, a new metric for competitiveness was developed in the 2018 edition of the World Energy Outlook[23] – the value-adjusted levelized cost of electricity (VALCOE).

VALCOE combines the projected levelized costs of electricity with a simulated energy value, flexibility value and capacity value by technology.

FORATOM goes beyond this metric by identifying further parameters that should be developed for a proper comparison of the costs of production of the different power sources, as network integration costs and also external costs must be considered.

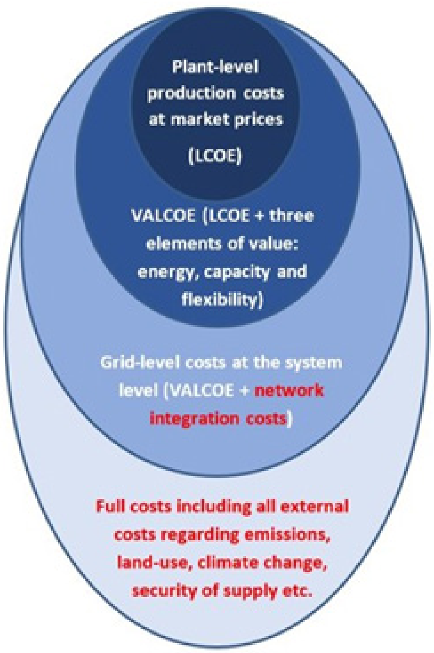

Fig. 10. Assessing the full costs of generation for the different technologies

c. VALCOE

The IEA report[24] concludes that generation costs from nuclear LTO are very competitive compared to other low-carbon options. In fact, the figures are even better in cases where the system costs of higher shares of intermittent generation are included. Under such circumstances the Value Adjusted LCOE (VALCOE) for nuclear is almost unaffected, whereas solar PV suffers from a significant reduction in value when the share of intermittent renewables in the generation mix is higher.

[23] IEA report on *"World Energy Outlook 2018".*
[24] *IEA report on "Projected Costs of Generating Electricity 2020".*

d. Network integration costs

In one of OECD-NEA's recent reports, network integration costs (connection and T&D costs) have been assessed.

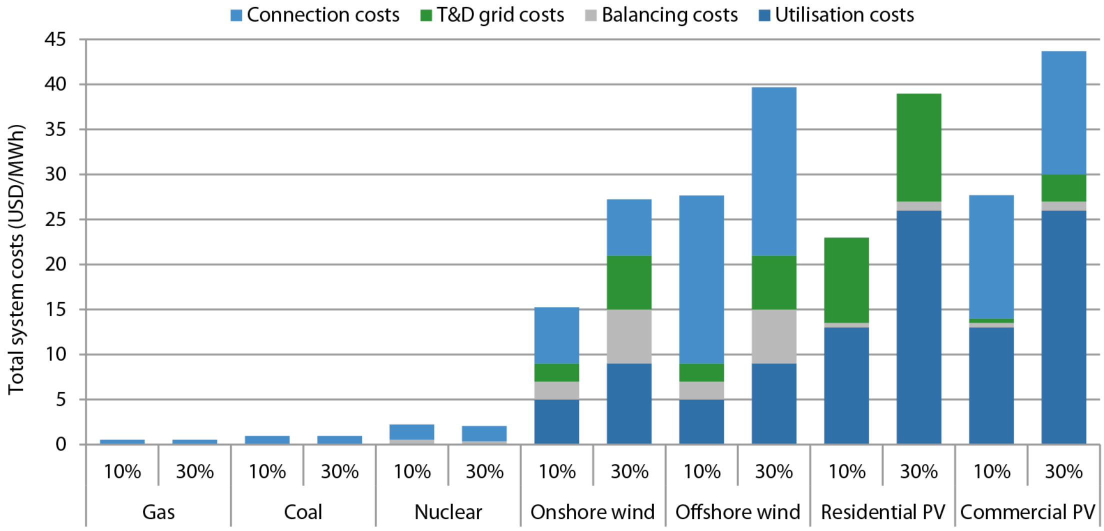

Fig. 11. Grid-level system costs of selected generation technologies for shares of 10% and 30% of variable renewables generation

It can be clearly highlighted that in any scenario including the implementation of variable renewables (10% or 30%), the above-mentioned network integration costs are significantly higher for renewables than for nuclear. In the case of nuclear LTO the costs are zero due to the connections already being in place.

e. External costs

While some countries are assessing options to replace the existing nuclear fleet, external costs are also an important parameter that should be taken into account when the decision is made. According to EC's report on external costs[25], nuclear at 15 €/MWh is at the same cost as solar CSP and way lower than gas at 68 €/MWh. Those costs are important and must be considered, particularly when decisions are made for developing new gas capacities instead of granting LTOs for the existing nuclear fleet.

f. Customer costs

An early closure of nuclear capacity would impact the undiscounted customer cost by more than €200 billion by the mid-century. Customers would benefit from the savings in the short to medium term (before 2035), further strengthening the contribution of nuclear generation in the transition to a decarbonised economy.

