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Nuclear energy market consultation

1 July 2021

Report

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Ministry of Economic Affairs and Climate Policy
Attn: Maaike van Asten
By email

Amstelveen, 1 July 2021

Re: KPMG nuclear energy market consultation report

Dear Ms Van Asten,

In accordance with the Award Decision dated 31 January 2021, we are pleased to share our report setting out the results of our nuclear energy market consultation.

Aim of the consultation

The market consultation aimed to answer the three key questions from the motion posed by Member of Parliament Dijkhoff et al:

1. Under what conditions would Dutch and international market participants be prepared to invest in nuclear power plants in the Netherlands?
2. What public support would be required?
3. In which regions is there interest in the construction of a nuclear power plant?

After receiving interview responses from the consultation, we challenged, analysed and collated them. Where possible, we also consulted the literature for information to substantiate the perspectives recorded in the interviews. We then incorporated the results into this independent report.

It is important to note that our findings do not contain recommendations with regard to a decision on the possible expansion of nuclear energy in the Netherlands.

Distribution and important notice

This report is intended solely for you as the client. KPMG accepts no responsibility or liability to any other party for the use of the report.

The important notice set out on the next page should be read in conjunction with this report.

Acknowledgements

We would like to thank the market participants and regional officials we interviewed for sharing their insights. We would also like to thank the Ministry of Economic Affairs and Climate Policy for its helpful collaboration.

Yours sincerely,

Marc Roels
Partner

Important notice

This report is an English translation of the Dutch original. We have taken the utmost care to make the translation as close to the Dutch original as possible. In case of errors, omissions, ambiguities and/or discrepancies, the Dutch original takes precedence over this translation.

Our work started on 8 February 2021 and was completed on 1 July 2021. Our report is based on the results of our market consultation, comprising of in-depth interviews and desk research performed up to 1 July 2021. We have not amended the report in response to events or circumstances arising, or data received, after that date.

This report supersedes all previous verbal, provisional or interim reports and presentations. Any person who makes use of such verbal, provisional or interim reports and presentations does so entirely at their own risk.

This report is based on responses given in in-depth interviews and on publicly-available information sources. In preparing this report, we relied on the accuracy and completeness of the responses given in the interviews and of the information sources without independently verifying them. We accept no liability for these responses or this information. We have made every effort to satisfy ourselves, as far as possible, that the information presented in our report is consistent with other information and sources of information that we obtained/examined during our work, in accordance with the terms of our service agreement. However, we did not carry out any further work to verify the reliability of the sources.

This document refers to 'KPMG analysis'; this indicates only that we have (where specified) undertaken certain analytical activities on the underlying data to arrive at the information presented; we do not accept responsibility for the underlying data.

The nature of the work means that we have not conducted an audit, review or any other type of assurance service. Accordingly, no assurance may be derived from this report with regard to the accuracy of financial or other information. Our advice in this report is solely based on the agreed scope of work and the results of that work. If we had performed additional work, or if we had conducted an audit, review or assurance service, other topics might have been identified that could have warranted inclusion in the report.

We accept no liability if the report is used for any purpose other than that for which it was prepared: to answer the three questions from the Dijkhoff motion. To the fullest extent permitted by law, we accept no liability for the use of the report by any party other than the Ministry of Economic Affairs and Climate Policy.

The contents of this report may not be copied, in whole or in part, or used for other purposes, without the written consent of KPMG.

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Glossary of terms

Glossary of terms used in this report

AHTR	Advanced High Temperature Reactor
ANVS	Authority for Nuclear Safety and Radiation Protection
BWR	Boiling Water Reactor
CAPEX	Capital expenditure (investments)
CCGT	Combined Cycle Gas Turbine
CfD	Contract for Difference (see page 80 for more details)
CHP	Combined Heat and Power
COVRA	Central Organisation For Radioactive Waste (Netherlands) (in Dutch: 'Centrale Organisatie Voor Radioactief Afval')
ECA	Export Credit Agency
EMEA	Europe, Middle East & Africa
ENEC	Emirates Nuclear Energy Corporation
EPR	European Pressurised Reactor
ESG	Environment, Social and Governance
ETI	Energy Technologies Institute
EU	European Union
EWEC	Emirates Water and Electricity Company
FANR	Federal Authority for Nuclear Regulation (UAE)
FOAK	First Of A Kind (a FOAK reactor is the first reactor of its type to be constructed)
FNS	Fast Neutron Spectrum reactor
HABOG	High-Level Radioactive Waste Treatment and Storage Building (Netherlands) (in Dutch: 'Hoogradioactief Afval Behandelings- en Opslag Gebouw')
HFR	High Flux Reactor
HOR	Higher Education Reactor (in Dutch: 'Hoger Onderwijs Reactor')
HTR	High Temperature Reactor (see page 40 for more details)
IAEA	International Atomic Energy Agency
kV	Kilovolt
kWh	Kilowatts per hour
LCOE	Levelised Cost Of Electricity (see page 38 for more details)
LFR	Lead-Cooled Fast Reactor (see page 40 for more details)
LWR	Light-water reactor
Ministry	Ministry of Economic Affairs and Climate Policy
MMR	Micro Modular Reactor
MSR	Molten Salt Reactor (see page 40 for more details)
MW / GW / TW / kW	Megawatt / Gigawatt / Terawatt / Kilowatt
MWh	Megawatts per hour
NEA	Nuclear Energy Agency
NFW	Nuclear fission waste
NOAK	Nth Of A Kind (with a NOAK reactor, several reactors of the same type have already been constructed)
O&M costs	Operation and maintenance costs
OECD	Organisation for Economic Co-operation and Development
PJ	Petajoule
PPA	Power Purchase Agreement (see page 80 for more details)
PWR	Pressurised Water Reactor
R&D	Research and development
RAB model	Regulated Asset Base model (see page 79 for more details)
SDE	Stimulation of Sustainable Energy Production scheme (in Dutch: 'Stimuleringsregeling Duurzame Energieproductie')
SFM	Spent fissile materials
SLE	Service life extension
SMR	Small Modular Reactor (see page 54 for more details)
STUK	Radiation and Nuclear Safety Authority (Finland)
t	Tonne
TAEK	Turkish Atomic Energy Authority
UAE	United Arab Emirates
UK	United Kingdom
USA	United States of America
WACC	Weighted average cost of capital
WENRA	Western European Nuclear Regulators Association

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Introduction	**This study looks at how nuclear energy can be achieved as economically as possible and what role the government can play. This study explicitly does not examine the question of whether the Netherlands should proceed with nuclear energy expansion** — The study was prompted by the Dijkhoff motion,[1)] which posited the following research questions: - Under what conditions would Dutch and international market participants be prepared to invest in nuclear power plants in the Netherlands? - What public support would be required? - In which regions is there interest in the construction of a nuclear power plant? — This study looks at how nuclear energy can be achieved as economically as possible. To that end, the Ministry of Economic Affairs and Climate Policy ('the Ministry') supplemented the key questions from the motion with a number of sub-questions. KPMG developed these sub-questions further. — In addition, the Dijkhoff motion (see the third key question above) included a request to consider where a nuclear power plant could possibly be constructed. This involved a brief consultation with provincial authorities, two municipalities and the Port of Rotterdam, but no comprehensive planning study was carried out. **The study consisted of a market consultation with nuclear market participants from across the entire value chain** — The market consultation consisted of interviews with various relevant Dutch and international market participants, including contractors, nuclear technology suppliers, operators, decommissioning specialists and financiers. — A total of 41 market participants were interviewed. By category, interviews were conducted with four contractors, eight nuclear technology suppliers, 10 operators, two decommissioning specialists, eight financiers and nine people in the 'other' category (Rijkswaterstaat, TenneT, other governments, experts, etc.). — This market consultation primarily took the form of an interview programme, following which KPMG challenged, analysed and collated the responses, then incorporated them into this report. Where possible, source literature was also consulted for information to substantiate the perspectives recorded in the interviews.

Source: (1) Memorandum 35570-11, House of Representatives (2020).

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Technology overview	**Reactor technology can broadly be divided into four generations, as well as into traditional and modular designs (e.g. the small modular reactor)** — Generation II reactors are reactors that were largely built between the end of the 1960s and the late 1990s. The current Borssele power plant is a modern Generation II design. — Generation III power plants are an 'evolutionary improvement' on Generation II reactors. There are also Generation III+ reactors; this generally refers to the safety improvements made in response to the Fukushima disaster. In this report, no distinction is made between Generation III and III+, and only post-Fukushima designs are discussed, since most designs were modified after Fukushima to improve safety. — Generation IV reactors are new designs that are primarily based on a different type of cooling technology (using salt instead of water, for example) or that use a different energy source (such as thorium instead of uranium), which may lead to the production of less waste and/or may be safer. — A distinction can also be drawn in terms of engineering concepts between a traditional (often large) reactor and a small modular reactor (SMR). The main point of difference for an SMR is that it is (usually) smaller and has a modular construction. - Because of their modular design, SMRs are intended to be built in a more standardised way, which may make the construction time for SMRs shorter and more predictable than that of traditional reactors. - The standardised construction process, part of which can take place in a factory environment, should compensate for the diseconomies of scale of the smaller design compared with traditional (large) designs. - The reactor technology in an SMR is primarily Generation III+ or Generation IV. **Most reactors currently operating in Europe are Generation II reactors, while the reactors that are planned or under construction are largely Generation III+ reactors** — There are 141 nuclear reactors operating in Europe, consisting largely of Generation II reactors which were primarily constructed between the 1960s and the 1990s.[1)] In 2020, these reactors collectively supplied around 26% of the EU's electricity.[2)] - Of the 141 reactors operating, approximately half are located in France (56) and the United Kingdom (15). — Since 2005, construction has started on a number of reactors in Europe. Construction began on the first Generation III+ reactors in Europe in 2005 (Olkiluoto 3 in Finland), 2007 (Flamanville 3 in France), 2013 (Astravets in Belarus) and 2018 (Hinkley Point C in the United Kingdom and Akkuyu in Turkey).[3)] — The reactors planned in Europe in the (near) future are largely Generation III+ (such as Hanhikivi in Finland and Paks in Hungary). A number of countries are also considering an SMR (such as the UK, France, Denmark and Estonia).[2)]

Source: (1) Nuclear power in the European Union, World Nuclear Association (https://www.world-nuclear.org/information-library/country-profiles/others/european-union.aspx, last accessed on 28 May 2021). (2) Info graphics, FORATOM (2020). (3) Reactor database, World Nuclear Association (https://www.world-nuclear.org/Information-Library/Facts-and-Figures/Reactor-Database.aspx, last accessed on 28 May 2021).

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Selecting the technology	**The majority of market participants emphasised the importance of selecting proven technology that complies with current safety requirements, which means that there was a broad consensus in favour of selecting a Generation III+ reactor** — There was a broad consensus among market participants that the Netherlands should opt for a Generation III+ reactor with a proven design. This means the Dutch government would have access to proven, safe and already-available technology, which would be expected to involve fewer ‘first-of-a-kind’ (FOAK) issues that could lead to cost overruns and delays. — A modern, standardised Generation II reactor design may be an economically-attractive option, since this is a cheaper design that has already been proven. However, nearly all market participants considered this to be infeasible in terms of obtaining public support, since this design would not meet the additional safety requirements put in place after Fukushima. — Generation IV reactors have potential with possible benefits in the areas of safety and/or waste but are not expected to enter the market until after 2040, meaning they would arrive too late to help the Netherlands achieve its 2050 climate targets. Accordingly, market participants broadly indicated that the Netherlands would be better off opting for a Generation III+ reactor now, and to build a Generation IV reactor in due course, once the technology has been proven. - Some market participants suggested that it might be wise for the Dutch government to start investing in the development of Generation IV technology if it decides to expand nuclear energy. **There is a broad consensus that a Generation III+ reactor in the Netherlands would not necessarily suffer the problems experienced in other countries in terms of costs overruns and delays, and could also have significant savings potential** — To minimise issues related to costs and delays, the selected Generation III+ design should be one of which a number of reactors have already been built or are under construction. In EMEA and North America, these are the reactor technologies of EDF (Olkiluoto, Flamanville, Hinkley Point C), Westinghouse (Vogtle), KEPCO (Barakah) and Rosatom (Astravets, Akkuyu, Hanhikivi, Paks II). - At the request of the Ministry, Rosatom was excluded from the scope, as were the Chinese reactor technologies. — The market participants indicated that all of the above designs are robust. It is expected that a final choice can be made in 2021-2023 when one or more reactors have been built for all of the designs. — Because the designs of these Generation III+ reactors are mature and knowledge and expertise are being built up in Europe, costs are expected to be lower. It is estimated that in an optimistic scenario it is possible to save up to approximately 28-40% per MW[1)] compared with a FOAK reactor when building a nuclear power plant with two reactors based on a proven design. - Avoiding FOAK issues in engineering and construction could deliver estimated savings of around 20-30%.[1),2)] These savings would be gained from learning effects with the design during construction, and by building on licensing work from previous projects. - Productivity effects from serial production could reduce construction costs by around 2% for a second reactor, rising to around 8-13% for a fifth reactor.[(3)] If the second reactor is constructed in the same power plant, this could potentially produce additional savings of some 6-8%.[1),3)] — These savings are supported by experiences in France and the United Arab Emirates (UAE), among other countries. - An NEA model shows that savings from serial production could be as high as around 33-45% per MW compared with a FOAK reactor.[3)] - The second KEPCO reactor in Barakah (UAE) is expected to be around 25% cheaper per MW than the first Barakah reactor.[4)]

Source: (1) Synthesis on the economics of nuclear energy, William D’haeseleer for the European Commission (2013). (2) KPMG interview programme (2021). (3) Reduction of capital costs of nuclear power plants, OECD-NEA (2000). (4) The ETI nuclear cost drivers project – full technical report, Energy Technologies Institute (2020).

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Large or SMR?	**SMRs were also seen as an interesting option by many market participants...** — The market participants thought SMRs were an interesting option because they could potentially be built faster and require less investment, which might make them easier to finance. - There is significant uncertainty around the precise cost estimates for an SMR, which depend on a range of factors. The investment that is expected to be required for a 300 MW SMR could be between approximately EUR 1.4 and 2.7 billion.[1] In comparison, recent Western FOAK Generation III+ reactors of 1,200-1,500 MW cost between EUR 7.0 and 13.2 billion.[a),2)] — SMRs generally have a capacity of between 10 and 300 MW. By combining several SMRs in an integrated power plant, this could be increased to as much as 900 MW. SMRs can be based on either existing Generation III+ reactor technology or on new Generation IV reactor technology. — SMRs are intended to cost the same per MWh as traditional large reactors. The aim is for standardisation and serial production to generate learning effects to compensate for the diseconomies of scale of a smaller reactor. - At EUR 40 to 91 per MWh,[3] the expected 'levelised cost of electricity' (LCOE) for SMRs is more or less in the same range as the LCOE of traditional large reactors (EUR 35 to 84 per MWh).[4] — Due to their small size, SMRs are easier to integrate into the energy system and could potentially be built closer to consumers. This would create benefits with regard to infrastructure investments. Because more nuclear power plants can be built, more flexibility is also created in the way the plants are deployed (e.g. in load-following mode for the provision of adjustable power). **…but commercial availability of SMRs is still some time away...**[b)] — Globally, more than 70 SMR concepts are in development. According to the International Atomic Energy Agency (IAEA), designs by NuScale Power, GE-Hitachi Nuclear Energy, KAERI and Terrestrial Energy Inc. are currently in the licensing phase and are therefore the most likely to become commercially available within a relatively short time frame.[b),5)] The market participants also mentioned the UK Rolls-Royce SMR as potentially interesting due to its support from the British government, as well as the NUWARD SMR, which is being developed by EDF. — The first SMRs are expected to become fully operational as FOAK power plants in the period between 2027 and 2033.[b),5),6)] **…which means there is still uncertainty around how vulnerable they will be to FOAK issues** — SMRs are expected to be more efficient to build than traditional large reactors. However, this is yet to be proven in practice. In addition, it is essential that SMRs be produced in series, to compensate for the diseconomies of scale of a smaller reactor. That can only be achieved by a successful developer who can build SMRs in multiple locations. — It is believed that the Netherlands can minimise its risks by waiting until any FOAK issues have been resolved and it is clear which developers are able to successfully build SMRs. In that case, it will only be after 2027-2033, once the first SMRs are operational, that the Netherlands can potentially initiate the process of constructing an SMR. Collaboration with other European countries will also be an option.

Note: (a) Based on Flamanville 3, Hinkley Point C, Olkiluoto 3, Hanhikivi and Vogtle. (b) At the request of the Ministry of Economic Affairs and Climate Policy, Chinese and Russian technologies were excluded from this analysis.

Source: (1) Economics and finance working group report, Canada's SMR Roadmap (2018). (2) Reports by EDF, Fennovoima, the British government and the World Nuclear Association. (3) Economics and finance of Small Modular Reactors, Mignacca & Locatelli (2020). (4) Projected costs of generating electricity 2020 edition, IEA & OECD-NEA (2020). (5) Advances in small modular reactor technology developments, IAEA (2020). (6) Reports and press releases from the designers concerned.

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Financing summary	**As part of the market consultation, the possibilities and impossibilities of private financing were investigated, as well as the preconditions that private financiers are expected to have** — For this part of the market consultation, interviews were held with asset managers, banks and investment banks, government agencies, export financiers and pension funds. These conversations were supplemented with research into the financing of existing nuclear energy projects. — The analysis included non-financial preconditions and possible financial (government) guarantees and contributions, such as ESG (*Environment, Social and Governance*) characteristics (including a green taxonomy), stable political policies, public support and the handling of waste, as well as possible guarantees around commercial risk (revenue risk), construction risk (ordinary and licensing risks) and future decommissioning costs. **The interview programme revealed that market participants are expected to place a wide range of terms on their potential participation** — Nuclear power plants have an average lead time for design and construction of around 11 to 15 years, with substantial risk of delays. This means that it is a relatively long time before any revenue can be generated from the sale of energy. At the time of investment, a picture must be formed of how the energy market will look more than 10 years into the future, which for many participants is too long. — Existing (FOAK-)Generation III+ projects are primarily financed by the government and/or the nuclear technology supplier (vendor). Where there is partial private financing, the government is involved via various guarantees. The expectation is that vendors will have very little willingness or ability to provide financing, so the government would have to play a significant financial role in any Dutch nuclear project.
Non-financial elements: Public support, political climate, ESG and waste handling	**Adequate public support and stable government policies are preconditions for private financing** — The majority of private financiers consider non-financial risks to be individually preconditional. Due to the long lead time and substantial level of investment, stable political policies supported by adequate public support for nuclear energy are key requirements for private financiers. Their absence would result in too great a risk of policy changes before the project is complete. The government can show commitment by embedding nuclear energy in policy, as well as by acquiring a financial stake in a reactor project. At a minimum, private financiers are expected to require some form of investment protection (in case the project is terminated prematurely, due to policy changes for example). **The proposition must fit within investors' ESG frameworks to gain approval for an investment in nuclear energy. The classification of nuclear energy as a green, sustainable investment is seen as beneficial for gaining approval** — When making an investment decision, private financiers look at the broad ESG characteristics of the proposition. Partly from the perspective of reputation, the ESG case (both environmental and social aspects) must stack up. If it does not, the investment is unlikely to make it past the *investment committee* or internal decision-making structure. Investors are increasingly attaching great importance to *net-zero investments*. The EU could make a positive contribution by including nuclear energy in its green taxonomy. — As part of the ESG assessment, private financiers indicated that nuclear waste is a significant reputational risk and that in order to proceed with the financing of a nuclear power plant it is important that there is positive outlook on a long-term solution.