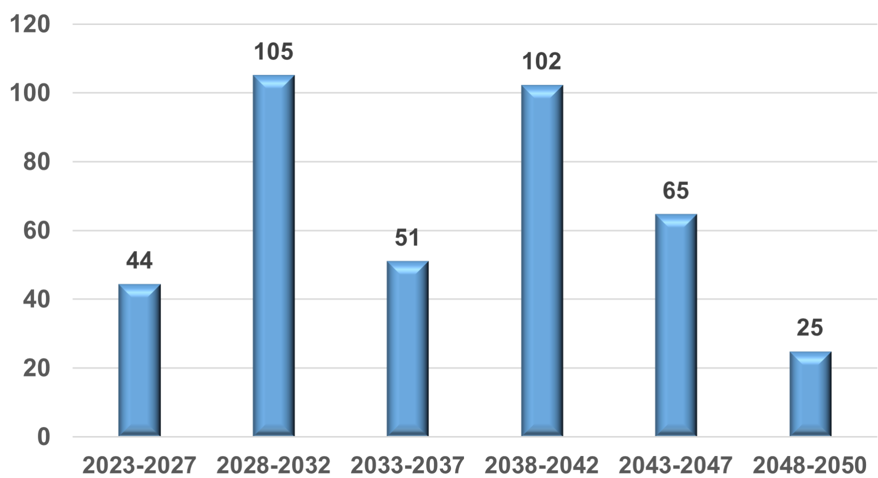

Fig. 12. EU 27 - Customer costs due to the early closure of nuclear reactors compared with LTO (€ billion) – FORATOM calculations based on Compass Lexecon results[26]

[25] *Energy costs, taxes and the impact of government interventions on investments: final report – External costs, EC 2020.*
[26] *Compass Lexecon report on "(2021 Updated Results) Pathways to 2050: Role of nuclear in a low-carbon Europe."*

g. Low investment risks

As of today, around 30% of the world's fleet is operating under LTO conditions[27], mainly in the US and Europe. The associated high volume of LTO projects has contributed to developing and sustaining industrial capabilities, as well as reducing the LTO costs over time (Fig. 13). The robust industrial capabilities, continuous learning and low capital costs result in low investment and financing risks for LTO projects that can be easily handled by operators.

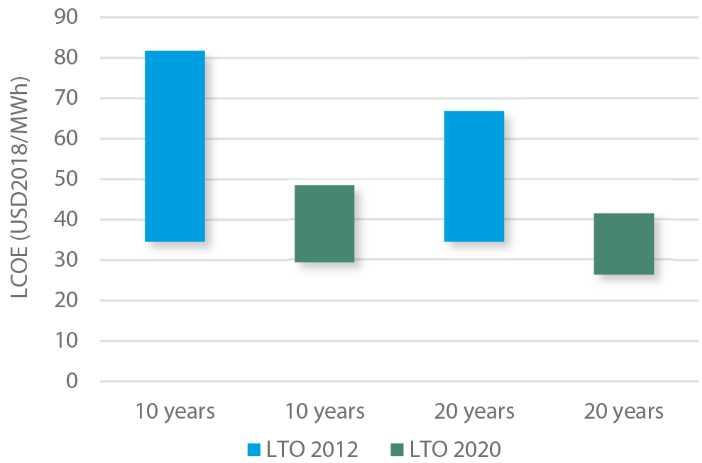

Fig.13. Evolution of LTO LCOE for different licence extension periods[28]

3.3 Regulatory aspects

Key message: From a technical point of view, the LTO of nuclear reactors provides a great advantage thanks to the "…timely implementation of reasonably practicable safety improvements to existing nuclear installations"[29] which brings older generation reactors to a level of safety which complies with the amended Nuclear Safety Directive[30].

The operating time of NPPs is limited by the economic rationale of investments and the ongoing licensing procedure or framework which aims to achieve the highest European and international nuclear safety standards. The decision authorising the operation does not distinguish between "before LTO" and "after LTO" as the licensing conditions remain the same. In fact, most laws or regulations provide for indefinite operation terms, or allow for unlimited licence extensions[31].

According to the IAEA's definition[32], LTO is a continuous operation beyond a framework defined by the technical project or licence, after an assessment and if regulatory conditions are met. LTO is neither a major nor a minor change because it does not alter the physical aspects of the project[33] and it is important to keep in mind that the safety requirements for NPPs "before long-term operation" are the same or higher as those "during long-term operation". Nuclear reactors will operate under the same conditions based on normal operation, such as after a planned outage.

[27] *https://www.oecd-nea.org/jcms/pl_60310/long-term-operation-of-nuclear-power-plants-and-decarbonisation-strategies.*
[28] *Ibid.*
[29] *Nuclear Safety Directive 2014/87 – article 8.a.*
[30] *https://www.oecd-nea.org/jcms/pl_60310/long-term-operation-of-nuclear-power-plants-and-decarbonisation-strategies.*
[31] *https://www.oecd-nea.org/jcms/pl_15154/legal-frameworks-for-long-term-operation-of-nuclear-power-reactors?details=true.*
[32] *IAEA (2017): Handbook on Ageing Management for Nuclear Power Plants.*
[33] *Case C-275/09 Brussels Hoofdstedelijk Gewest v. Vlaamse Gewest ECJ "the extension of the licence in the absence of any work or interventions involving alteration to the physical aspect of the site is not a project under EIA directive".*

The nuclear industry has been a precursor in applying the highest and most stringent quality assurance principles. Over time, it has developed a comprehensive safety culture encompassing both design and human aspects. Based on this, the industry has been able to fully analyse and learn lessons from any incidents and accidents that occurred during its 18000 reactor-years of operation in the world[34] . European operators also participate in international initiatives such as ENREG[35], IAEA SALTO and WANO peer-reviews which enable the dissemination of lessons learned as well as the early detection of potential deviations from best international standards. As a result, the plants currently operating today in Europe benefit fully from these improvements, rendering them much safer than when they were commissioned.

It should be noted that there is no real cliff edge effect in either the level of safety or technical degradation due to ageing when reaching the original design lifetime. The latter is based on initial assumptions taken for life-limiting components (e.g. reactor pressure vessel) and should not be confused with the remaining useful life of a nuclear power plants. The remaining useful life is periodically re-evaluated by taking into account the actual plant conditions and the latest available knowledge. In almost all cases, the remaining useful life is greater than the originally assumed design lifetime[36].

3.4 Operational aspects

Key message: Nuclear operations can improve during LTO. This can be explained by i) plant enhancements implemented by operators during LTO refurbishments, ii) growing operational capabilities and iii) governing frameworks that enable best practice sharing

Global performance indicators from IAEA PRIS suggest that a nuclear power plant's operation improves despite ageing and could even improve further during LTO (fig 14). This can be explained by a combination of technical and organisational factors. During LTO refurbishments, operators make the necessary replacements, safety improvements but also implement plant enhancement to increase the reliability of the plants (e.g. digital I&C systems, overall plant modernization). Furthermore, operators can capitalize on the experience and skills gained over 30 to 40 years of operation to maintain or even improve performance levels during LTO. Operational experience sharing at the international level led by organisations such as the IAEA and OECD-NEA could also bring additional performance benefits.

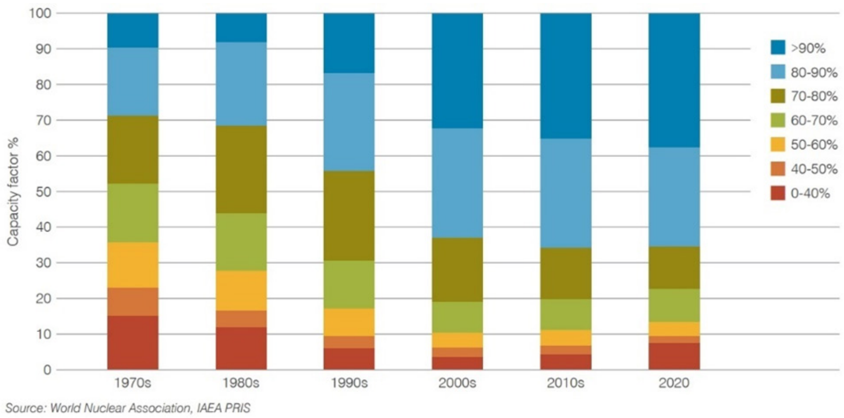

Fig. 14. Global long-term trends in capacity factors[37]

[34] IAEA Power Reactor Operation Years (PRIS).
[35] http://www.ensreg.eu/.
[36] https://www.oecd-nea.org/jcms/pl_60310/long-term-operation-of-nuclear-power-plants-and-decarbonisation-strategies.
[37] World Nuclear Performance Report 2021, WNA.

3.5 Security of supply

Key messages: LTO will reduce the EU's energy import dependency (mainly fossil fuels), providing security of supply to the power system.

While the increased reliance on thermal generation has a negative impact on the EU's climate changes ambitions, it also puts security of energy supply in danger.