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Guarantees and risk appetite of private financiers	**Based on the interview feedback, it is expected that private financiers will require a range of guarantees from the government. Private financiers are willing to bear the risks they can control, with the government shouldering any other risks** — Private financiers were nearly unanimous in stating that revenue certainty is important and must be provided via the financing model and/or government guarantees. The participants indicated that provided a revenue guarantee was forthcoming, and provided the reactor concerned was not a FOAK, there would be willingness to bear the 'ordinary' risks of construction. A guarantee covering substantial cost increases is expected to be required, partly due to *black swan* risks. Private financiers are prepared to bear ordinary operating risks after the start of operations. — Although there is a willingness to bear ordinary construction risks, private financiers would require a guarantee covering licensing risks during construction. Several private financiers also stated that they would only become involved once a licence had been obtained. Changes to licensing requirements (during construction) could lead to substantially higher costs and longer lead times. Private financiers indicated that the government should bear this risk, since financial backers have no influence on policy changes by regulators. — The market participants signalled a willingness to set up the required fund to cover future decommissioning, provided the return from the overall business case remains appropriate. The private financiers indicated that the risk of a rise in decommissioning costs is substantial and that there is little willingness to pay additional decommissioning costs on top of the initial estimate, or to bear costs resulting from so-called '*black swan*' events (such as a bankruptcy or incident). A black swan event will certainly lead to the loss of the investment, or a significant portion of it, but could also result in additional losses. These risks could be substantial, and cannot be estimated or controlled by private financiers. Consequently, they should be covered by a guarantee. To protect their reputations, private financiers expect a sound decommissioning plan to be in place.
Returns and cash flows	**Private financiers indicated that revenue guarantees are imperative for private financing. Such guarantees can be provided through a range of financing structures** — It is difficult to get an indication of the required return, partly due to the limited involvement of private financiers in existing nuclear projects. - The interviews and desk research showed that the return on equity required by private financiers ranges from around 7-9% (Hinkley Point C) to around 10-15%.[1)] Return requirements depend partly on the project's risk profile, and partly on the type of private financier. A lower required return could potentially lead to a lower LCOE. — Market participants need a degree of certainty around returns. To this end, a range of financing structures are applied in the market, offering either price guarantees (*Contract for Difference*, 'CfD', or *Power Purchase Agreement*, 'PPA') or offtake guarantees (Mankala model or PPA). — The market participants indicated that many prefer the *Regulated Asset Base* (RAB) model, which is untested in a nuclear energy context. Under this model, the government pays a fee to the investor during the construction phase, and also provides revenue certainty during the operating phase. Application of the RAB model to a Dutch nuclear power plant project would present significant challenges.

Source: (1) Hinkley Point C – Report by the comptroller and auditor general, National Audit Office (2017).

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Financing structures	**With almost all current nuclear projects, a financing structure is used where the government and/or the nuclear technology supplier is directly and/or indirectly involved** — In addition to full government financing, a range of financing structures have been used in the market, such as the Finnish Mankala model, CfDs and PPAs. The RAB model was also mentioned as an interesting option. In practice, the RAB model has, to date, mainly been used to finance large infrastructure projects in the United Kingdom.[1)] **The cooperative Mankala model is a 'power at cost' model in which the investment and (depending on guarantees) a significant portion of the risks are borne by a large number of private parties (including around 50-60 large industrial electricity consumers)** — The Mankala model is a 'power at cost' model in which a consortium is formed by multiple private parties who collectively hold a majority of shares in the nuclear reactor. After commissioning, these parties are required to purchase energy from the nuclear power plant at cost. They primarily use the energy they purchase for their own activities. The remaining portion may be sold by these parties to non-participating consumers. — During construction, the current practice (as seen at Hanhikivi, for example [2)]) is that a substantial amount of the financing is provided by the nuclear technology supplier (via equity or subordinated loans), possibly in combination with export financing. This means the construction risk is largely borne by the developer and the vendor. — This model appears to be less suitable for use in the Netherlands, partly due to the lack of sufficient participants (i.e. large industrial consumers). **Other financing structures mainly focus on providing revenue certainty** — To limit the revenue risk, in certain projects a PPA or CfD is used. A PPA is an agreement between an energy supplier and a major consumer about prices and purchase volumes. In the current market, PPAs have an average term of 10-15 years. PPAs generally have an immediate start date, or start within a few years. It is not possible to sign a PPA with a start date more than 11-15 years in the future, because no active market exists. — A CfD provides a long-term price guarantee (35 years, for example) for the operator at a '*strike price*'. If the market price is less than the strike price, the government makes up the difference. When the market price is higher than the *strike price*, the supplier pays the difference to the government. — In addition to revenue certainty through a PPA or CfD, financiers are expected to ask the government for a range of guarantees. A situation such as the one at Hinkley Point C, where the *vendor* (EDF) carried the full construction risk, is not expected to be realistic for a new project. **Under the RAB model, revenue is generated during construction. This must provide a reasonable return to financiers to compensate for the construction risk and decommissioning risk** — The RAB fee is made up of several components. Under the RAB model, part of this fee is already paid out during the construction phase. The fee must cover 'reasonable' costs (including depreciation costs, operating costs and costs related to decommissioning, up to a certain level) and provide a reasonable return on regulated assets. The RAB model can also mitigate construction risks for private financiers. The government can issue a guarantee ('*funding cap*'), which means investments above a certain amount will be covered by the government. In this situation, the government receives an equity stake in the project in exchange for the investment.

Source: (1) Consultation on a regulated asset base (RAB) model for nuclear, Department for Business, Energy & Industrial Strategy (2019). (2) Mankala Principle, Finnish Ministry of Economic Affairs (2018).

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Financing mix	**Government involvement appears inevitable due to the substantial size of the investment, substantial risks and long lead time** — Most existing projects feature significant government involvement, often via direct financing, as well as a significant degree of financing by the nuclear technology supplier. — Several existing projects involve a significant degree of financing by the nuclear technology supplier. The market participants indicated that this is not realistic for new projects, due to the financial capacity of these vendors. In addition, the main goal of such financing for the vendor is to develop the first reactor (FOAK) using its technology, in order to prove the technology. - Russian and Chinese suppliers might still be prepared to provide financing. However, at request of the Ministry, these parties were not included in this study. — The market participants indicated that private financing without extensive government guarantees would be difficult or impossible to achieve. In addition to various government guarantees, the government is expected to participate in the project and provide a significant portion of the equity financing. A large nuclear power plant is too big an investment for many private investors, and has too long a horizon. — A number of market participants suggested that the government should build a new reactor, and should largely finance the project itself (through equity, loans (low-interest or zero-interest) or a combination of the two). After commissioning or after the start of operations, the reactor's risk profile decreases for private financiers, at which point a sale could be considered. — It should be noted that private parties not only contribute capital, they also contribute knowledge. The involvement of private financiers can also have a disciplining effect. This could be a reason to consider private financing via pension funds, institutional investors and/or a *vendor*/energy supplier, alongside government investment. **If the right preconditions are put in place, and if the technology and design are proven, the development of an SMR could offer greater opportunities for private financing** — Although SMRs are still in development, they could offer opportunities for private financing due to the shorter construction time and lower investment required. This is based on the premise that the ESG case is strong, there is adequate public support and stable political policies are in place. In such a situation, financing could, for example, be provided by a combination of institutional investors and an energy supplier. The government would still have to provide the range of guarantees mentioned above. — The market participants indicated that private financing will only become realistic in Europe once several SMRs have been successfully built and the technology and design have been proven, with the design being built in series (i.e. after 2033). With SMRs, the FOAK risks will have to be borne by the government, similarly to large nuclear reactors.

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Regulations	**In the recent past, cost and time overruns resulting from the licensing process have been a common problem. The design and licensing process poses a significant cost risk and thus a barrier to developing a nuclear power plant** — Delays and cost overruns resulting from the licensing process can occur due to factors including modifications to the design because a country has set specific safety requirements (such as fire safety requirements for Hinkley Point C) or adjustments to safety requirements during construction (as happened with Olkiluoto 3 after Fukushima). — The decision-making model used in the licensing and investment decision-making process can also result in high costs and risks, creating a barrier to entry. In the case of Hinkley Point C, according to various market participants the developer spent roughly EUR 1 billion on the design phase before the investment decision was made and another EUR 1 billion on pre-construction preparatory work.[1)] **The market participants therefore advocate for transparency, harmonisation and predictability in the Dutch licensing process** — Issuing a licence for a nuclear power plant is not a simple process. As well as international regulations, every country has its own design and safety requirements. — To keep costs down, the market participants indicated a strong desire for the Netherlands to align as closely as possible with international standards and to allow as much use as possible to be made of the evidence used in licensing processes in other Western countries. — Another significant desire of the market participants is for the licensing authority not to require any changes to be made to the design during construction. However, the construction time for a nuclear power plant is long, and there is a high chance of relevant developments occurring during that period (such as policy changes or an incident). It is important to determine in advance how such developments will be handled and who will bear the costs. — The market participants also proposed that, following a positive decision to develop a nuclear power plant, the licensing authority should enter into conversation with possible suppliers as soon as possible, to ensure everyone is on the same page and to align expectations. **The market participants are cautiously optimistic that this will happen in the Netherlands** — The Dutch licensing authority (ANVS) indicated that it is aligned as closely as possible with international standards and that the Dutch legal framework is goal-oriented. It allows scope for the use of foreign design codes, standards and evidence rules, provided the reactor is suitable for the location and meets Dutch (and European) requirements. However, nuclear installations are required to make continuous improvements. New insights can thus lead to tighter requirements, within reason. The ANVS is the competent authority in this regard. — The market participants think that actually achieving cost savings in the licensing process will be challenging. Such an achievement would significantly depend on the level of open communication, collaboration and trust between regulators and their foreign colleagues (if they are to accept information from abroad). — Based on experiences in other countries, the market participants indicated that additional demands and requirements are often still imposed, which have the effect of driving up costs.

Source: (1) EDF's Hinkley Point seen overrunning budget – Le Monde \| Reuters (last accessed on 10 June 2021).

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Topic	Summary
Construction time	**The expectation is that a Generation III+ nuclear power plant can be built within 11-15 years from the start of the licensing process** — The licensing process for a nuclear power plant based on a proven design is expected to take three to five years. — Based on recent construction projects outside the EU, Generation III+ nuclear power plants have a construction time of approximately eight to ten years. The ongoing Generation III+ nuclear power plant projects within the EU (in France and Finland) are not yet complete, and deviate from this range with expected construction times of 15 and 16 years, respectively.[1] The market participants indicated that they expect that with the experience gained, the construction time could be reduced to six to eight years. **For an SMR based on a Generation III+ reactor design, construction is expected to take around 10 years from the start of the licensing process, but a proven design will not be available until 2027-2033 at the earliest** — The licensing process for an SMR based on a proven Generation III+ reactor design is expected to take around five years. For a design based on a Generation IV reactor, the process is expected to take around 10 years. — The expected construction time for a FOAK SMR would be around four to five years, but construction times for such a reactor have not yet been proven.[2] — A proven operational design of a Generation III+ SMR is not expected to be available until 2027-2033 at the earliest (expected to be in Canada or the US).[3] Large-scale commercial implementation of the first Generation IV technology is not expected until around 2045.[4],[5] Of the Generation IV technologies, it is expected that uranium-based models will be the first to emerge. - The market participants indicated that the Netherlands could opt for an SMR design sooner, but the options would be more limited and the Netherlands would have to deal with potential FOAK costs and delays.

Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). (2) Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020). (3) Advances in small modular reactor technology developments, IAEA (2020). (4) Preparing the future through innovative nuclear technology: outlook for generation IV technologies, GIF (2018). (5) GIF R&D outlook for generation IV nuclear energy systems: 2018 update, GIF (2018).

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Topic	Summary
Decommissioning	**Decommissioning a nuclear power plant is a lengthy and complex process that can take up to 20 years (in the case of immediate decommissioning)** — In the Netherlands, nuclear power plants must be decommissioned immediately after normal operations end. Depending on the size of the power plant, the target end state and local laws and regulations, the process of immediate decommissioning can take up to 20 years.[1),2),3)] — Furthermore, in the Netherlands it has been agreed that decommissioning work must be completed as quickly as reasonably possible, and that the end result must be a 'green field', suitable for alternative purposes.[2),3)] **The average costs of immediate decommissioning for European nuclear power plants are estimated at around EUR 0.6 million per MW** — The costs of immediate decommissioning of European nuclear power plants are estimated at around EUR 0.6 million per MW on average.[1)] The actual costs of decommissioning depend on the type of decommissioning, the lead time, wage costs and the size of the power plant, among other factors. — In the Netherlands, decommissioning costs are to be paid by the licence holder, which must be able to show that it has sufficient financial resources for the task. Every five years the decommissioning plan and financial collateral must be approved by the government.[3),4)] — The financial collateral may be provided through the creation of a fund, by means of a bank guarantee, or by providing any other suitable security that covers the decommissioning costs.[3),4)] **In the Netherlands, there is a preference for financial collateral in the form of a fund** — In the Netherlands, fund creation is preferred over other forms of collateral. Creating a fund into which money is periodically deposited provides the greatest degree of certainty because the money is actually set aside.[5)] — An alternative model for safeguarding the financial collateral that is used in some countries is to maintain a reserve for decommissioning costs on the balance sheet of the licence holder (against cash or cash-like assets). — The market participants expressed a preference for the creation of a fund; they indicated that this is more robust, and less exposed in the event of bankruptcy. Creating a fund in the name of a separate entity is the approach currently adopted in the Netherlands; Borssele, for example, uses the entity Foundation for the Management of Decommissioning Funds for the Borssele Nuclear Power Plant (in Dutch: 'Stichting Beheer Decommissioningsgelden Kerncentrale Borssele', 'BOKB').[6)]

Source: (1) The cost of decommissioning nuclear power plants, OECD-NEA (2016). (2) Decree on nuclear installations, fissile materials and ores. (3) Removal of energy installations (Part II): Nuclear installations, van Beuge (2016). (4) The Nuclear Energy Act. (5) Financial Collateral under the Nuclear Energy Act, KPMG (2005). (6) 2020 Annual Report, N.V. Elektriciteits-Productiemaatschappij Zuid-Nederland EPZ.

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Topic	Summary
Decommissioning	**The market participants would therefore like to see additional guarantees from the government to cover risks over which they have little control and which would have major financial consequences** — The market participants would like to see a guarantee from the government to cover decommissioning costs in the event of premature bankruptcy of the operator. If the operator goes bankrupt, the shareholders would lose their investment, and might also have to bear the cost of the shortfalls in, and remaining contributions to be made into, the decommissioning fund. — The market participants indicated that the risk of unforeseen cost increases related to decommissioning must be borne by the government. They also pointed out that decommissioning costs are difficult to predict in advance. - The technical uncertainties associated with decommissioning may decrease as countries around the world gain more decommissioning knowledge and experience. In 2021, COVRA will start designing the necessary future decommissioning and waste infrastructure and will make calculations/estimates of the investments that will be required. The results of this study can be used in developing cost estimates for decommissioning. - However, possible interim amendments to laws and regulations and changes to waste handling costs are expected to always result in a degree of uncertainty with regard to the actual decommissioning costs. — In addition, the market participants expect a guarantee to cover black swan risks (such as an incident), as well as the reimbursement of costs for decommissioning before completion of the construction phase (for example if the government decides to cease construction of the power plant in response to an incident).

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Topic	**Summary**
Waste	**In the Netherlands, nuclear waste is handled centrally by COVRA** — Through COVRA, a 100% state-owned company, the Netherlands provides medium-term storage of nuclear waste for approximately 100 years. COVRA is the only recognised organisation in the Netherlands that is allowed to collect, process, package and store radioactive waste.[1)] — COVRA charges its customers a fee, in return for which it accepts the nuclear waste and takes full responsibility for it. COVRA bears the long-term management risk including final disposal, which ensures that producers of radioactive waste are not subsequently confronted with higher, unforeseen costs.[1),2)] This is important for private financiers. **COVRA regularly expands its storage capacity, ensuring it has sufficient capacity to store currently-expected waste** — COVRA has 20 hectares of land on which five storage buildings are located. Some of the storage is designed for low- and medium-level radioactive waste and some for high-level radioactive (nuclear) waste.[1)] — The radioactive waste from Borssele, the HFR in Petten and the reactor in Delft is stored in the high-level radioactive waste treatment and storage building (HABOG). Work is currently underway to expand the HABOG.[1),3)] — Once this expansion is complete there will be sufficient capacity to store the nuclear waste from Borssele until its planned closure in 2034, possibly enough for a further extension of operations, and sufficient capacity available for waste from the possible new Pallas reactor.[1),2)] **If a new nuclear power plant is built, the capacity will have to be expanded again** — A Generation III+ reactor with a capacity of 1,600 MW could generate approximately 10 to 11.5 m3 of additional high-level radioactive waste per year and around 230 to 250 m3 of low- and medium-level radioactive waste per year. [a) 2)] — Because COVRA's storage capacity has a modular setup, a further expansion of capacity would be relatively simple from a technical point of view. However, if new nuclear power plants are developed, additional industrial land is expected to have to be purchased for the storage of low- and medium-level material. There does appear to be sufficient space, but public support would be required.[2)] **According to the market participants, underground (geological) final disposal is the only real and technically feasible long-term solution for radioactive waste, but this is not expected to be achieved in the Netherlands until 2130 for technical and economic reasons** — In Europe, no underground final disposal for high-level and long-lived radioactive waste is currently in operation. However, work is being done in Finland, Sweden and France to create final disposal facilities. The first facility is expected to become operational in 2025 in Finland.[2),3),4)] — According to COVRA research, final disposal in the Netherlands is certainly possible. The Netherlands has sufficient suitable salt and clay deposits where final disposal could be achieved at a depth of 500 metres.[2)] — The Dutch government has decided that COVRA should store radioactive waste for at least 100 years before proceeding with final disposal. Geological final disposal is anticipated in around 2130. In around 2100, a decision will be made about the final location.[5)] — According to COVRA, final disposal can technically be achieved sooner, but doing it later might be more economical (lower costs per m3 of waste and more time to earn returns on financial provisions) and opens up the possibility of benefitting from new technological developments.[2)]

Note: (a) The Borssele nuclear power plant produces around 3 to 3.5 m3 of high-level radioactive waste per year, and around 70 to 75 m3 of low- and medium-level radioactive waste per year. Extrapolating this volume, an EPR with a capacity of 1,600 MW could generate 10 to 11.5 m3 of high-level radioactive waste and 230 to 250 m3 of low- and medium-level radioactive waste per year (KPMG analysis, indicative).

Source: (1) 2020 Annual Report, COVRA (2020). (2) KPMG interview programme (2021). (3) Storage building for high-level radioactive waste being expanded (https://www.covra.nl/nl/organisatie/nieuws/uitbreiding-habog/, last accessed on 15 June 2021).

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Topic	**Summary**
Deploying a nuclear power plant	**A nuclear power plant can be operated in baseload mode or load-following mode** — A grid has a base load and a peak load. The base load is the minimum electricity supply required on the network for a specific period, given the demand. The peak load is the maximum electricity supply required on the network for a specific period. — A nuclear power plant can be used to supply the base load, which means the plant will operate continuously. A nuclear power plant can also be deployed in load-following mode, thereby producing adjustable power to cover the peak load. Or it can be used as a combination of the two. — Nuclear power plants are largely operated as baseload power plants with a capacity factor of >80%.[1)] — France and Germany are examples where nuclear power plants are partially operated as load-following power plants. In Germany, they serve as a backup to the relatively high percentage of solar and wind energy, which have a variable production profile. In France, they supply adjustable power because the mix of nuclear energy in the overall system is high, at 71%.[1),2)] **The market participants advised that a nuclear power plant in the Netherlands should be operated as a baseload power plant** — The market participants indicated that baseload operation is the most economic way to use a nuclear power plant. The fixed costs (construction costs) are very high and the variable costs relatively low (uranium is cheap per MWh).[3),4),5)] On this basis, it is more economic to operate a nuclear power plant continuously. This means a nuclear power plant can supply cheaper electricity (LCOE) at a higher capacity factor.[5)] — Furthermore, baseload operation better aligns with the technical aspects of existing nuclear power plants. It is technically complex to switch them on and off, and to scale them up or down. The technology is not particularly flexible or fast, unlike a gas-fired power plant, for example.[2),6),7)] Modern power plants can do this better (most power plants can handle load variations of 50-100% of the rated output at a rate of 3-5% per minute), but it costs more because of the technical actions required, and also results in more maintenance costs due to the increased wear and tear.[2),8),9),10)] **If the government wants a nuclear power plant to be able to operate continuously, government intervention in the market will be necessary** — Nuclear energy has lower marginal costs than fossil fuel alternatives, but not as low as the marginal costs for wind and solar. This leads to the possibility that wind and solar could push nuclear energy (and energy from coal and gas) out of the market at times of peak production (in very sunny and/or windy conditions) when there is insufficient demand to absorb the peak supply. This is expected to happen more often in the future as the share of wind and solar in total production increases.[11),12)] - According to a TenneT forecast, in 2030 a nuclear power plant might only be able to operate 68% of the time.[13)] — If the government wants the nuclear power plant to operate all the time, it will have to issue a price guarantee (in the form of a CfD, for example) to allow the nuclear power plant to produce power below cost. The market participants also suggested that nuclear energy could be subsidised, for example through the SDE++ scheme.

Source: (1) World nuclear performance report 2020, World Nuclear Association (2020). (2) Non-baseload operation in nuclear power plants, IAEA (2018). (3) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). (4) Uranium markets, World Nuclear Association (2020). (5) Projected costs of generating electricity 2020 edition, IEA & OECD-NEA (2020). (6) Nuclear energy and renewables, OECD-NEA (2012). (7) Load following capabilities of nuclear power plants, Sustainable Nuclear Energy Technology Platform (2017). (8) Technical and economic aspects of load following with nuclear power plants, OECD-NEA (2011). (9) Additional costs for load-following nuclear power plants, Elforsk (2012). (10) Load-following with nuclear power plants, Lokhov (2011). (11) Energy transition model. (12) Nuclear energy economics, TNO (2018). (13) Monitoring Security of Supply 2020, TenneT (2020).

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Topic	Summary
Deploying a nuclear power plant	**Nuclear energy can also be deployed to provide carbon-free adjustable power to keep the grid stable, but this is a relatively expensive solution** — Electrification and the sharp rise in the proportion of renewable energy have put pressure on the stability of the grid. Grid operator TenneT stated that more flexibility in power generation will be required in the future to balance supply and demand, perhaps as much as 24-27 GW by 2030.[1)] — In the Netherlands, adjustable power is traditionally provided by gas-fired power plants, which according to policy projections are going to be phased out. The market participants indicated that various alternatives to natural gas are available to provide carbon-free adjustable power, including hydrogen, green gas and nuclear energy.[2),3),4)] — Modern nuclear power plants in particular possess considerable flexibility and can be used as a backup to solar and wind energy. They are not as effective in this role as gas-fired power plants, but are better than coal-fired power plants.[5),6),7)] — The market participants indicated that nuclear power plants could be deployed in load-following mode to provide adjustable power, but that this is a very expensive way to operate them. - The LCOE increases by around 10% when the capacity factor falls from 80% (base load) to 70% (load following). One reason why the average costs increase is that the relatively high fixed (investment) costs are spread out over fewer productive hours.[8)] In addition, the deployment of a nuclear power plant in load-following mode results in additional maintenance and fuel costs.[6)] — To make flexible operation profitable, the government would have to provide a subsidy to compensate for the lower production hours. — The market participants indicated that if flexibility in power generation is desired, it would be better to build several small SMRs than one large nuclear power plant. This would give more flexibility with upscaling and downscaling as well as more security when production issues occur than at a single nuclear power plant. **When used to provide adjustable power, surplus nuclear energy could be used for hydrogen production to improve the profitability of nuclear power plants** — Hydrogen may play a key role in the transition towards a carbon-neutral energy supply. Projections show that demand for hydrogen could rise to as high as 1,600 petajoules per year by 2050.[9)] — Nuclear power plants can produce hydrogen when other technologies (with lower marginal costs) are producing sufficient electricity. This would mean the nuclear power plants would have to scale down less often. — Although the technology has not yet been proven on a large scale,[10),11)] several market participants indicated that nuclear power plants are particularly well-suited to hydrogen production. — Some market participants and studies indicate that hydrogen produced from nuclear energy may not be able to compete with other technologies, while other projections predict that new-generation nuclear power plants built around 2030 will be able to supply relatively cheap hydrogen.[10),12)]

Source: (1) 2030 electrification and demand profile, TenneT (2020). (2) 2020 Climate and Energy Outlook, PBL (2020). (3) Scenarios for a climate-neutral energy system, TNO (2020). (4) The energy system of the future, Netbeheer Nederland (2021). (5) Nuclear energy and renewables, OECD, NEA (2012). (6) Non-baseload operation in nuclear power plants, IAEA (2018). (7) Load following capabilities of nuclear power plants, Sustainable Nuclear Energy Technology Platform (2017). (8) Projected costs of generating electricity 2020 edition, IEA & OECD-NEA (2020). (9) Hydrogen in the Netherlands, TNO (2020). (10) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (11) Hydrogen production and uses, World Nuclear Association (https://www.world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.aspx, last accessed on 1 June 2021). (12) Missing link to a livable climate, Catalyst (2020).

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Topic	**Summary**
Borssele	**The market participants recommended extending the service life of Borssele for financial reasons and maintaining the knowledge/value chain in the Netherlands** — Several studies show that the electricity generated in nuclear power plants following a service life extension is associated with lower electricity costs than electricity from new nuclear power plants (more than 65% lower in some cases).[1)] — The market participants also emphasised that it is important to maintain the knowledge and expertise currently present in the Netherlands (both with parties in the value chain and with the regulator ANVS). This will give the Netherlands flexibility to add nuclear energy to the energy mix now or in the future. **If the service life is extended, it will be necessary to review Borssele's financing and ownership structure** — The Borssele nuclear power plant is subject to commercial risks, since market prices sometimes fall below the cost price and Borssele does not have a guaranteed minimum purchase price. When this happens, the shareholders have to absorb the loss. If the service life is extended, it is expected that the shareholders will not be willing to continue to bear these commercial risks. - RWE and PZEM buy electricity from the Borssele nuclear power plant at a fixed price of EUR 43 per MWh, under a tolling agreement. EPZ therefore receives a cost-plus price for the electricity produced.[2)] - RWE and PZEM sell the electricity on the open market. Because the market prices of electricity are sometimes lower than the cost-plus purchase price they pay to EPZ,[3)] at those times, they make a loss on their stake in the power plant. — As with the financing of a new nuclear power plant, if the service life is extended it is expected that a government contribution will need to be considered. This could take the form of a government stake and/or a CfD (or an SDE++ subsidy) guaranteeing a minimum purchase price. **Borssele will have to undergo a safety evaluation before its service life can be extended, but the market participants indicated that they did not anticipate any issues** — To keep the Borssele nuclear power plant operating for longer, the Nuclear Energy Act would have to be amended and the current licence would have to be modified. For operations to continue after 2033, the underlying safety report would also have to be updated. In the safety report, the licence holder must demonstrate that the nuclear power plant can meet the technical safety requirements.[4)] — The market participants indicated that they did not anticipate that this would cause any issues for Borssele. Borssele has undergone a number of safety adjustments over the years and a recent benchmark report indicated that Borssele is in the top 25% of the safest pressurised-water nuclear power plants in the Western world.[5)]

Source: (1) Projected costs of generating electricity 2020 edition, IEA & OECD-NEA (2020). (2) Advice on financial issues in the Province of Zeeland, Jansen Temporary Committee (2017). (3) Bloomberg (2021). (4) Authority for Nuclear Safety and Radiation Protection (https://www.autoriteitnvs.nl/, last accessed on 31 May 2021). (5) Borssele safety benchmark, Borssele Benchmark Committee (2018).

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Topic	**Summary**
Impact on the local economy	**The market participants indicated that they expect that construction of a nuclear power plant in the Netherlands could make a positive contribution to the Dutch economy. Estimates range from around 20% to 80% of the total work** — Construction of a 1,000 MW nuclear power plant would require approximately 12,000 direct working years.[1)] — The market participants indicated that large numbers of local suppliers could potentially be involved in the construction phase of a nuclear power plant. The proportion of local suppliers would depend on local knowledge and expertise, regulations and the financing structure, among other factors. Estimates range from around 20% to 80%. - In the construction of Hinkley Point C, approximately 64% of the work was contracted out to local companies.[2)] — This locally-contracted work is primarily civil engineering work. The market participants indicated that approximately 60% of the construction of a nuclear power plant consists of civil engineering work. Support activities such as catering, security, equipment, etc. could also be sourced locally. — It is likely that less work would be sourced locally if an SMR were to be built, because the intention would be for a significant amount of construction to take place in a factory. — The market participants indicated that, in theory, any capacity, knowledge or skills that are not immediately available can be imported, but this depends on local legislation such as labour laws. **After commissioning, a nuclear power plant could continue to contribute to the local economy and boost employment** — The operation of a 1,000 MW nuclear power plant would require an average of 600 full-time jobs per year, based on a 50-year service life. Over the entire service life of a nuclear power plant of this size, a further 1,000 indirect jobs would be created.[1)] — The jobs created would mainly be well-paid, highly-skilled jobs. For some regions outside the Randstad region of the Netherlands, this could be a significant consideration. — The market participants also indicated that the construction of a new nuclear power plant would boost nuclear knowledge infrastructure in the Netherlands.

Source: (1) Measuring employment generated by the nuclear power sector, OECD-NEA & IAEA (2018). (2) How construction of Hinkley Point C is supporting companies in Britain, EDF (https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/for-suppliers-and-local-businesses/built-in-britain, last accessed on 30 May 2021).

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Topic	Summary
Location	**Based on the interviews, two possible locations can be identified, with one more promising than the other** — Until recently, the Dutch government had set aside three locations for a potential nuclear power plant, namely Eemshaven, Maasvlakte I and Borssele. Eemshaven was recently ruled out following a motion in Parliament.[1)] However, other possible locations have not been excluded. — In the context of answering the third question of the market consultation, provincial authorities and a number of government bodies were approached for an interview. It was agreed with these parties that the information gathered from the interviews would be shared within this report, as set out in the 'Nuclear power plant location' chapter of this report, only with their permission. — Based on the interviews and relevant preconditions, one possible location emerged where one or more large nuclear power plants and/or SMRs could be built: the municipality of Borssele in the province of Zeeland. This location has local support, appears the most promising from a cooling water perspective, and seems to have no problems with grid connections. — There is another location, in the province of North Brabant, where a nuclear power plant could possibly be built at some point in the future. The challenges for that location relating to local support, cooling water and integration appear more significant than for the possible location in Zeeland. **Neither of the two possible locations is expected to face challenges around electricity grid congestion** — The market participants indicated that situating a large nuclear power plant along the main power grid is the obvious choice. Such a location is expected to require the least amount of infrastructure investment and relatively easy integration, since little to no new infrastructure would have to be built. - The key figure for the cost of a standard double-circuit connection is approximately EUR 10 million per kilometre.[2)] — With large nuclear power plants, local congestion must be considered, for example near landing locations for offshore wind energy. — SMRs have more flexibility because of their lower power output (10-300 MW) and the ease of integrating them into the grid is comparable to that of smaller coal-fired power plants (such as the former Maasvlakte power plants). — At Borssele, there appears to be capacity for one or two large nuclear power plants (1,200-1,500 MW) due to the already-planned expansion of the main power grid. The potential electrification of local industry could offer even more capacity. [a),b),3)] — There also appears to be sufficient transmission capacity in West Brabant (Moerdijk/Geertruidenberg) due to the same planned expansion. — For both locations, the relationship with and dependence on possible future developments applies to both the production side and the demand side, in addition to what has already been taken into account.

Note: (a) After the expansion, there will be approximately 6,500 MW of grid capacity. Taking offshore wind (around 3,500 MW) and the current Borssele nuclear power plant (around 500 MW) into account, there will be 3,000 MW left over. Possible future developments (on both the production side and the demand side) above this capacity demand, particularly from offshore wind, could have consequences for grid capacity. (b) If two nuclear power plants were connected, a new transformer station would have to be built, to ensure that an outage at the station would not result in disruption to the electricity supply. TenneT applies the rule of thumb of a maximum of 5.5 to 6 GW of production capacity per station.

Source: (1) Motion by Member of Parliament Beckerman et al. ruling out Groningen as a nuclear power plant site (4 March 2021). (2) The energy system of the future: Comprehensive Infrastructure Survey 2030-2050, Netbeheer Nederland (2021). (3) TenneT.

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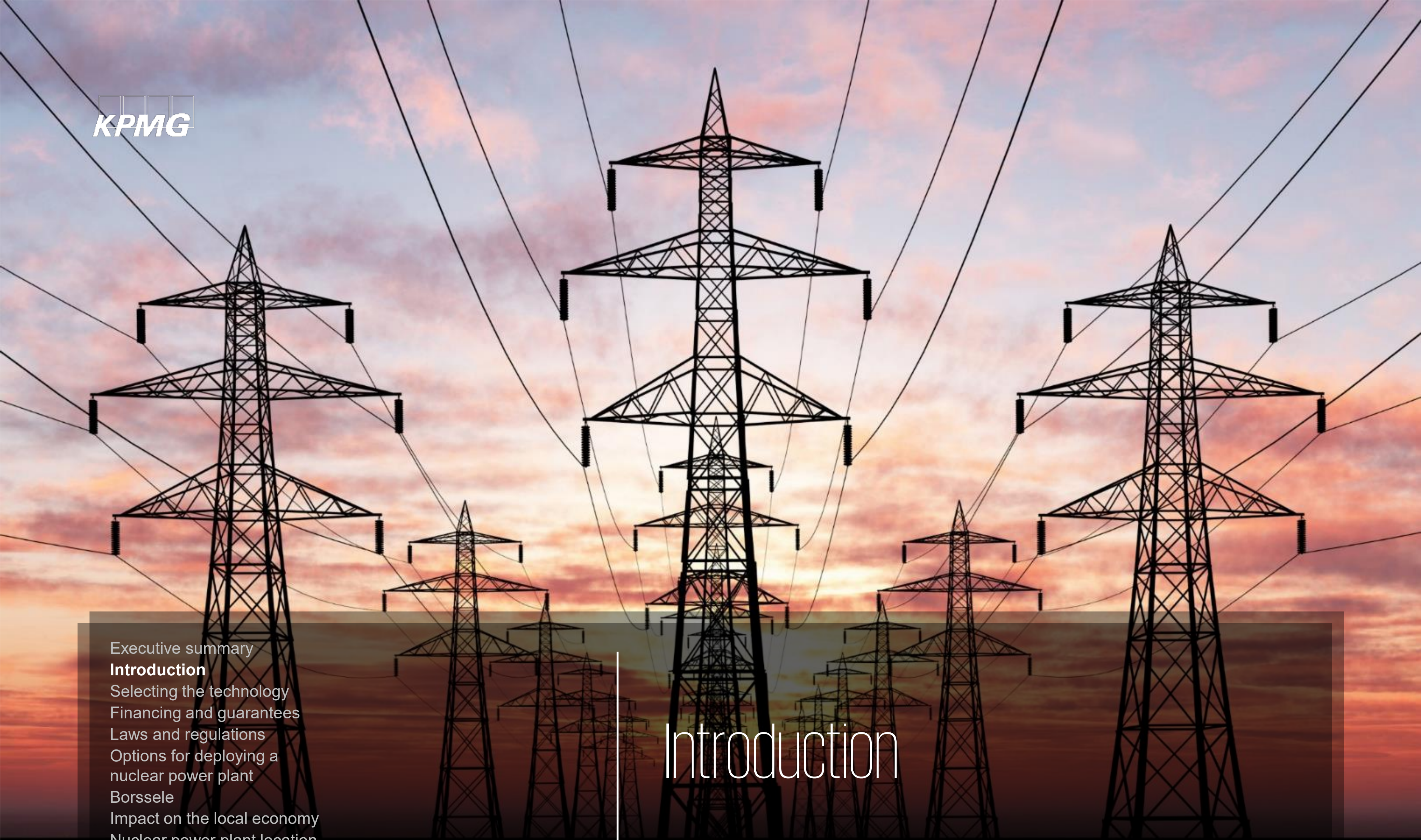
Topic	**Summary**
Location	**For any possible location, the availability of cooling water is essential, and from that perspective a location near the sea would probably be the most viable** — In relation to the discharge of cooling water, surface water temperature is the most restrictive precondition for a new nuclear power plant. The effect on fish from the intake of cooling water is another possible issue to consider. — Given their small volume, regional bodies of surface water (smaller bodies of water, controlled by a water board) cannot be considered for this purpose. Of the large bodies of water, the IJsselmeer is also not a desirable location, given its poor flow-through and the maximum permitted rise in water temperature. — In addition, nearly all of the large rivers in the Netherlands face challenges relating to surface water temperature and are not expected to have sufficient thermal capacity to serve as cooling water for a large nuclear power plant. — If an SMR is selected, it can be investigated whether it could be located at the site of a coal-fired power plant that is to be decommissioned, to take advantage of the thermal capacity of the cooling water that would be freed up. However, given the restrictive situation in terms of temperature and the fact that each new initiative (even if it replaces an existing power plant) must be assessed again against the current legal framework, it cannot be taken for granted that there will be sufficient thermal capacity at such sites for the use of cooling water. — If a decision is made to build a new nuclear power plant, it seems that a coastal location offers the most opportunities for integration. However, when the exact location is known it will be necessary to examine specifically the precise local effects of the use of cooling water on the ecology (particularly the consequences of cooling water intake on fish and the consequences of the heat discharge on the ecosystem). — The above is a very generalised high-level assessment, based on general information and principles. Assessing the effects on water quality for licensing purposes requires specific and careful ecological consideration for each potential location. **Based on the interviews, building multiple nuclear power plants (SMRs) in multiple locations in the Netherlands does not appear feasible** — The provincial authorities indicated that fitting a nuclear power plant into spatial planning in several different parts of the country would be an enormous challenge, given urbanisation, areas becoming more densely populated and suitable locations already being earmarked for other purposes. — Even if it were possible from a technical and safety point of view to build a nuclear power plant in one or multiple locations, there could be public opposition. From this perspective, it seems more sensible to opt for one or several nuclear power plants at a single location. — The expectation of the regional authorities and market participants is that there would be insufficient public support for the option of using multiple locations, even if the SMRs are situated on the site of a coal-fired power plant.