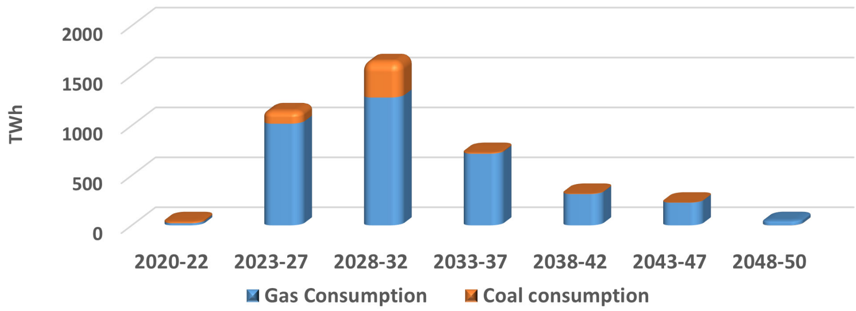

Fig. 5, Fossil fuel consumption in the power sector differences between the High and the Low scenarios[38] (TWh)

As mentioned above, the findings of the Compass Lexecon report[39] show that the early closure of the nuclear fleet would lead to a total additional fossil fuel power production need of 4150 TWh over 2020-2050. Over 80% of additional fossil generation would be needed in the short and medium term (up to 2037). This is mainly derived from the need for dispatchable generation during the implementation of renewable technologies. The early stages of the renewable transition will rely on storage technologies which are not mature enough today to compensate for system instability.

The EU is highly dependent on fossil fuel imports (see fig. 16), making the transition towards 2030-2035 very challenging from a security of supply point of view in the case of early close of the existing nuclear fleet.

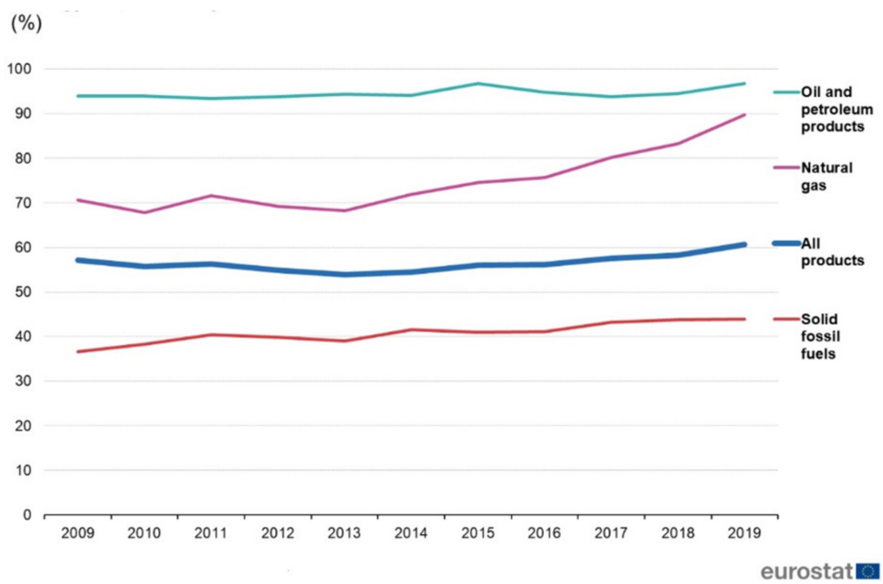

Fig. 16. Energy dependency rate, EU27, 2009-2019[40]

[38] *Compass Lexecon report on "[(2021 Updated Results) Pathways to 2050: Role of nuclear in a low-carbon Europe.](#)"*
[39] *Ibid.*
[40] *[Eurostat.](#)*

In the case of nuclear fuel fabrication, most of the uranium needed for the EU's nuclear fleet is also imported. However, compared to fossil fuels, and even if the market is rather limited, the diversity of the suppliers provides enough alternatives in cases where one supplier is unavailable.

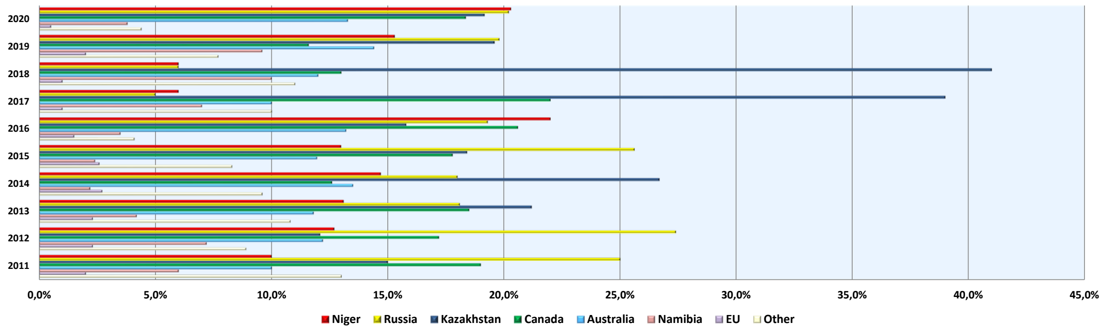

Fig. 17. Evolution of EU uranium imports[41]