KPMG

Introduction

The Ministry of Economic Affairs and Climate Policy requested KPMG to perform a market consultation on nuclear energy in the Netherlands

Dijkhoff motion

Central questions from the Dijkhoff motion[1)]

… call on the government to conduct a market consultation:

1. Under what conditions would Dutch and international market participants be prepared to invest in nuclear power plants in the Netherlands?
2. What public support would be required?
3. In which regions is there interest in the construction of a nuclear power plant?

In response to the Dijkhoff motion,[1)] the Ministry of Economic Affairs and Climate Policy requested KPMG to perform a market consultation on nuclear energy in the Netherlands

- The Ministry of Economic Affairs and Climate Policy ('the Ministry') indicated in the invitation to tender that nuclear energy could play a role in the energy mix in the transition to a low-carbon energy supply.[2)]
- To date, the government has left it up to the market to take the initiative with regard to the potential construction of new nuclear power plants. The market has shown no interest in doing so thus far.
  - The lengthy construction time, high level of investment, financing options and regulatory risk, combined with the long lead time and possible obstacles from the government may all have played a role in this lack of interest.
- On 17 September 2020, a motion was passed in the House of Representatives ('the Dijkhoff motion') calling on the government to conduct a market consultation into the conditions under which market participants would be prepared to invest in nuclear power plants in the Netherlands, to investigate what public support would be required and to discover in which regions there is interest in the construction of a nuclear power plant.[a)]
- The Ministry commissioned KPMG to perform this market consultation. The result of the market consultation is an independent report which elaborates on these questions and provides insight into them.

Note: (a) The government has previously attempted (via the Yesilgoz-Zegerius/Mulder motion on 26 June 2019) to investigate the possible role of nuclear energy in the energy mix and obtain a picture of the costs and conditions of the construction of new nuclear power plants in other countries. The questions in that motion were of a different character and scope to the questions in the Dijkhoff motion. However, there is some overlap between the two sets of questions, and the results of the present market consultation could provide relevant insights and/or starting points for that investigation.

Source: (1) Memorandum 35570-11, House of Representatives (2020). (2) Invitation to tender, Ministry of Economic Affairs and Climate Policy, nuclear energy market study (17 December 2020).

The market consultation looked at the conditions under which market participants would be prepared to invest in nuclear power plants in the Netherlands and the role the government could play

Substantive sub-topics for the market consultation

Substantive sub-topics for the market consultation

1. Under what conditions would Dutch and international market participants be prepared to invest in nuclear power plants in the Netherlands?
- To what extent do the market participants see restrictions on the development of nuclear energy in the current regulations?
- What administrative/political restrictions do the market participants see on the development of nuclear energy?
- What commercial restrictions do the market participants see on the development of nuclear energy in the Netherlands?
- Which generation of reactor technology would be the best fit for the Netherlands?
- What specific opportunities and challenges do SMRs present compared with large reactors?
- What time frame would be realistic for obtaining an operating licence?
- What would the market participants recommend doing with regard to the existing reactor in Borssele?

2. What public support would be required?
- What contribution would the government have to make with regard to financing?
- What guarantees would the government have to give?
- What are the key financial considerations of market participants with regard to investing in nuclear power plants?
- What contribution to the economy (and job creation) do the market participants anticipate in exchange for this government support?

3. In which regions is there interest in the construction of a nuclear power plant?
- In which province/municipality is there the highest likelihood of a suitable location and the greatest willingness to host a nuclear power plant?
- What conditions would the province/municipality want to see met before being chosen as the site for a nuclear power plant?
- Is there any interest from the currently-designated areas?

Three key questions were the focus of the market consultation (as requested in the Dijkhoff motion)

- The Ministry formulated three key questions for the market consultation in line with the Dijkhoff motion. The Ministry also formulated a number of sub-questions.
- KPMG added structure and detail and expanded these research questions, where this would add value to the market consultation (see the box on the left).
- The questions and sub-questions broadly relate to a number of substantive topics. This report is structured around these topics. See page 31 for a table of contents and an explanation of the structure of the report.

This study does not examine the question of whether the Netherlands should expand the use of nuclear energy, only the question of how nuclear energy can be achieved as economically as possible

- In answering the questions in the market consultation, this study only examines how nuclear energy can be achieved as economically as possible, according to the market participants.
- This study does not examine the question of whether the Netherlands should expand the use of nuclear energy. It also does not investigate how nuclear energy compares to renewable energy sources and/or other technologies (this was not part of the research questions).

The study consisted of a market consultation of nuclear market participants from across the entire value chain, supplemented with a review of source literature

For the market consultation, interviews were conducted with nuclear market participants and provincial authorities

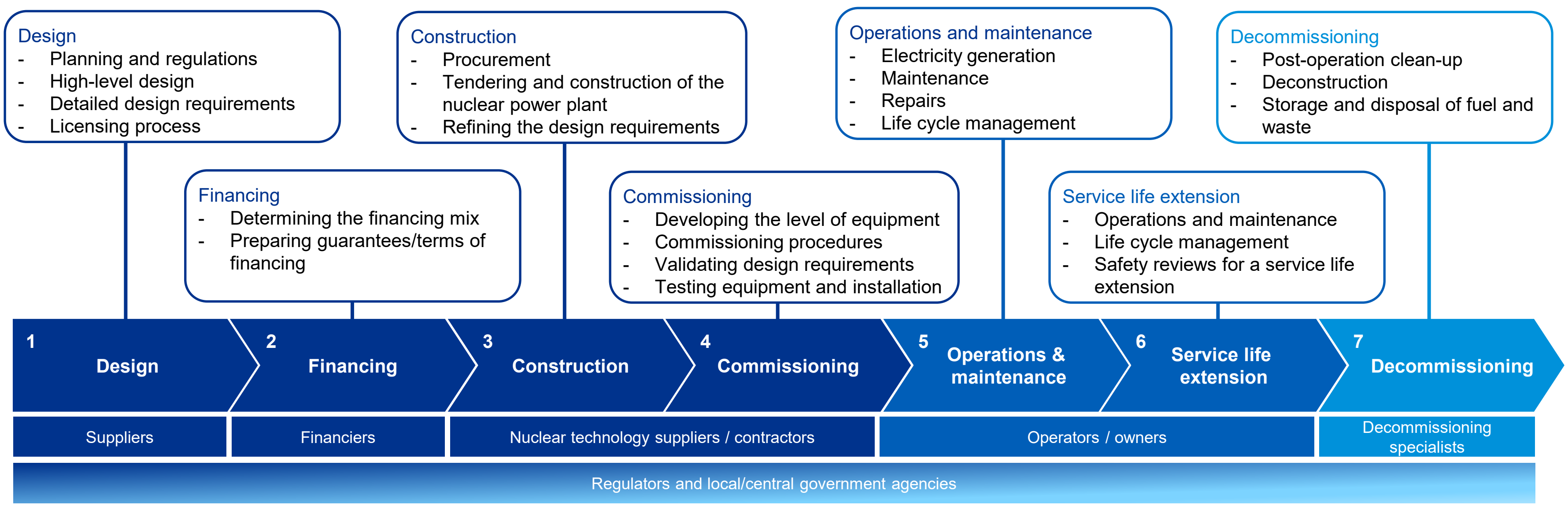
— The market consultation consisted of interviews with various relevant Dutch and international market participants. The market participants were selected by determining the key players involved in nuclear power plants over the course of a reactor's life (construction, nuclear technology, financing, energy production and decommissioning) (see diagram below).

— A range of regional parties were also consulted. First, all provincial authorities were approached for an interview, then the relevant municipalities were selected for additional interviews based on the outcomes of the conversation with the associated provincial authority. The municipalities selected by the government as potential locations for nuclear power plants (in Dutch: 'waarborglocaties') were included. Eemshaven, one of the selected locations, was not included in the consultation, having been recently ruled out following a motion in Parliament.[1)]

— After receiving the responses from the consultation, KPMG challenged, analysed and collated them. Where possible, source literature was also consulted for information to substantiate the perspectives recorded in the interviews. The results were then incorporated into the present report.

— The appendices on pages 148 and 149 contain a comprehensive overview of the market participants interviewed and the key sources consulted for this study.

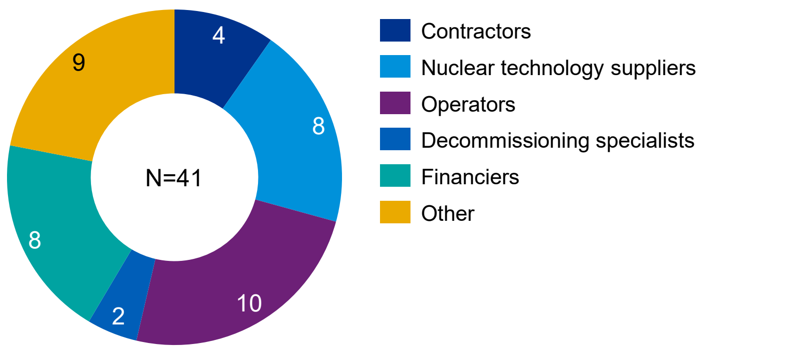
Nuclear value chain



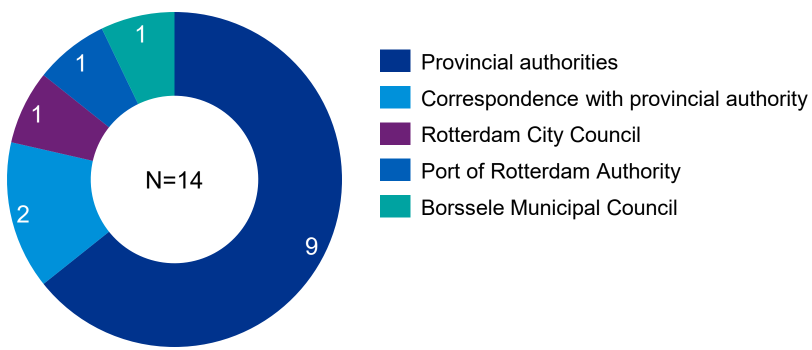
Source: (1) Motion by Member of Parliament Beckerman et al. ruling out Groningen as a nuclear power plant site (4 March 2021).

A total of 41 Dutch and international market participants were interviewed, as well as 14 regional authorities

Overview of market participants interviewed



Overview of regional authorities interviewed



Example of a quote

"The government can opt for a Generation III/proven technology power plant now, with a view to CO_2 reduction, while at the same time investing in the development of Generation IV technology for the really long term."

A total of 41 Dutch and international market participants were interviewed

- The market consultation consisted of interviews with various relevant Dutch and international market participants, in the broadest sense of the word.
- A total of 41 market participants were interviewed. By category, interviews were conducted with four contractors, eight nuclear technology suppliers, 10 operators, two decommissioning specialists, eight financiers and nine people in the 'other' category (including grid operators, experts and foreign government agencies).
- At the request of the Ministry, Chinese and Russian market participants were excluded from the consultation.

14 regional authorities were also interviewed, to determine the regions in which there is interest in the construction of a nuclear power plant

- A brief consultation was carried out with various relevant regional parties to determine the regions in which there may be interest in the construction of a nuclear power plant. No independent technical and/or planning study was performed (this was not part of the research questions).
- All provincial authorities were approached for an interview. In the end, nine interviews were held with provincial authorities (two further provincial authorities responded in writing, and no response was received from one provincial authority). Talks also took place with two municipal authorities and the Port of Rotterdam Authority.
- As part of the consultation with regional authorities, Rijkswaterstaat and TenneT were approached for feedback on the availability of cooling water and electricity infrastructure.

Insights from the interviews

- For privacy protection reasons, all information obtained from the interviews has been anonymised, or where this was not possible, is used with permission.
- For the purposes of illustration, quotes from the interviews are included throughout this report. These quotes are only a selection for illustrative purposes and do not provide a full picture of all responses. An example of a quote is shown on the left.

The report is structured around the substantive topics explored in the market consultation

Table of contents

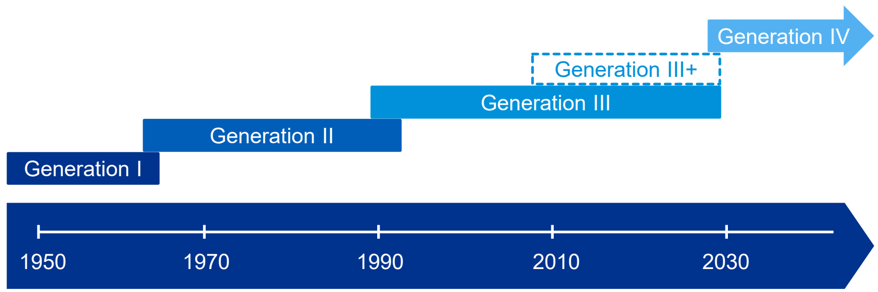
The report is structured as follows:

- **Chapter 1** explains the various nuclear reactor technologies and identifies the technology that the market participants consider would be the best fit for the Netherlands.
- **Chapter 2** explores the financing, preconditions of financing, possible financing structures and financing mix of nuclear power plants, as well as the possible role that the government could play.
- **Chapter 3** provides an overview of relevant regulations in the areas of decommissioning and waste as well as the licensing process and the consequences of such on the construction time of a nuclear power plant.
- **Chapter 4** looks at the various ways in which nuclear power plants can be deployed and which method the market participants consider to be the most economical.
- **Chapter 5** addresses the Borssele nuclear power plant and the thoughts of the market participants on a possible service life extension.
- **Chapter 6** deals with the impact on the local economy of a nuclear power plant, both during construction and after commissioning.
- **Chapter 7** examines the locations in the Netherlands where there might be interest in the construction of a nuclear power plant, including consideration of general preconditions such as cooling water and grid capacity.

Technology overview

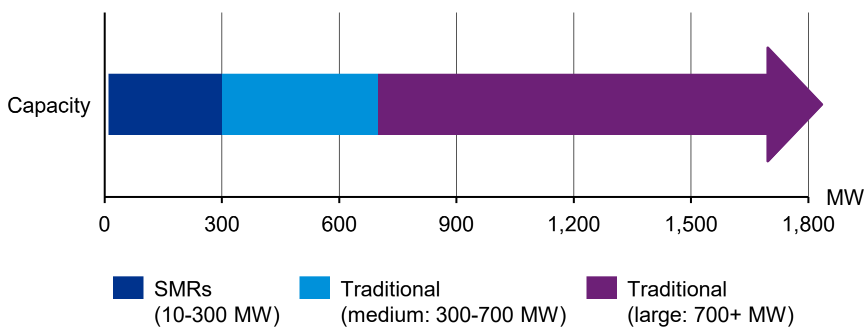
Reactor technology can broadly be divided into four generations, as well as into traditional and modular (SMR) designs

Generations of nuclear reactors



Source: Nuclear Energy Outlook 2008, NEA (2008). KMPG analysis.

Capacity of SMRs and traditional reactors (in MW)



Source: (1) Small nuclear power reactors, World Nuclear Association (https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx, last accessed on 25 May 2021). (2) Small modular reactors: challenges and opportunities, OECD-NEA (2021). KMPG analysis.

Reactor technology can broadly be divided into four generations

— Generation II reactors are reactor designs that were largely built between the end of the 1960s and the late 1990s. The current Borssele power plant is a modern Generation II design.

— Generation III reactors are an ‘evolutionary improvement’ on Generation II reactors. There are also Generation III+ reactors; this generally refers to the safety improvements made in response to the Fukushima disaster. In this report, no distinction is made between Generation III and III+, and only post-Fukushima designs are discussed, since most designs were modified after Fukushima to improve safety.

— Generation IV reactors are new designs that are primarily based on a different type of cooling technology (using salt instead of water, for example) or use a different energy source (such as thorium instead of uranium), which may lead to the production of less waste and/or may be safer.

A distinction can also be drawn between a traditional design and a modular design (SMR)

— A distinction can be drawn between a traditional (often large) reactor and a small modular reactor (SMR).
  - SMRs are generally defined as reactors with a capacity of between 10 and 300 MW.[1)] By combining several SMRs in an integrated power plant, this can be increased to as much as 900 MW.
  - Because of their modular design, SMRs are intended to be built in a more standardised way, which may make the construction time for SMRs shorter and more predictable than that of traditional reactors.
  - The reactor technology in an SMR is primarily Generation III+ or Generation IV.
  - See page 52 onwards for more information about SMRs.