In a report[42] released in March 2020, the Euratom Supply Agency (ESA) analysed the nuclear fuel availability at EU level from a security of supply perspective and identified potential risks. In terms of overcoming potential shortages in supply, ESA acknowledged that "uranium inventories can fuel EU utilities' nuclear power reactors for 2.75 years on average"[43]. This feature of the nuclear sector provides an advantage compared to fossil fuels, especially in the current situation where gas reserves are at a low level.

Lastly, in the current context of high energy prices, nuclear power can contain wholesale electricity prices by pushing fossil-fired generation out of the merit order curve. At the same time, the operational costs of nuclear facilities are low and stable over time and could be used to lower electricity prices for customers subject to a regulated-tariff contract[44]. LTO would extend these benefits in time and enhance the overall affordability of the electricity provision.

3.6 System reliability

Key message: Low-carbon nuclear generation provides firm capacity to the electricity system and supports the integration of higher shares of VRE at lower integration costs

Many Member States are considering the replacement of thermal generation with massive amounts of intermittent renewables in their decarbonization trajectories. Coal generation will be phased-out by 2030 in France, Spain, Italy, Portugal, the Netherlands, Demark, Sweden, the UK, Finland and Austria. Meanwhile Germany has proposed to more than halve coal capacity by 2030 and to phase-out nuclear by 2022. France will cap nuclear generation at 50% by 2035, after delaying its previous goal of 2025. Overall, the capacity gap could account for 160 GW by 2040, representing around 40% of the dispatchable capacity in Europe (see figure 18).

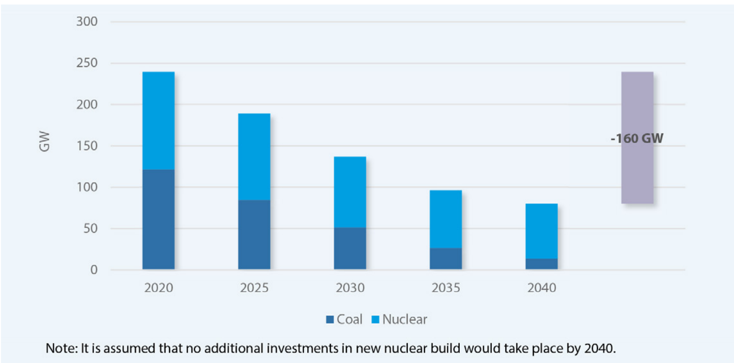

Fig. 18. Evolution of nuclear and coal capacity in Europe according to Stated Policies, 2040

[41] *EURATOM Supply Agency annual reports (2011-2020).*
[42] *Analysis of nuclear fuel availability at EU level from a security of supply perspective.*
[43] *EURATOM Supply Agency annual report 2020.*
[44] *https://www.foronuclear.org/en/press-room/press-releases/nuclear-power-as-part-of-the-solution-for-lowering-high-energy-prices/.*

Due to their inherent variability, the contribution of intermittent renewables to system reliability is very limited. This can be illustrated by assessing the capability of variable renewables to provide firm capacity. Firm capacity is the minimum capacity available for the system in a worst-case scenario (i.e. a day of maximum demand and low supply). For example, wind generation provides a firm capacity equivalent of less than 10% of its installed capacity. Photovoltaic generation provides zero MW of firm capacity. In contrast, thermal and nuclear generation in particular, provide a firm capacity of more than 90% of their installed capacity.

There are reports that claim storage technologies will be able to solve the renewable intermittency issues. However, this will lead to a reliance on storage technologies which are still immature. According to the Compass Lexecon report[45], a low share of nuclear in the energy mix will significantly increase the power system's reliance on large scale yet immature storage technologies (reaching around 325 GW of batteries and seasonal storage such as P2X2P in 2050 in the Low scenario).

In addition, interconnections cannot provide any firm capacity in the event of a generalized issue with system reliability in Europe. Indeed, it seems difficult to justify that all countries can simultaneously depend on their neighbours to ensure security of supply, without any of them being able to ensure their own. This is even more important in a context where some countries are taking decisions to phase-out dispatchable capacity unilaterally with limited consultation of neighbouring countries.

As a result, the European Commission should recommend Member States to include an in-depth analysis of security of supply in their National Energy and Climate Plans. Member States should phase out thermal generation at the pace that minimizes emissions whilst guarantying security of supply. The role which nuclear capacity can play in this scenario is key in terms of ensuring security of supply during the energy transition due to the high availability which this technology guarantees.

A recent France Strategy report[46] "What security of supply Europe by 2030?" compiled assumptions about the evolution of the European power mixes. A spreadsheet has been drawn up that lists France's six border countries (including Belgium, UK, Germany, Italy, Spain and Switzerland) and their means of production, demand, flexibilities and interconnections for 2025, 2030 and 2035.

For all seven countries studied, if no dispatchable generation technologies – other than those already planned – are added to the network during this period, and if the objectives development of renewables are respected, power safety margins decrease from 34 GW in 2020, to 16 GW in 2025 and then become negative at -7.5 GW in 2030 and -10 GW in 2035.

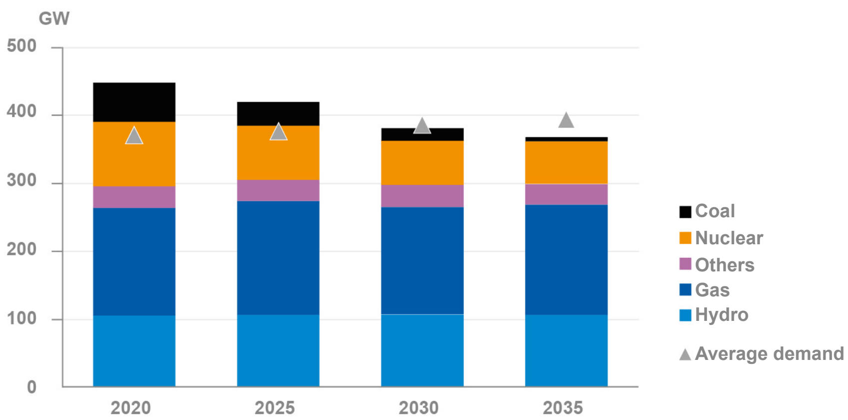

Fig. 19. Forecast of France's dispatchable electrical capabilities and neighbouring European countries (2020-2035) - Average peak demand for France is that assessed by RTE in its forecast and for other countries by the corresponding accredited bodies.

[45] *Compass Lexecon report on "(2021 Updated Results) Pathways to 2050: Role of nuclear in a low-carbon Europe."*
[46] *France Stratégie.*

The development of flexible solutions such as interconnectors, storage, demand side response and sector coupling approaches (e.g. hydrogen) could enhance the overall reliability of the system while phasing out large amounts of dispatchable generators. Nevertheless, the large-scale deployment of these types of solutions is uncertain, since some of them have not achieved full industrial maturity[47].

Existing nuclear can also offer a source of flexibility to the system (seasonal, weekly and daily horizon) and provide a range of grid services, including load-following. Countries like France and Germany have extensive experience in operating nuclear power plants in load-following mode[48] and the flexibility of nuclear reactors is a feature that some countries are relying on[49]. LTO projects are a good opportunity to retrofit existing reactors and enable them for flexible operation if the associated business case is economically robust. The flexible operation of nuclear power, both new build and existing reactors in LTO, can foster the development of higher shares of VRE while lowering system costs, especially in the event of a high share of variable renewables penetration[50].

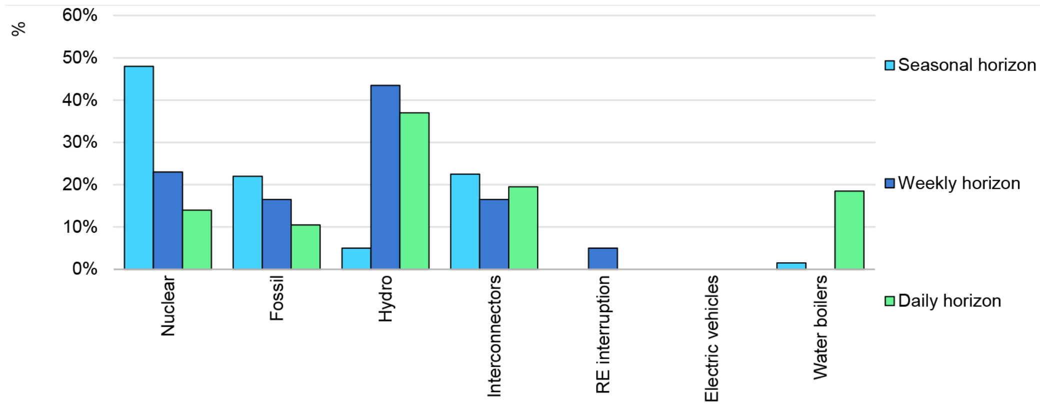

Fig 20. Flexibility sources in France, Source: *"Conditions and Requirements for the Technical Feasibility of a Power System with a High Share of Renewables in France Towards 2050",* IEA January 2021.