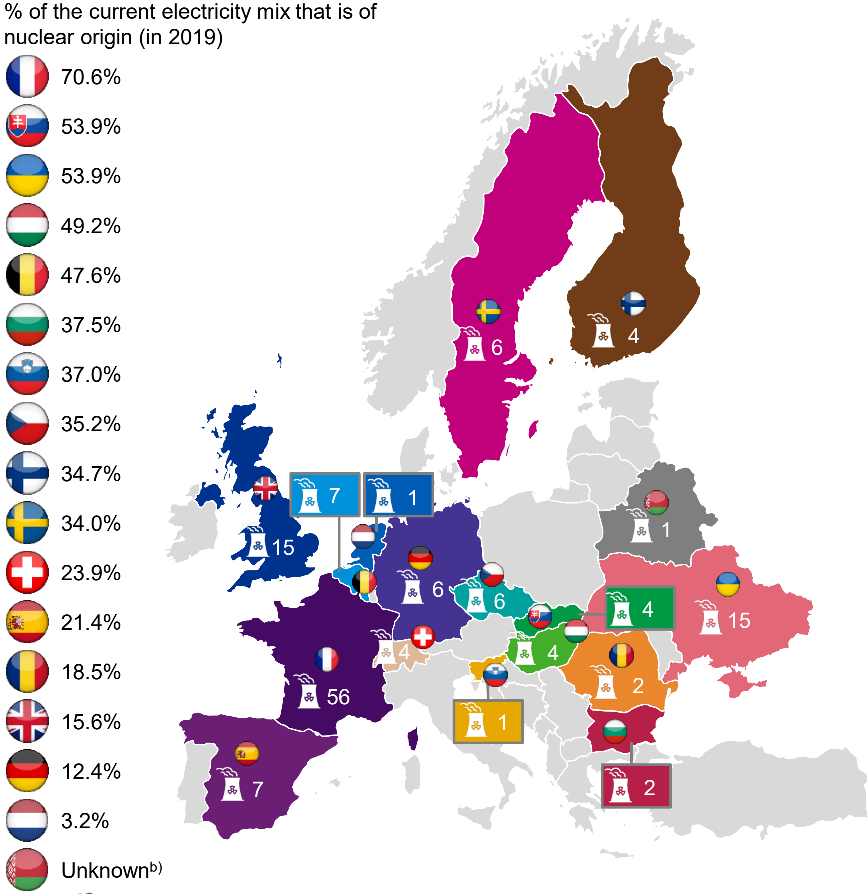
— The vast majority of traditional reactors currently under construction are large reactors with a capacity of over 700 MW.[2)]

Source: (1) Small modular reactors: challenges and opportunities, OECD-NEA (2021). (2) Plans for new reactors worldwide, World Nuclear Association (https://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx, last accessed on 28 May 2021).

Existing nuclear power plants in Europe largely consist of Generation II reactors constructed between the 1960s and the 1990s

Active nuclear reactors in Europe[a)]

% of the current electricity mix that is of nuclear origin (in 2019)



Key: Number of active nuclear reactors.

Note: (a) Situation in February 2021. (b) Has come online very recently, so the exact share is not yet known.

Source: Nuclear power in the European Union, World Nuclear Association (https://www.world-nuclear.org/information-library/country-profiles/others/european-union.aspx, last accessed on 28 May 2021).

There are 141 nuclear reactors operating in Europe, mostly consisting of Generation II reactors

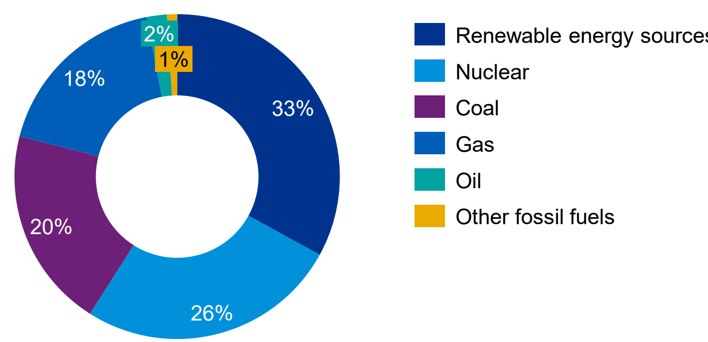
- There are 141 nuclear reactors operating in Europe.[1)] They were primarily constructed in the period between the 1960s and the 1990s.
- Nearly all of the nuclear reactors operating in Europe are Generation II reactors.
  - There are no longer any Generation I reactors operating in Europe.[2)]
  - Since 2020, there is one Generation III+ reactor operating in Belarus.[3)]

In 2020, nuclear reactors collectively supplied 26% of electricity in the EU

- In 2020, 26% of the EU's electricity was supplied by nuclear reactors.
- By way of comparison, in 2020 renewable energy sources represented 33% of the EU's electricity supply, while coal and gas represented 20% and 18% respectively.

Source: **(1)** Nuclear power in the European Union, World Nuclear Association (https://www.world-nuclear.org/information-library/country-profiles/others/european-union.aspx, last accessed on 28 May 2021). (2) Nuclear reactors: generation to generation, American Academy of Arts and Sciences (2011). (3) Reactor database, World Nuclear Association (https://www.world-nuclear.org/Information-Library/Facts-and-Figures/Reactor-Database.aspx, last accessed on 28 May 2021).

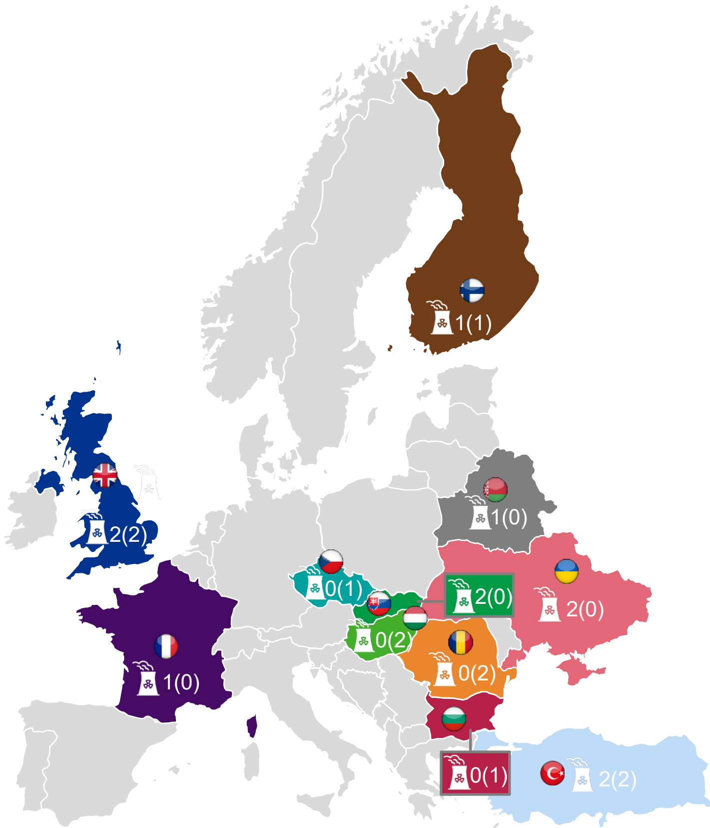
Percentage of the electricity supply in the EU (in 2020)



Source: Info graphics, FORATOM (2020). KMPG analysis.

The nuclear power plants which are currently planned or under construction mostly consist of Generation III+ reactors

Nuclear reactors planned or under construction in Europe[a)]



Key: Number of nuclear reactors under construction (number of planned nuclear reactors).

Note: (a) Situation in February 2021.

Source: Nuclear power in the European Union, World Nuclear Association (https://www.world-nuclear.org/information-library/country-profiles/others/european-union.aspx, last accessed on 28 May 2021).

After the 1990s, the construction of nuclear reactors in Europe virtually ceased

— After the 1990s, the construction of nuclear reactors in Europe virtually ceased. This was due to a change in public opinion after the Chernobyl disaster, which, together with the earlier incident at Three Mile Island, diminished public faith in nuclear energy.[1)]

Since 2005, construction has started on 11 nuclear reactors in Europe

— In 2005 (Olkiluoto 3 in Finland) and 2007 (Flamanville 3 in France), construction began on the first Generation III+ reactors in Europe.[2)]

- Many problems were encountered during the construction of these reactors[3)] (see also page 46), which may also have had an impact on the relatively low number of new European nuclear construction projects in this period.[1)]

— Since 2014, construction has started on a further five Generation III+ reactors and one Generation III+ reactor has been completed.

- Astravets 1 in Belarus was constructed between 2013 and 2020.[2)]
- Other Generation III+ reactors under construction include Astravets 2 in Belarus (since 2014), Hinkley Point C1 and C2 in the UK (since 2018 and 2019) and Akkuyu 1 and 2 in Turkey (since 2018 and 2020).[2)]

— The other four reactors under construction are Generation II reactors (Mochovce 3 and 4 in Slovakia and Khmelnytskyi 3 and 4[a)] in Ukraine).[2)]

A further 11 nuclear reactors are planned in Europe

— There are seven Generation III+ reactors planned in Europe.

- The Generation III+ reactors planned in Europe are: Akkuyu 3 and 4 in Turkey, Hanhikivi 1 in Finland, Paks 5 and 6 in Hungary and Sizewell C1 and C2 in the UK.[4)]

— Two updated Generation II reactors are also planned (in Romania) and two reactors of which the type is not yet known (in Bulgaria and the Czech Republic).[4)]

Note: (a) The construction of these reactors has been suspended.

Source: (1) Nuclear energy in the European Union after Fukushima: political and economic considerations, Kiyar & Wittneben (2012). (2) Reactor database, World Nuclear Association (https://www.world-nuclear.org/Information-Library/Facts-and-Figures/Reactor-Database.aspx, last accessed on 28 May 2021). (3) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). (4) Country profiles, World Nuclear Association (https://www.world-nuclear.org/information-library/country-profiles.aspx, last accessed on 28 May 2021).

Selecting the generation type

The majority of market participants emphasised the importance of selecting proven technology that complies with current safety requirements

"Choose an existing design, and don't make/ask for any changes."

"I would choose a Generation III+ reactor, because it's proven technology. We can harness the existing supply chain. In the OECD, we're just starting to see the first economies of scale in terms of learning effects."

"I wouldn't choose a Generation II reactor. If you want a new nuclear reactor, you have to make it Generation III+."

"The discussion you need to have is whether you go with a large reactor or an SMR."

The majority of market participants emphasised the importance of selecting a Generation III+ reactor with a proven design

- Some market participants indicated that a modern, standardised Generation II reactor design could be an economically-attractive option, but by far the majority saw this as infeasible because it wouldn't comply with the additional safety requirements imposed after Fukushima.
- There was broad consensus among the market participants that the Netherlands should opt for a Generation III+ reactor with a proven design.
  - A range of Generation III+ designs are already proven and are therefore expected to face fewer 'first-of-a-kind' (FOAK) problems, which can lead to delays and cost overruns.
  - A Generation III+ reactor would comply with the stricter safety requirements put in place after 9/11 and the Fukushima disaster.
  - A Generation III+ reactor could be ready in time to help contribute to achieving the 2050 climate targets.
- Generation IV reactors have potential with possible benefits in the areas of safety and/or waste but are not expected to enter the market until after 2040, meaning they would arrive too late to help the Netherlands achieve its 2050 climate targets.
  - The market participants suggested that it might be prudent for the Dutch government to start investing in the development of Generation IV technology if it decides to expand nuclear energy.

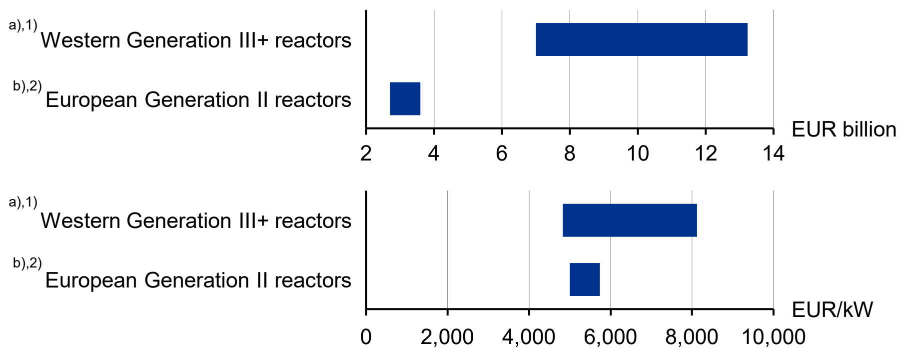
The market participants also mentioned Small Modular Reactors (SMRs) as an interesting option

- The market participants thought SMRs were an interesting option because they could potentially be built faster and require less investment.
- A disadvantage is that the first SMRs are not expected to become fully operational as FOAK power plants until 2027-2033.[1)2)] See page 52 onwards for more information about choosing between SMRs and traditional reactors.

Source: (1) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (2) Advances in small modular reactor technology developments, IAEA (2020).

A modern Generation II reactor could be an economically-attractive option...

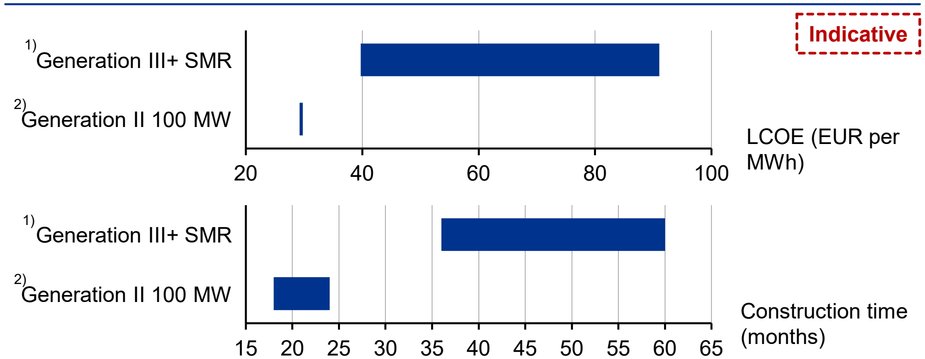
The investment required for recent Eastern European Generation II reactors compared with Western Generation III+ reactors



Note: (a) Based on Western Generation III+ reactors: Flamanville 3, Hinkley Point C, Olkiluoto 3, Hanhikivi and Vogtle. (b) Based on the Generation II projects in Slovakia and Romania.

Source: (1) Reports by EDF, Fennovoima, the British government and the World Nuclear Association. (2) Country profiles, World Nuclear Association (https://www.world-nuclear.org/information-library/country-profiles.aspx, last accessed on 28 May 2021). KMPG analysis.

Potential advantages of a 100 MW Generation II reactor over a Generation III+ SMR



Source: (1) Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020). (2) OPEN100 Fact Sheet, Energy Impact Center (2020). KMPG analysis.

A modern, standardised Generation II reactor design may be an economically-attractive option, since it is a cheaper design that has already been proven

- Some market participants indicated that an updated Generation II design could be sufficiently safe. Because the design would not include any of the complex (some would say excessively complex) post-Fukushima safety measures, the design could be cheaper.
- For the Generation II projects in Slovakia and Romania, the investment per reactor is around EUR 2.7 to 3.6 billion. Per kW, the cost of these reactors is between EUR 5,000 and 5,732.[a)]
  - By way of comparison, recent Western Generation III+ reactors cost between EUR 7.0 and 13.2 billion. Per kW, the cost of these reactors is between EUR 4,826 and 8,122.[a)]
- An example of a modern Generation II design comes from the OPEN100 initiative,[1)] the goal of which is to modernise and largely standardise a Generation II design to achieve maximum learning effects. Because it is a 100 MW design, it is comparable to a Generation III+ SMR in terms of scale. The advertised advantages include:
  - A Generation II design is already proven and can therefore avoid FOAK issues.
  - The Levelised Cost of Electricity (LCOE)[b)] is expected to be around EUR 30 per MWh.[1)] That is significantly lower than the expected LCOE of SMRs, which is between EUR 40 and 91 per MWh (see also page 57).[2)]
  - The advertised construction time is only 18 to 24 months, whereas the expected construction time of an SMR is four to five years for a FOAK reactor and three to four years for each subsequent reactor.[2)]

"You don't have to literally choose Generation II. You can upgrade a Generation II design, without changing the core concept."

Note: (a) For the source, see the notes for the top left graph. (b) The LCOE is a benchmark for the average of all costs per unit of electricity incurred throughout the entire service life of a power plant. It is equal to the minimum price for which the energy must be sold in order to break even.

Source: (1) OPEN100 Fact Sheet, Energy Impact Center (2020). (2) Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020).

…but a Generation II reactor is considered infeasible since the Fukushima disaster due to a lack of public support

"A Generation II reactor is technically possible, but difficult in terms of public opinion. Try explaining that you've chosen a less-safe design."

"There's not a single country that is currently suggesting Generation II. Everyone's building Generation III+, because they're designed to keep the radiation in the reactor. The design takes account of external factors such as aeroplanes and terrorism."

"You can't explain to the public that you opted for a cheaper but less safe nuclear power plant."

However, nearly all market participants considered a Generation II reactor design infeasible in terms of obtaining public support, since it would not meet the additional safety requirements put in place after Fukushima

— Interview feedback suggested that although a Generation II design was an interesting idea, nearly all of the market participants considered it infeasible.
  - Although Generation II designs are probably safe enough, most of the market participants do not think they would meet the strictest safety requirements imposed after the Fukushima disaster.
  - To achieve sufficient public support for nuclear energy, it is expected that the design will need to meet the most stringent requirements.
  - Generation II is old technology, and Generation III+ designs are now becoming proven and moving beyond FOAK issues.

Generation IV reactors have potential due to possible benefits in the area of nuclear waste...

Generation IV waste aspects[a)]

Tech.	Advantages	Challenges
HTR	✓ The graphite in which the fissile material is contained can simultaneously act as a basis for safe storage	× It is difficult to extract fissile material from graphite. It would result in a large volume of waste
MSR	✓ Potential for reuse ✓ Smaller volume of waste ✓ Further reduction of waste if thorium is used	× The coolant must be treated as low- or medium-level radioactive waste
LFR	✓ Potential for reuse ✓ Smaller volume of waste	× The waste has a higher radiation intensity

Note: (a) A selection of possible advantages and challenges; see the IRSN report for a complete list.

Source: (1) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (2) Review of Generation IV nuclear energy systems, IRSN (2015). KMPG analysis.

Three different Generation IV technologies can be expected to play a possible role in the Netherlands

— At present, six different Generation IV technologies are being developed.[1)] Three of these are seen as the most promising for the Netherlands.[2)]

- High-Temperature Reactors (HTRs) are graphite-moderated helium-cooled reactors.[3)]
- Molten Salt Reactors (MSRs) use molten salts both as a coolant and as a solvent in which to dissolve the fuel.[3)]
- Lead-cooled Fast Reactors (LFRs) are fast-neutron reactors that are cooled by liquid metal.[3)]

— These technologies are potentially promising because there is an existing knowledge base for them in the Netherlands.[2)] They also offer possibilities for process heat applications (primarily HTRs) and options for waste reuse and reduction (MSRs and LFRs).[2)]

Generation IV designs could have advantages in terms of waste if they can solve certain challenges

— In the development of Generation IV reactors, the goal is to minimise nuclear waste, and in particular to produce less long-lived waste.[1)] Although they have significant potential, these different techniques face many challenges in the area of waste, which will have to be solved through R&D programmes before any possible advantages can be exploited.[4),5)]

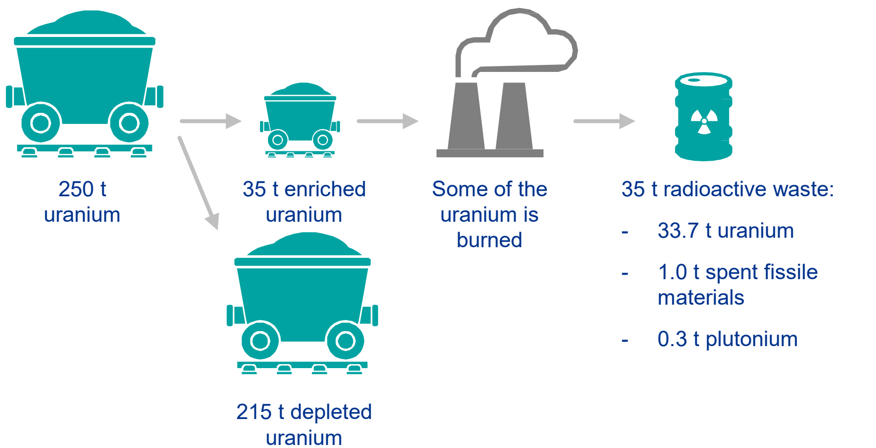
- In HTRs, the fissile material is embedded in graphite. This could be an advantage in that it ensures safe storage.[4)] At the same time, the graphite will result in a large volume of waste. R&D programmes are currently investigating alternative solutions.[5)]
- With MSRs, the fissile material can be continuously reused, resulting in a small volume of waste.[4)] At the same time, R&D is being conducted into the processing of all the waste that would be produced, as well as the coolant.[5)]
- LFRs can generate around 20 times more energy than existing reactors from the same amount of fuel. Efficient use of fuel will result in much less radioactive waste. The downside is that the waste will have a higher radiation intensity.[4),5)]

Source: (1) Technology roadmap update for Generation IV nuclear energy systems, GIF (2014). (2) Nuclear energy for our future – Roadmap for the role of nuclear energy in a carbon-free energy supply in the Netherlands, Nuclear Netherlands (2017). (3) The Future of Nuclear Energy in a Carbon-Constrained World: An Interdisciplinary MIT Study, MIT (2018). (4) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (5) Review of Generation IV nuclear energy systems, IRSN (2015).

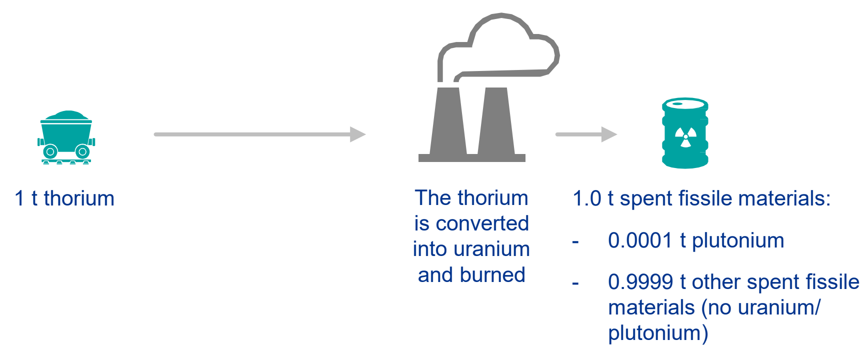
...and using thorium as a fuel could reduce waste even further

Fuel and radioactive waste: Light Water Reactor versus thorium reactor (MSR)

Uranium-fuelled LWR



Thorium-fuelled MSR



Note: Based on a 1 GW LWR and a 1 GW MSR.

Source: Liquid fluoride thorium reactors, Hargraves and Moir (2010).

Using thorium as a nuclear fuel can further reduce long-lived radioactive waste

— Thorium is a weakly radioactive material suitable for use as a nuclear fuel and is three to four times more naturally abundant than uranium.[1),2)] However, the estimated quantities in economically extractable reserves are roughly equal, at around 6,150,000 tonnes for uranium and 6,355,000 tonnes for thorium.[3),4),5)]

— MSRs and HTRs in particular are extremely well-suited to using thorium, but other technologies, including water-cooled reactors (Generation II/III+), could also use thorium as a fuel.[2),3)]

— Using thorium could lead to much less radioactive waste – around 250 times fewer tonnes of radioactive waste containing around 3,000 times less plutonium.[6),7)] This is because thorium does not have to be enriched and thus can be almost entirely converted into fissile material, which can then be used in the reactor.[1),6),7)]

- Uranium has to be enriched before being used as fuel in a reactor. Depending on the enrichment process, 100 tonnes of uranium produce 14 tonnes of enriched uranium suitable for use as a fuel. More than 85% of the original material cannot be used and must be processed and stored.[6),8)] A limited amount can be reused.[3),9)]

— In addition, the waste stays radioactive for a much shorter period. After 300 years, the waste from a thorium reactor is harmless and around 10,000 times less radioactive than uranium or plutonium waste (after 10 years, approx. 85% of the waste is already stable and suitable for recycling).[6)] However, in some cases (in the short term), the remaining waste does have a higher radiation intensity.[10)]

— So far, there has been limited large-scale and/or commercial experience with the use of thorium. Furthermore, converting thorium into a usable fuel is a complex process which can result in additional costs for nuclear power plants.[3)]

Source: (1) Thorium fuel cycle, potential benefits and challenges, IAEA (2005). (2) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (3) Thorium, World Nuclear Association (https://world-nuclear.org/information-library/current-and-future-generation/thorium.aspx, last accessed on 1 June 2021). (4) Uranium 2020: Resources, production and demand, NEA-IAEA (2020). (5) Uranium 2016: Resources, production and demand, NEA-IAEA (2016). (6) Liquid fluoride thorium reactors, Hargraves and Moir (2010). (7) Introduction of thorium in nuclear fuel, OECD-NEA (2015). (8) Enrichment process, Urenco (https://www.urenco.com/about/nuclear-fuel-supply-chain/enrichment-process, last accessed on 15 June 2021). (9) Mix Oxide (MOX) Fuel, World Nuclear Association (https://world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/mixed-oxide-fuel-mox.aspx, last accessed on 15 June 2021). (10) 232 and the Proliferation-Resistance of U-233 in Spent Fuel, Kand and von Hippel (2001).

Generation IV reactors also have potential advantages in the area of passive and inherent safety

Generation IV safety aspects[a)]

Tech.	Advantages	Challenges
HTR	✓ Great potential for inherently safe systems ✓ A meltdown could not occur, because the heat can be fully absorbed by the graphite	× Penetrating air or water could cause dangers, such as the production of flammable gas
MSR	✓ Great potential for inherently safe systems ✓ A meltdown could not occur, because the fissile material is dissolved in the coolant ✓ Low-pressure system	× The molten salts solidify at high temperatures, which can lead to blocked pipes × Not draining the molten salts at the right time can lead to a system breakdown due to the high temperatures
LFR	✓ Great potential for inherently safe systems ✓ Low-pressure system ✓ Metals can absorb a lot of heat because they have a high boiling point	× The metals solidify at high temperatures, meaning that the temperature range within which the reactor can operate is small × The metals corrode and erode stainless steel constructions

Note: (a) A selection of possible advantages and challenges; see the IRSN report for a complete list.

Source: (1) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (2) Review of Generation IV nuclear energy systems, IRSN (2015).

The Generation IV HTR, MSR and LFR technologies could have significant advantages in terms of safety...

— HTRs, MSRs and LFRs potentially have a higher degree of passive or inherent safety than Generation III+ technologies.[1),2)]

- The Fukushima disaster increased the importance of passive safety (safety that does not require any electricity or human actions).
- Generation III+ reactors mainly increase safety by using passive safety systems that mitigate the impact of abnormal events using gravity or natural convection.[a),1),3)]
- Generation IV reactors go a step further by using more passive safety systems, and by using safety features inherent in the basic properties of the materials used and the chemical characteristics of system components.[1)]

...but there are also challenges in the area of safety, and the inherent safety of these technologies is still largely unproven

— The inherent safety of Generation IV technologies is still largely unproven.[1),4)] There are still considerable challenges to be overcome in the area of safety before the potential advantages can be exploited.[1),2),4)]

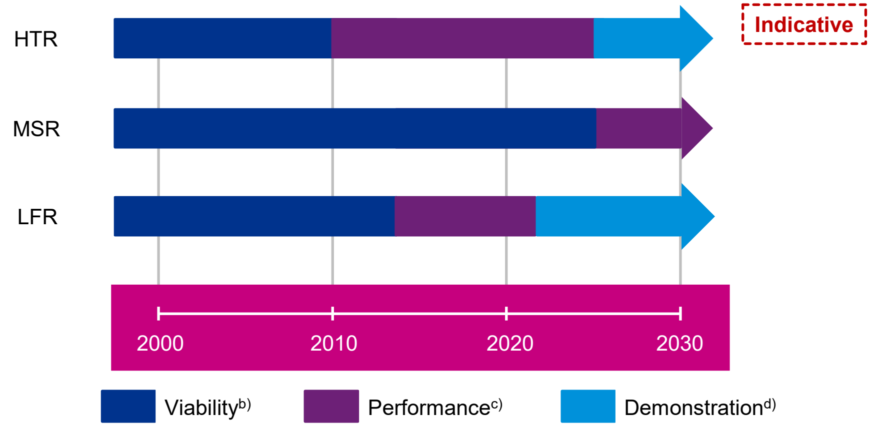
- The main challenge for HTR technology is the proven strengthening of the defence against accidents due to the penetration of water or air.[4)]
- MSR technology is very different from all other Generation III+/IV technologies due to the use of a liquid fuel that is combined with the coolant.[1),4)] A great deal of R&D is required before the safety of MSR technology can be proven.[1),4)]
- Likewise, considerable R&D is required before the safety of LFR technology can be adequately proven, for example in relation to the possible consequences of the metals solidifying in a reactor.[4)]

Note: (a) Convection is the heat flow of a gas or liquid.

Source: (1) The Future of Nuclear Energy in a Carbon-Constrained World: An Interdisciplinary MIT Study, MIT (2018). (2) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (3) Nuclear reactors: generation to generation, Goldberg & Rosner (2011). (4) Review of Generation IV nuclear energy systems, IRSN (2015).

Generation IV reactors are not expected to enter the market until after 2040, meaning they would arrive too late to help the Netherlands achieve its 2050 climate targets

The technology road map[a] for the Generation IV HTR, MSR and LFR technologies



Note: (a) The updated technology road map for Generation IV technologies from 2014 was still current in 2018. (b) During the viability phase, concepts, technologies and processes are tested so that potential showstoppers can be identified and resolved. (c) Once viability is proven, the performance phase begins. In this phase, the processes and material possibilities are verified at a technical scale and optimised under prototype conditions. (d) After a successful performance phase, the demonstration phase begins. This phase is expected to last for at least 10 years. This phase consists of the licensing, construction and operation of prototypes or demonstration systems. The detailed design is also finalised in this phase. Only after this phase can the technologies become commercially available on the market.

Source: Preparing the future through innovative nuclear technology: outlook for generation IV technologies, GIF (2018). KMPG analysis.

“We cannot afford to wait until Generation IV comes online. The risk is that you’ll have to wait a very long time. You don’t know when the technology will be proven.”

“The government can opt for a Generation III/proven technology power plant now, with a view to CO_2 reduction, while at the same time investing in the development of Generation IV technology for the really long term.”

Generation IV technologies are not expected to enter the market until after 2040, meaning they would be unable to make a significant contribution to achieving the 2050 climate targets

- The market participants indicated that they do not expect Generation IV reactors to enter the market until after 2040.
  - The market participants expect that MSRs that use uranium will be the first to present a proven operational design in an SMR application.
  - According to the technology road map from the Generation IV International Forum (GIF), in 2030 the Generation IV HTR and LFR technologies are expected to be in the demonstration phase, while MSR technology will still be in the performance phase (see the diagram on the left).[1)]
  - Large-scale commercial implementation of the first Generation IV technologies is expected around 2045.[1),2)]
- For this reason, the market participants suggested that it would be unwise to wait for Generation IV if nuclear energy is required to make a significant contribution to achieving the climate targets before 2050.
  - Waiting is considered ill-advised, because there is no certainty about when the technologies will actually be proven.
- Furthermore, it is expected to take between 10-20 years to set up new licensing frameworks for these technologies (see page 96).

The market participants suggested that it might be prudent for the Dutch government to start investing in the development of Generation IV technology if it decides to expand nuclear energy

- Several market participants made the suggestion of constructing a Generation III+ design now, to maintain and expand nuclear knowledge, while investing in Generation IV technologies for the long term.
- There is already a strong knowledge base in the Netherlands with regard to the Generation IV HTR, LFR and MSR technologies, at both NRG and Delft University of Technology.[3)]
- According to the market participants, the combination of a new construction of a Generation III+ reactor in the short term and investing in Generation IV technology in the long term could allow the Netherlands to play a leading role in Generation IV technologies.

Source: (1) Preparing the future through innovative nuclear technology: outlook for generation IV technologies, GIF (2018). (2) GIF R&D outlook for generation IV nuclear energy systems: 2018 update, GIF (2018). (3) Nuclear energy for our future – Roadmap for the role of nuclear energy in a carbon-free energy supply in the Netherlands, Nuclear Netherlands (2017).

There is broad consensus that a Generation III+ reactor in the Netherlands would not necessarily suffer the problems experienced elsewhere in terms of costs and delays

To minimise issues related to cost overruns and delays, the selected Generation III+ design should be one of which a number of reactors have already been built

— The market participants recommended selecting a Generation III+ design of which a number of reactors have already been built.

— Because such a design would be mature and relevant knowledge and expertise would have been built up in Europe, the market participants expect that the costs would be lower and the delays fewer than for the first Generation III+ projects in Europe.

> *"If you opt for a FOAK design, you'll probably face the same budget overruns as in France and the US."*

By using a proven design and potentially building several reactors, the savings potential is estimated to be around 28-40% per MW in the most optimistic scenario

— It is estimated that avoiding FOAK issues in engineering and construction by using a proven design could deliver savings of up to 20-30% (see page 48).

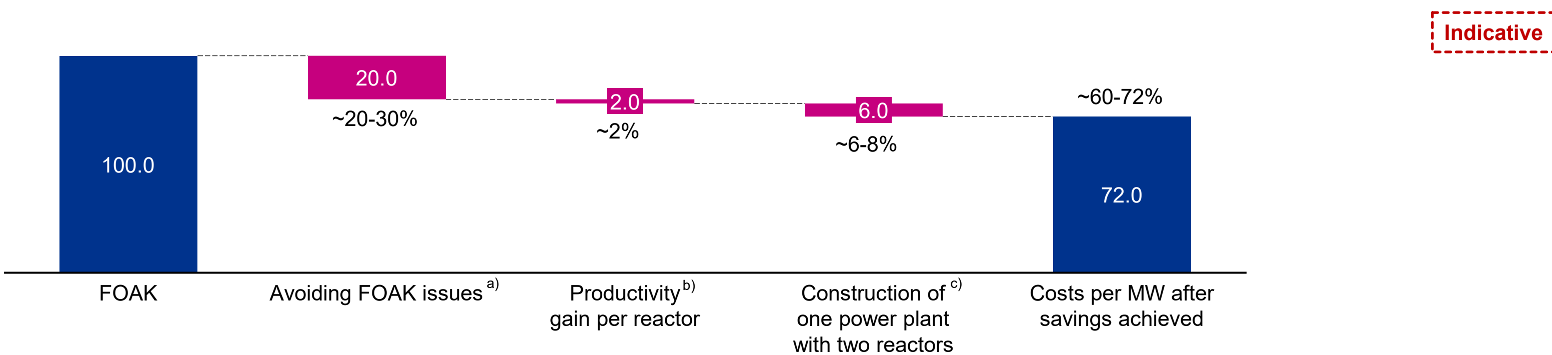
  - These savings would be gained from learning effects with the design during construction and building on licences for previous projects. This last point is subject to the condition that design adjustments to obtain a licence must be avoided as much as possible (see page 48).

— Producing multiple reactors in series could potentially produce productivity gains of around 2% per reactor (see page 49). Once five reactors have been built, the productivity gain could rise as high as 8-13% (see page 49).

— If a second reactor is constructed in the same power plant, it could potentially produce savings of 6-8% (see page 50).

— Based on the construction of two reactors in one nuclear power plant using a proven design, cost savings of between 28 and 40% could be achieved.

Potential savings per MW compared with costs per MW of a FOAK reactor



Note: (a) It is estimated that avoiding FOAK issues in engineering and construction by using a proven design could deliver savings of up to 20-30% (see page 48). (b) Producing multiple reactors in series could potentially produce productivity gains of around 2% per reactor (see page 49). (c) If a second reactor is constructed in the same power plant, it could potentially produce savings of 6-8% (see page 50).

Accordingly, a selection should be made from among Generation III+ designs of which a number of nuclear power plants have already been built

Generation III+ projects in EMEA (excl. Russia)[a] and North America

Developer (type)	Country	Reactor	Start of construction	Grid connection
EDF (EPR)	Finland	Olkiluoto 3	2005	2021[b]
	France	Flamanville 3	2007	2023[b]
	UK	Hinkley Point C1	2018	2026[b]
	UK	Hinkley Point C2	2019	2027[b]
Westinghouse (AP1000)	USA	Vogtle 3	2013	2021[b]
	USA	Vogtle 4	2013	2022[b]
KEPCO (APR-1400)	UAE	Barakah 1	2012	2020
	UAE	Barakah 2	2013	2021[b]
	UAE	Barakah 3	2014	2022[b]
	UAE	Barakah 4	2015	2023[b]
Rosatom (VVER-1200 & VVER-TOI)	Belarus	Astravets 1	2013	2020
	Belarus	Astravets 2	2014	2022[b]
	Turkey	Akkuyu 1	2018	2023[b]
	Turkey	Akkuyu 2	2020	2024[b]
	Turkey	Akkuyu 3	2021	2025[b]

Note: (a) Europe, the Middle East and Africa, excluding projects in Russia. (b) Most recent published or estimated year of grid connection, as at March 2021.

Source: (1) Reactor database, World Nuclear Association (https://www.world-nuclear.org/Information- Library/Facts-and-Figures/Reactor-Database.aspx, last accessed on 28 May 2021). (2) Plans for new reactors worldwide, World Nuclear Association (https://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx, last accessed on 28 May 2021).