3.7 Hydrogen economy

Key message: Nuclear LTO is capable of providing low electricity prices and a high reliability (over 85% capacity), and thus the perfect candidate for establishing a competitive low-carbon hydrogen economy by 2030.

As FORATOM explained in its recent position and background papers[51], in order to be competitive against fossil-based hydrogen production, hydrogen obtained through electrolysis should meet three important characteristics:

1. It should be low carbon
2. t should be affordable
3. it should provide a high reliability in terms of electricity production

The first characteristic is fulfilled by both nuclear and renewables. The second characteristic can be fulfilled by nuclear LTO and some renewables. The third is only fulfilled by nuclear. As mentioned above, nuclear is the largest low-carbon, non-weather dependant source of electricity.

3.8 Additional benefits

a. Circular economy

Nuclear power is the low-carbon technology with the lowest mineral intensity. The LTO of nuclear reactors will continue to save raw materials, as the electricity will be produced with existing facilities and far fewer raw materials will be required during their extended operation. It will also reduce the amount of radioactive waste produced (quantity of waste / TWh), as the amount of waste or so-called waste intensity resulting from decommissioning will be divided by a larger amount of TWh produced. This does not apply to nuclear fuel which remains at the same level for as long the nuclear reactor operates.

[47] https://www.oecd-nea.org/jcms/pl_60310/long-term-operation-of-nuclear-power-plants-and-decarbonisation-strategies.
[48] https://www.oecd-nea.org/jcms/pl_14754.
[49] FORATOM's position paper on "Flexible operation of nuclear power plants", 2018.
[50] https://www.oecd-nea.org/jcms/pl_15000/the-costs-of-decarbonisation-system-costs-with-high-shares-of-nuclear-and-renewables.
[51] FORATOM position and background papers on nuclear hydrogen production.

b. Industrial development and trade

- Competitiveness

Choosing the LTO option will maintain and develop the European nuclear supply chain, rendering it competitive both locally as well as globally. According to a study undertaken by Deloitte[52], thanks to a combination of LTO and new nuclear reactors, the EU-28 trade surplus (the difference between exports and imports) will increase from a current value of 18.1 billion €33.5 billion in 2050. The main reason for this increase will be because the development of the supply chain will not only cover the EU-28 market, leading to a decrease in imports, but will also increase the export of local components and potential new reactor designs. The conclusion is that, in addition to covering the EU-28 market, the supply chain will be able to increase exports outside Europe.

- Maintaining workforce competences

By choosing LTO, the nuclear industry will benefit from maintaining and upgrading the competences of operators and suppliers as well as providing an additional 350000 jobs according to the same Deloitte study[53].

c. Risk management

It is difficult to foresee the full consequences of current climate policies, especially beyond 2030. It is possible that some of these policies do not yield the expected results in terms of carbon emission reductions. While wind and solar can be scaled up quickly, uncertainties remain about the timely availability of innovative solutions to deliver large-scale electricity system flexibility, hence increasing potential security and reliability of supply concerns. In parallel, more ambitious decarbonisation targets in Europe will require the use of mature and ready-to-deliver, low-carbon solutions. LTO emerges as an option to support short and medium term ambitious decarbonisation targets while minimising potential risks along the way. The additional time provided by LTO could also be used to develop innovation without impacting carbon emission targets and security of supply.

4. CHALLENGES

4.1 Regulatory aspects

As already indicated, even if from a technical point of view LTO cannot be considered as a change in the way the reactor operates, there are still discussions regarding the applicability of certain requirements stemming from the Espoo and Aarhus conventions regarding the lifetime extension of nuclear reactors.

4.2 Industrial challenges

With LTO we maintain skills and the vast expertise of the nuclear sector but also the existing supply chain. As explained above, LTO improves the existing fleet's operation and this can be done only with the contribution of innovation and technological breakthroughs in the areas of material aging science, digitalisation of instrumentation and control full analogic systems, full scale simulators, 3D models, etc.

4.3 Jobs

According to the Deloitte[54] study, the impact of LTO on jobs is around 350000 direct and indirect jobs. These jobs will be lost without the LTO of the current fleet. Not going ahead with LTO could also pose several other challenges: attracting talent, adapting the workforce to new technologies, ensuring new employees to replace those who retire, maintaining a high level of skills and so on. According to the same Deloitte[55] study, currently around 47% of nuclear industry employees in the EU are highly skilled, therefore making the transition to a new generation of workers even more challenging and dependent on access to a well-developed high education system.