In EMEA and North America, Generation III+ reactors are currently being built by four parties (EDF, Westinghouse, KEPCO and Rosatom)

— EDF's EPR design is being built in Finland (Olkiluoto 3), France (Flamanville 3) and the United Kingdom (Hinkley Point C1 and C2). The first grid connection is expected in 2021 at the Olkiluoto reactor.

— Westinghouse's AP1000 design is being built in the United States (Vogtle 3 and 4). The first grid connection is expected in 2021.

— KEPCO's APR-1400 design is being built in the United Arab Emirates (Barakah 2, 3 and 4). The Barakah 1 reactor is already finished and was connected to the grid in 2020.

— Rosatom's VVER-1200 and VVER-TOI designs are being built in Belarus (Astravets 2) and Turkey (Akkuyu 1, 2 and 3). The Astravets 1 reactor is already finished and was connected to the grid in 2020. These designs are also planned for Finland (Hanhikivi) and Hungary (Paks 5 and 6).

There is no consensus on which design is the best; the market participants consider all of the Generation III+ reactors listed above to be sound options

— The market participants expressed preferences for various specific designs, while stating that all of the designs by EDF, Westinghouse, KEPCO and Rosatom are robust designs.

— If a Generation III+ design is seriously considered, it will be necessary to work out which of the designs is most suitable for the Netherlands. The obvious options are the EDF, Westinghouse and KEPCO designs.

  - At the request of the Ministry of Economic Affairs and Climate Policy Rosatom has been deemed out of scope, as have the Chinese reactor technologies.

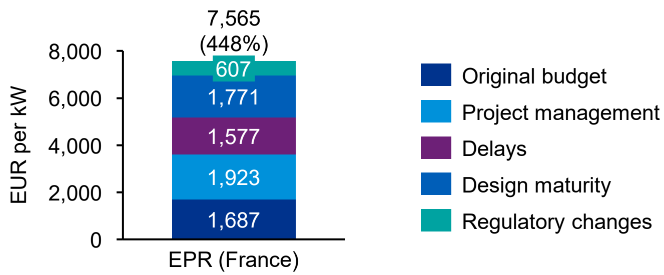
A choice can only be made once a sufficient number of projects have actually been completed

— It is expected that by 2023, enough nuclear power plants of all types will have been built to enable a choice to be made between proven designs.

"There are no good or bad designs. The key thing is that the more power plants you build, the lower the risks. That's what keeps the costs down."

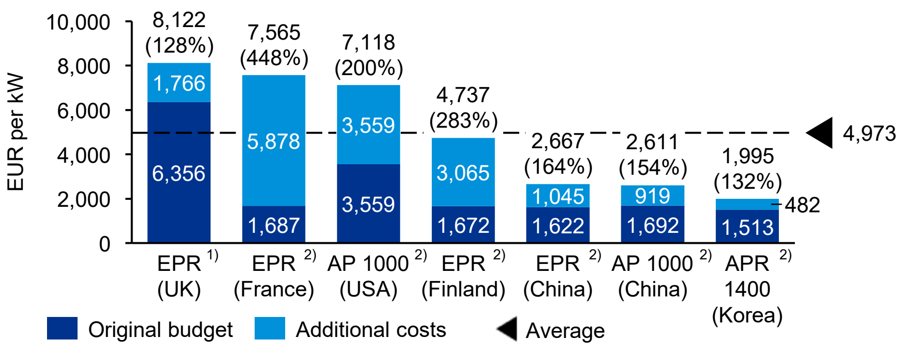
The first FOAK Generation III+ projects turned out more expensive than originally estimated...

Key drivers of the cost overruns in the construction of the Flamanville 3 EPR reactor in France



Note: The percentages show the total costs compared to the original budget (in EUR per kW).
Source: Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). KMPG analysis.

Construction costs for a selection of FOAK Generation III+ projects



Note: The percentages show the total costs compared to the original budget (in EUR per kW).
Source: (1) UK government reports, among other sources. See the appendices for more details. (2) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). KMPG analysis.

"No power plants were built in Europe for about 20 years, so the value chains disappeared. The people who built the previous 20 power plants in France are now retired."

The first FOAK Generation III+ projects turned out more expensive than originally estimated due to immature designs...

— The construction of one of the first Generation III+ reactors, Flamanville 3, is expected to be significantly more expensive than budgeted. Expressed as a percentage of the original budget, the total costs are expected to be 448%, with this reactor representing the biggest cost in percentage terms.[1)]
  - This probably happened because when construction began, it is estimated that the design was only around 40% complete. This caused delays and design adjustments. Regulatory changes and project management also played a role.[1)]

— The construction costs of other Generation III+ reactors are also expected to be higher than budgeted. Expressed as a percentage of the original budget, the expected costs vary from 128% (for an EPR project in the UK) to 283% (for an EPR project in Finland).[1)]
  - Similarly, when construction on the EPR project in Finland (Olkiluoto 3) began, only part of the design and the engineering studies were ready.[1)] This meant the supply chain was not in place when the project started.[1)]

...cost underestimates resulting in overly low budgets...

— The original budgets may also have been too optimistic, making budget overruns unavoidable.
  - According to a 2013 study, a FOAK reactor is estimated to cost around EUR 4,100 to 6,600 per MW (including budget overruns), with a FOAK reactor in Europe probably falling at the upper end of that range.[2)] The original budgets were nearly always below that range.

...and a lack of knowledge and established supply chains

— The market participants indicated that an important factor in the cost overruns for FOAK Generation III+ projects, particularly in Europe, is the lack of knowledge, expertise and established supply chains.[1),2)]
  - Because no nuclear power plants were built for around 20 years, knowledge disappeared and supply chains were eroded.

Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).
(2) Synthesis on the economics of nuclear energy, William D'haeseleer for the European Commission (2013).

...but because the designs of Generation III+ reactors are now mature and knowledge has been built up again in Europe, costs are expected to be lower

"Mistakes that we made in the past, we won't make again."

"If you opt for a recent design, you can reuse much of the supply chain."

"The second reactor is expected to be 20% to 25% cheaper."

"We can save 20% on the next reactor because the design will be the same and we won't have to do any more safety tests."

"If you build two reactors, you can save 30% on the second reactor due to learning effects and because you don't have to repeat activities for the licence."

The market participants indicated that the Netherlands could profit from the more mature designs and from existing knowledge, expertise and supply chains in Europe

— The market participants stated that due to previous experience, the Generation III+ designs are now more mature.

— Knowledge, expertise and supply chains have also been built up again in Europe through the construction of Generation III+ reactors, after collapsing since the 1990s due to the decline in nuclear power plant construction.[1)]

Accordingly, the market participants expect that Generation III+ reactors with a proven design will be approx. 20-30% cheaper than FOAK Generation III+ projects

— The market participants expect that projects with a proven Generation III+ design will be approximately 20-30% cheaper.
  - This is because the design is mature and the safety is proven.
  - In terms of securing a licence, it will be possible to build on work done for previous projects.
  - The Netherlands could also learn from previous projects, avoiding mistakes and increasing productivity (see also page 49). To do so, it would be crucial to reuse all or part of the supply chains.

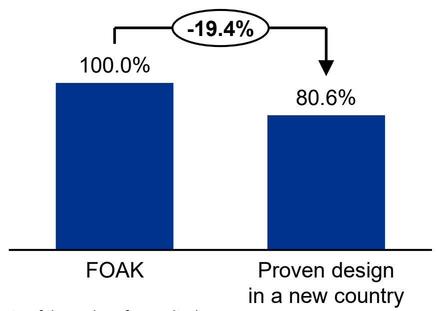
— The market participants also expect that there would be fewer delays than there were for the first Generation III+ projects in Europe.

Source: (1) The cost of new nuclear power plants in France, SFEN (2018).

Preventing FOAK issues in design and construction could deliver estimated savings of 20-30% compared with an average FOAK reactor

The relative costs per MW for a proven design in a new country compared with the costs per MW of a FOAK reactor

Indicative



Note: This is an estimate of the order of magnitude.

Source: Synthesis on the economics of nuclear energy, William D'haeseleer for the European Commission (2013). KMPG analysis.

> *"It's important to choose an existing design right at the start, and not tinker with the design during construction. If you tinker, you'll have overruns, and the costs will be difficult to estimate."*

By avoiding FOAK issues in design and construction, a proven design could deliver savings of around 20-30% compared with an entirely new design

— Learning effects in relation to the design acquired during construction and the ability to build on licensing work from previous projects are expected to deliver savings of around 20-30% compared with the costs of an average FOAK reactor (including budget overruns).
  - The market participants indicated that by choosing a proven design, savings of around 20-30% are possible (see previous page).
  - According to research, construction in a new country of a design that is already proven is expected to be 19.4% lower per MW than for a FOAK reactor.[1) 2)]

However, these cost savings can only be achieved if design adjustments to obtain a licence are minimised, both before and during construction

— The market participants indicated that in some cases up to 25% of the design has to be redone to comply with different national regulatory frameworks.
  - The associated additional costs could be largely or entirely avoided if the regulator accepts proof of other licensing processes (see also page 91).

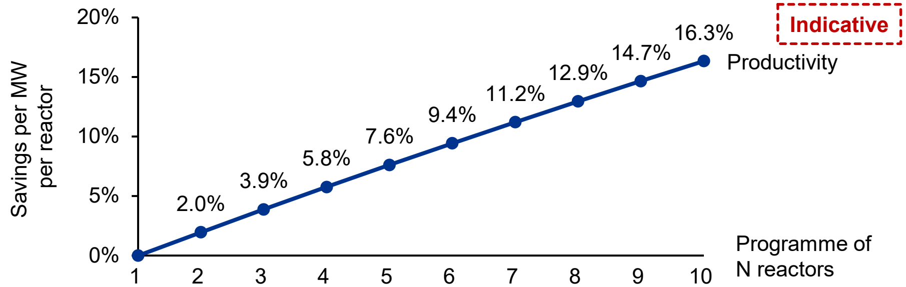
— The market participants emphasised the importance of not altering the design during the project to meet changing licensing requirements, since this could lead to major delays and cost increases (see also page 91).

— Choosing a proven design could also remove the need for design adjustments due to problems during construction, because such adjustments would already have been made during a previous project.

Source: (1) Synthesis on the economics of nuclear energy, William D'haeseleer for the European Commission (2013). (2) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).

Productivity effects from serial production could reduce construction costs by around 2% for a second reactor, rising to 8-13% for a fifth reactor

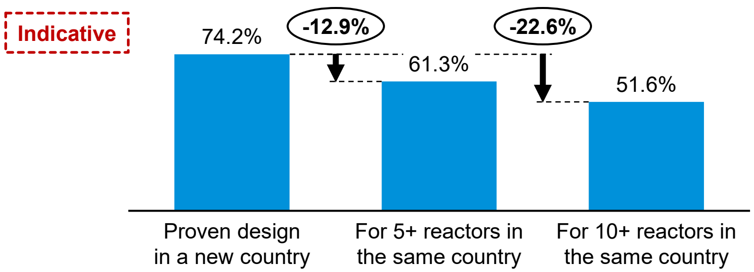
Savings per MW per reactor due to productivity effects in a programme of N reactors[a)]



Note: (a) This is an estimate of the order of magnitude. It is based on the assumption that productivity effects will be evident from the second reactor onwards.

Source: Reduction of capital costs of nuclear power plants, NEA (2000). KMPG analysis.

Relative costs per MW when producing reactors in series [a)] (FOAK reactor = 100%)[b)]



Note: (a) Based on constructing nuclear power plants with two reactors. (b) This is an estimate of the order of magnitude.

Source: Synthesis on the economics of nuclear energy, William D'haeseleer for the European Commission (2013). KPMG analysis.

> *"If you choose to build two identical reactors, you're already reaping the benefits of learning effects. A one-year delay between reactor 1 and reactor 2 is optimal for switching construction from one to the other."*

Productivity effects from serial production mean savings could rise from around 2% for a second reactor to 8-13% for a fifth reactor and 16-23% for a tenth reactor

- The market participants indicated that building multiple reactors in series could lead to significant savings per reactor, due to productivity effects.
  - These productivity effects could arise due to learning effects during design, during construction or during the manufacture of components in the supply chain.[1)]
- The NEA has created a model that provides indicative calculations of the possible savings arising from serial production. The model is based on EDF's experiences in France with Generation II reactors.[2)]
  - Serial production means that the exact same design is built multiple times by the same parties. This often occurs within a single country, but it can also be within a larger region, provided these conditions are met. Existing licence requirements must also be met.
- The NEA model shows that the savings due to productivity effects from serial production could rise from around 2% for a second reactor to around 8% for a fifth reactor and up to 16% for a tenth reactor.[a),2)]
- A model by William D'haeseleer shows that the savings per MW could be approximately 13% (for 5+ reactors) to 23% (for 10+ reactors) compared to a FOAK reactor.[3)]

To achieve these savings, the timing of the construction of the different reactors would have to be closely aligned

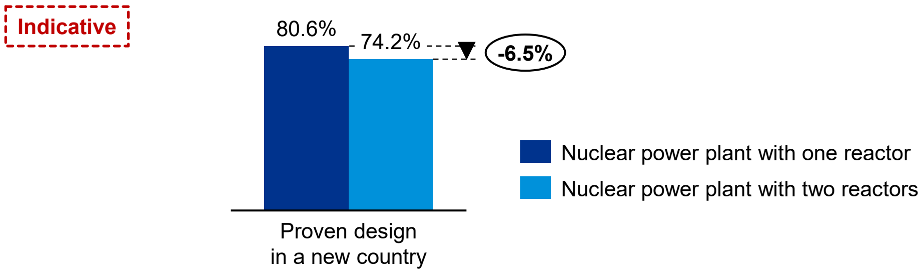
- The market participants indicated that it would be important to carefully time the construction of the different reactors, with the idea being to switch to the next reactor at the right time to optimise productivity effects.
  - Building in such a way would mean, for example, that as soon as the concrete pouring is completed for the first reactor, concrete pouring begins on the second reactor.

Note: (a) Based on the assumption that productivity effects will be evident from the second reactor onwards.

Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). (2) Reduction of capital costs of nuclear power plants, NEA (2000). (3) Synthesis on the economics of nuclear energy, William D'haeseleer for the European Commission (2013).

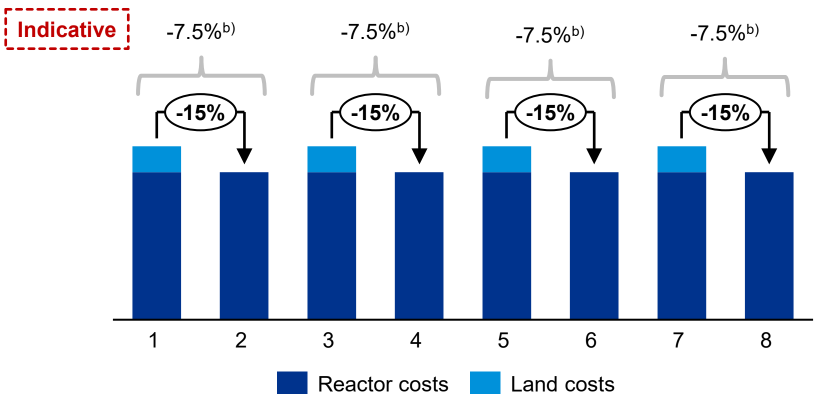
Savings of approximately 6-8% can be made by building two reactors in one nuclear power plant, because resource allocation can be optimised and land costs shared

Relative costs per MW for a nuclear power plant with one reactor versus a nuclear power plant with two reactors (FOAK nuclear power plant with one reactor = 100%)



Note: This is an estimate of the order of magnitude.
Source: Synthesis on the economics of nuclear energy, William D'haeseleer for the European Commission (2013). KPMG analysis.

Relative costs per reactor when building two reactors per nuclear power plant[a)]



Note: (a) This is an estimate of the order of magnitude. Excluding productivity effects and FOAK costs. (b) Shared between the two reactors, the 15% results in a saving of 7.5% per MW.
Source: Reduction of capital costs of nuclear power plants, NEA (2000). KPMG analysis.

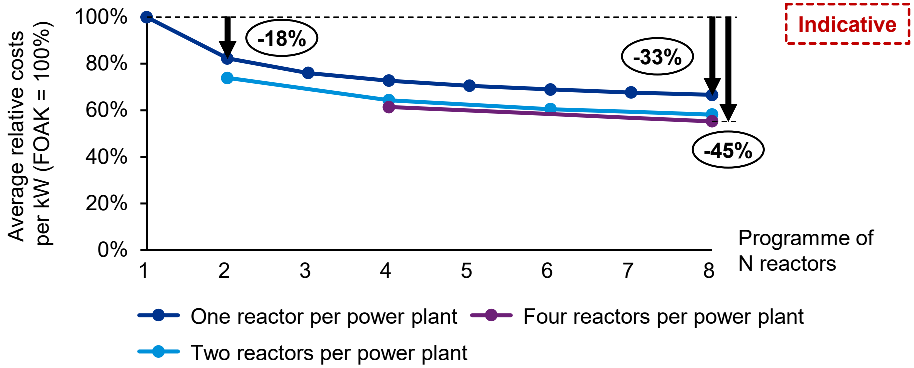
Building two reactors in one nuclear power plant could potentially deliver savings of up to approximately 6-8% per MW

- Building two reactors in one nuclear power plant could lead to savings of around 6% to 8% per MW.
  - According to William D'haeseleer's model, building a nuclear power plant with two reactors, based on a proven design but in a new country, would lead to savings of 6.5% per MW compared with a FOAK reactor.[1)]
  - According to the NEA, 15% could be saved on the second reactor if a power plant with two reactors is constructed. Shared between the two reactors, that results in a saving of 7.5% per MW.[2)]
- Costs can be saved through the reuse and optimal allocation of resources during the construction of two reactors at the same power plant and by spreading the land costs over two reactors.[3)]
  - Worldwide, approximately 90% of Generation II nuclear power plants have two or more reactors.[2)]

Source: (1) Synthesis on the economics of nuclear energy, William D'haeseleer for the European Commission (2013). (2) Reduction of capital costs of nuclear power plants, NEA (2000). (3) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).