[52] *Economic and Social Impact report – Deloitte, April 2019.*
[53] *Ibid.*
[54] *Ibid.*
[55] *Economic and Social Impact report – Deloitte, April 2019.*

4.4 Industrial and Energy Sovereignty

With the 3 main economic powers strengthening their position in energy matters by setting export and cooperation limiting regulations (export control for the US, export control from China, gas and oil tap control from Russia), LTO is a way for Europe to maintain a strong industrial asset capable of feeding the European electrical network for a long period and physically independent from limiting regulations set by other economic powers. Furthermore, the nuclear industry and R&D programs directly or indirectly related to LTO are important and critical to many industries (medical, food and agricultural, sensor development, space and aerospace, and physics and material physics research). LTO would support European energy and industrial sovereignty.

4.5 Specific taxes for the nuclear sector

The decision on whether to go ahead with LTO is an economic one. In Europe, and under current market conditions, LTO remains an attractive investment. In some countries, however, this decision is very much affected by the existence of taxes which apply only to the nuclear sector (i.e. Spain, France, Belgium).

4.6 Public acceptance

Whilst in some cases public opinion may not always be favourable towards nuclear, this is often due to the lack of information relating mainly to technical aspects. But as explained earlier on, LTO is an opportunity to align existing nuclear reactors to the latest nuclear safety standards. In addition, LTO can be considered as an opportunity as public acceptance in some countries is more favourable towards existing installations than new ones. Recent positive developments have been noticed in Netherlands and France, with an increase in support by the population for nuclear.

4.7 Stakeholder awareness

More broadly speaking, one important challenge is to raise awareness amongst a broad range of stakeholders (politicians, media, decision makers, influencers and the public) about the potential consequences of not going ahead with LTO, particularly in relation to climate change. The focus should be on the different benefits offered by all currently available low-carbon technologies as well as providing reliable information about breakthrough technologies which could become commercially viable in the future.

4.8 Supply chain challenges

In some European countries, in particular those with a low number of reactors and different design types, the increasing policy and market uncertainties have reduced the pool of qualified suppliers. In some cases, the original equipment manufacturers have ceased the production of some critical components (or simply left the market) accelerating supply chain obsolescence. To mitigate these risks, European operators have implemented a series of strategies including enhanced supply chain management, higher collaboration and harmonization levels, reverse engineering, the introduction of commercial grade components for low-safety class components and reverse engineering. There are various national projects (some of them in collaboration with regulators) taking place in Europe to foster the use of commercial grade dedication processes for some non-critical components[56].

[56] https://publications.jrc.ec.europa.eu/repository/handle/JRC121103.

5. POLICY RECOMMENDATIONS

Considering the challenges above, FORATOM would like to put forward the following policy recommendations:

- Ensure a coherent, consistent and stable EU policy framework (including Euratom).
    - Fully integrate nuclear power into all energy policy discussions, particularly those relating to the EU's decarbonization goals (European Green Deal / Fit for 55 package) as well as security of supply, the importance of which has become increasingly evident during the second half of 2021.
    - Ensure coherence between policies – for example, policies aimed at achieving climate goals should support all low-carbon technologies recognised in the EU's "A Clean Planet for All" communication.
    - Ensure technological neutrality.
    - Readdress market failures, taxation regimes and specific regulations that do not recognize the value that LTO provides to the electricity system.
- Agree an ambitious net-zero CO2 emissions target for the EU in 2050, in line with the European Commission's long-term vision for a climate neutral economy.
    - Include the existing nuclear fleet in for the increased EU's mid-term (2030) GHG reduction ambitions to ensure the EU is able to achieve climate neutrality by 2050 and decarbonize the electricity sector by 2040.
    - Allow equal market access and support for all forms of low-carbon generation. This will enable a more sustainable and cost-effective energy mix and reduce the need for non-market support schemes.
- Develop and implement a strong industrial strategy to ensure that Europe maintains its technological leadership.
    - Support supply chain optimization efforts.
    - Promote, together with regulators, a better alignment of licensing and regulatory processes, and contribute to more harmonization across the EU nuclear sector.
- Support human competences
    - Assist in attracting young people to this industry. To do this, and in line with other international organisations, the EU should be more vocal on the fact that nuclear power has a future in the 2050 low-carbon economy.
    - Policymakers, educational systems and industry should work together to ensure generation transition and competence transfer, as well as to help the workforce adapt to new technologies (digitalization, industry 4.0).

About us

The European Atomic Forum (FORATOM) is the Brussels-based trade association for the nuclear energy industry in Europe. The membership of FORATOM is made up of 15 national nuclear associations and through these associations, FORATOM represents nearly 3,000 European companies working in the industry and supporting around 1.1 million jobs.

FORATOM
THE VOICE OF THE EUROPEAN NUCLEAR INDUSTRY

Avenue des Arts 56
1000 Brussels
tel +32 2 502 45 95
foratom@foratom.org
www.foratom.org