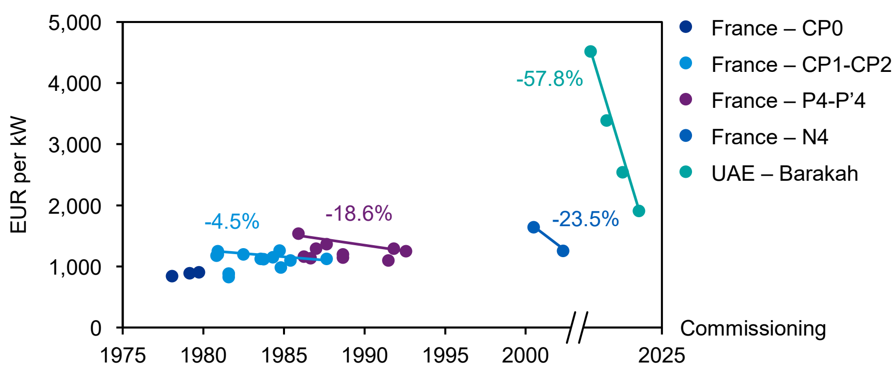
The possible savings compared with a FOAK nuclear power plant are supported by experiences in France and the United Arab Emirates

Average costs per kW in a programme of N reactors (FOAK nuclear power plant with one reactor = 100%)[a)]



Note: (a) This is an estimate of the order of magnitude. Based on EDF's experiences.
Source: Reduction of capital costs of nuclear power plants, NEA (2000). KMPG analysis.

Construction costs for the French nuclear fleet[a),1)] and the Barakah reactors in the United Arab Emirates[2)] (in EUR per kW)[b)]



Note: (a) The data points for the French nuclear fleet are the average of two reactors. (b) The percentages shown are the percentage difference in costs per kW between the first and last in a series.
Source: (1) Costs in the nuclear power generation sector, Court of Auditors (2012). (2) The ETI nuclear cost drivers project – full technical report, Energy Technologies Institute (2020). KMPG analysis.

An NEA model, based on the EDF's experiences in France, shows that the savings from serial production could be as high as ~33% per kW compared with a FOAK nuclear power plant

— The NEA model (see page 49) shows that the average costs per kW in a reactor programme with one reactor per nuclear power plant could drop by around 18% per kW if a second reactor is built and up to approximately 33% if an eighth reactor is built, compared with a FOAK nuclear power plant.[1)]
  - The costs per kW for a series of eight reactors with two or four reactors per power plant would be around 45% lower than for a FOAK nuclear power plant with one reactor.[1)]
  - The average costs would fall primarily because the FOAK costs would be spread across multiple reactors. The costs would also fall due to productivity effects of around 2% per reactor (see page 49).

Historical figures in France show that savings of up to around 23% could be achieved with Generation II reactors

— In the construction of the French nuclear fleet of Generation II reactors, it was possible to achieve cost savings between the first and last pair in nearly every series of reactors.[1),2)]
  - The savings between the first and last pair of the reactor series in France varied from 4.5 to 23.5%.[2)]

In the United Arab Emirates (UAE), the construction of the second Generation III+ reactor is expected to save 25.0% in costs, rising to 57.8% for the fourth reactor

— The second KEPCO reactor in Barakah in the UAE is expected to be around 25% cheaper per kW than the first Barakah reactor.[3)]
— The fourth KEPCO reactor in Barakah is expected to be around 58% cheaper per kW than the first Barakah reactor.[3)]

"The UAE projects show a clear learning effect. It is an absolute lesson in serial production."

Source: (1) Reduction of capital costs of nuclear power plants, NEA (2000). (2) Costs in the nuclear power generation sector, Court of Auditors (2012). (3) The ETI nuclear cost drivers project – full technical report, Energy Technologies Institute (2020).

KPMG

Large or SMR?

Many of the market participants saw SMRs as an interesting option, but there is still uncertainty about how proven they are and how vulnerable they might be to FOAK issues

"The business model of SMRs is revolutionary."

"Due to its size, in the long term an SMR would probably be easier for private parties to finance."

"If the Netherlands opts for an SMR, it should synchronise with other countries. By making sure the design is the same, it can benefit from economies of scale."

"If the decision is made to use proven tech, that means SMRs are not an option at the moment."

There was a broad consensus among the market participants that SMRs could be an interesting option

— Many market participants thought SMRs were an interesting option because they could potentially be built faster and require less investment, which might make them easier to finance.

— Due to their small size, SMRs are better able to increase the efficiency of passive safety systems, and it is possible to build SMRs in locations where a large Generation III+ reactor could not be built.

— SMRs are also more flexible due to enhanced opportunities for the delivery of adjustable power.

…but commercial availability of SMRs is still some time away...

— The first SMRs are expected to become fully operational as FOAK power plants in the period from 2027 to 2033 (see page 59).[1)]

…which means there is still uncertainty around how vulnerable they will be to FOAK issues

— If the Netherlands is interested in an SMR, the market participants indicated that it should choose a successful developer (or one that is expected to be successful) who can build SMRs in multiple locations. In doing so, the Netherlands could collaborate with other countries.

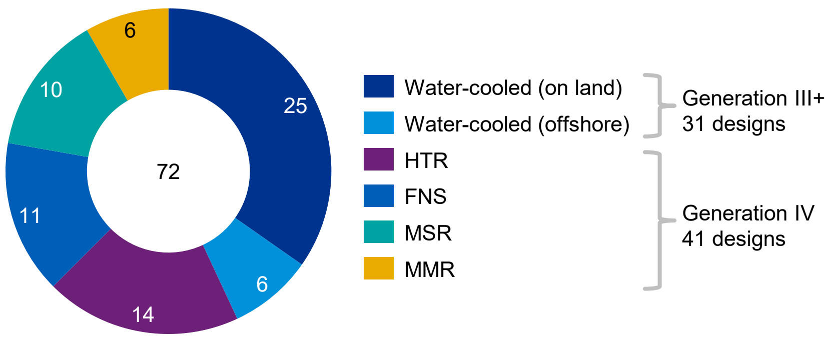
- SMRs are expected to be more efficient to build than traditional large Generation III+ reactors. However, this is yet to be proven in practice.
- In addition, it is essential that SMRs are produced in series, to compensate for the diseconomies of scale of a smaller reactor.

— It is believed that the Netherlands could minimise its risks by waiting until any FOAK issues have been resolved and it is clear which developers are able to successfully build SMRs. In that case, the Netherlands will not be able to initiate a potential process to construct an SMR until at least 2027-2033.

Source: (1) Advances in small modular reactor technology developments, IAEA (2020).

An SMR is a modular reactor with a capacity of between 10 and 300 MW that has a potentially attractive value proposition

Number of SMR designs around the world, by technology type



Note: HTR stands for High Temperature Reactor. FNS stands for Fast Neutron Spectrum reactor and comprises a group of fast reactors with various cooling options such as sodium, lead or gas. MSR stands for Molten Salt Reactor. MMR stands for Micro Modular Reactor. This reactor has a capacity of less than 10 MW.

Source: Advances in small modular reactor technology developments, IAEA (2020). KMPG analysis.

"Not all SMR designs include passive safety, but the most credible designs do."

Small Modular Reactors (SMRs) are reactors with a capacity of between 10 and 300 MW and a modular design

— SMRs are generally defined as reactors with a capacity of between 10 and 300 MW.[1)] By combining several SMRs in an integrated design, this can be increased to as much as 900 MW.

There are more than 70 SMR designs in development worldwide, most of which are based on Generation III+ technology

— SMRs can be based on either existing Generation III+ reactor technology or on new Generation IV reactor technology.[1)]

— There are at least 72 SMR designs in development around the world, including 31 designs based on water-cooled Generation III+ reactor technology and 41 designs based on Generation IV reactor technology.[2)]

  - See page 40 for a brief explanation of Generation IV reactor technology.

Due to their value proposition, SMRs could be an attractive alternative to traditional large Generation III+ reactors

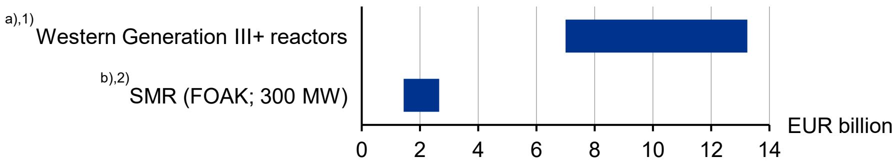
— SMRs could be an attractive alternative to traditional large Generation III+ reactors due to the following features:

  - Because of their smaller size and modular design, SMRs are expected to be faster to build and could be easier to finance.[1)]
  - The efficiency of passive safety systems may be higher due to the smaller size of SMRs, which leads to improved passive safety.[1)]
  - Partly because of the smaller cores, it is possible that a smaller emergency planning zone could be applied, which means SMRs could be built in more locations.[1)]
  - SMRs are flexible due to enhanced opportunities for the delivery of adjustable power (see also page 122). SMRs can achieve this through specific design aspects and through the use of multiple SMRs in one integrated nuclear power plant design.[1)]

Source: (1) Small modular reactors: challenges and opportunities, OECD-NEA (2021). (2) Advances in small modular reactor technology developments, IAEA (2020).

SMRs have lower investment requirements than traditional large reactors and may have certain advantages in terms of financing and risks

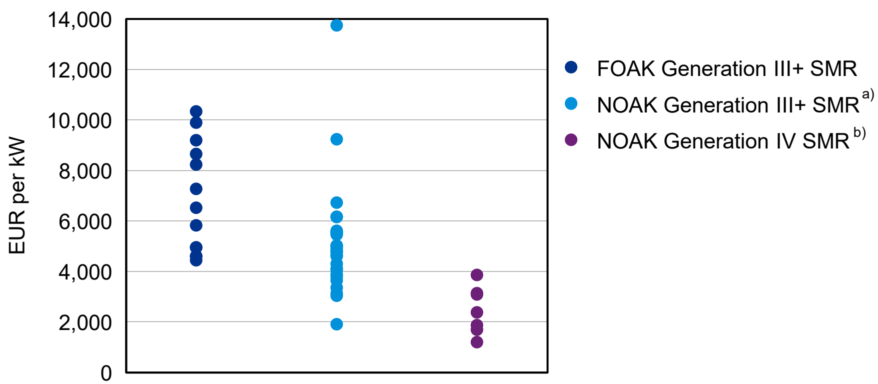
Required investment for a 300 MW FOAK SMR compared with Western Generation III+ reactors (in EUR billion)



Note: Based on Western Generation III+ reactors: Flamanville 3, Hinkley Point C, Olkiluoto 3, Hanhikivi and Vogtle. (b) Based on a FOAK SMR of 300 MW.

Source: (1) Reports by EDF, Fennovoima, the British government and the World Nuclear Association. (2) Economics and finance working group report, Canada's SMR Roadmap (2018). KMPG analysis.

Range of estimates for the required investment per kW for SMRs



Note: (a) NOAK stands for Nth Of A Kind, which means that several reactors of the same type have already been constructed. (b) The fact that the estimates for Generation IV SMR designs are much lower than for Generation III+ designs may be due to a lack of design maturity. Generally speaking, the greater the design immaturity, the greater the uncertainty and the more likely it is that the costs will be underestimated. See, for example, Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).

Source: Economics and finance working group report, Canada's SMR Roadmap (2018). KMPG analysis.

There is significant uncertainty around the precise cost estimates for an SMR, but costs are expected to be lower than for traditional large reactors

— The expected investment required for a 300 MW SMR is between EUR 1.4 billion and EUR 2.7 billion.[1)]
  - The amounts cited by the market participants are of the same order of magnitude.
  - By way of comparison, recent Western traditional Generation III+ reactors cost between EUR 7.0 billion and EUR 13.2 billion, but have capacities of 1,200-1,500 MW.[a)]

— However, there is significant uncertainty around the precise cost estimates for an SMR, and a literature review[1)] showed that estimates can vary widely. These substantial differences are due to the fact that the underlying assumptions can also vary significantly.
  - The estimates for the necessary investment for a FOAK Generation III+ SMR vary from EUR 4,444 to EUR 10,336 per kW.[b)]
  - By way of comparison, a Western traditional Generation III+ FOAK reactor is estimated to cost between EUR 4,826 and EUR 8,122 per kW (including budget overruns, see page 46).[a)]
  - For a NOAK[c)] Generation III+ SMR, the estimates vary from EUR 1,904 to EUR 13,739 per kW.[d)]

The market participants expect that the relatively low required investment and the relatively short construction time of an SMR could lead to a number of advantages in terms of financing and risks

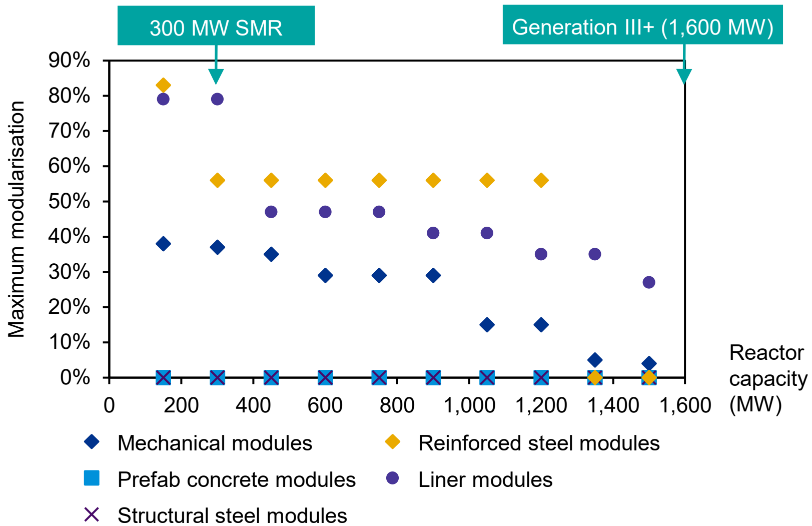
— Financing could be easier to obtain because less capital is required for an SMR (due to its smaller size). Furthermore, because of the shorter construction period there would be less construction risk, and faster cash flow would be generated from the investment.
  - See the 'Financing and guarantees' chapter on page 61 for more information about financing and the associated risks.

Note: (a) For the source, see the notes for the top left graph. (b) The lowest estimate came from a vendor; the highest estimate came from a study which explicitly assumed that for the first FOAK SMR, it is not possible to achieve good procurement, production or supply. (c) NOAK stands for Nth Of A Kind, which means that several reactors of the same type have already been constructed. (d) The lowest estimate came from a vendor, the highest estimate came from a study based on expert estimates.

Source: (1) Economics and finance working group report, Canada's SMR Roadmap (2018).

With their smaller size, modular design and partially factory-based construction, the aim is that SMRs can be built more quickly than traditional designs...

Maximum percentage of modularisation for different components in the design of a reactor



Source: The impact of modularisation strategies on small modular reactor cost, Lloyd, Roulstone & Middleton (2018). KMPG analysis.

“One advantage of SMRs is that much of the construction can be done off site, at a shipyard or factory for example. The factory aspect gives more control over quality and construction times.”

“An SMR design is much simpler. It is therefore much easier to build an SMR.”

SMRs can probably be built relatively quickly

— The construction time is expected to be four to five years for a FOAK SMR and three to four years for subsequent SMRs.[1)] This corresponds to what the market participants said in the interviews.

— By way of comparison, the construction time for traditional large Generation III+ reactors is at least six years.[1)] Recent experiences in Europe show that this can rise to as much as 16 years for a FOAK reactor (see page 95).

This may be because SMRs have a largely modular design, due to their smaller size, and because part of the construction takes place in a factory

— The lower the capacity of a reactor design, the more modularisation is possible. This means SMR components can be up to 80% modular in design.[2),3)]
  - SMRs have greater modularisation potential with liner and mechanical modules than large reactors.
  - Reinforced steel modules can even be made to be entirely modular, which is completely impossible with the largest reactors.[3)]

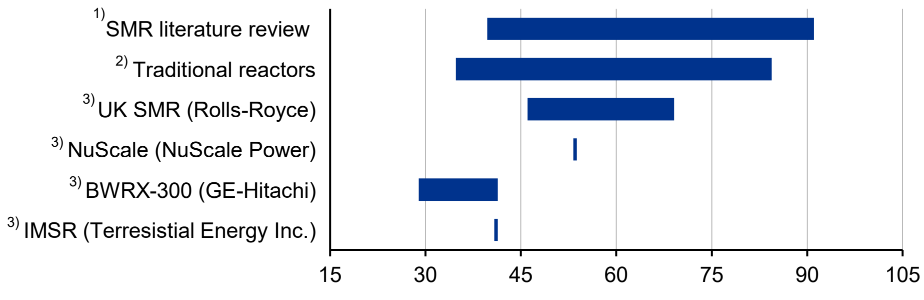
— The market participants also indicated that it is possible to have more control over quality and construction times when constructing an SMR, because SMRs can be partially built in a factory.
  - Due to the modular design of SMRs, the various modules can be transported to and assembled at the site, resulting in predictability and savings in construction time.[4)]

Source: (1) Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020). (2) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). (3) The impact of modularisation strategies on small modular reactor cost, Lloyd, Roulstone & Middleton (2018). (4) Small modular reactors: challenges and opportunities, OECD-NEA (2021).

…which means they can potentially compensate for the diseconomies of scale relative to large reactors, provided they are built in series

Minimum and maximum levelised cost of electricity (in EUR per MWh)

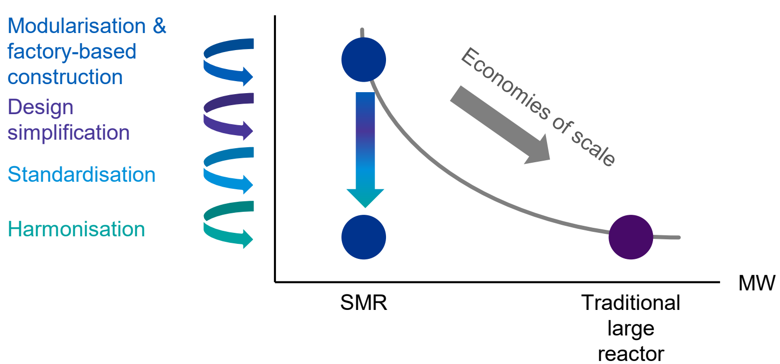
Indicative



Note: The LCOE for NUWARD (EDF) and SMART (KAERI & K.A. CARE) is unknown, and is therefore not shown here.

Source: (1) Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020). (2) Projected costs of generating electricity 2020, IEA (2020). (3) Reports and press releases by the designers. KMPG analysis.

Economic drivers of SMRs that could help compensate for the diseconomies of scale



Source: Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). KMPG analysis.

The aim is for SMRs to cost about the same amount per MWh as traditional large reactors...

— The market participants indicated that the aim is for SMRs to cost about the same amount per MW as a traditional large reactor.
  - According to a literature review, the LCOE for SMRs is expected to be between EUR 50 and 91 per MWh.[1)] This is largely the same range as the LCOE of large reactors (EUR 35 to EUR 84 per MWh).[2)]
  - The advertised minimum and maximum LCOE of a selection of promising SMR designs[a)] fall at the lower end of these ranges; some even fall below the range.

…but SMRs must be produced in series, to compensate for the diseconomies of scale of a smaller reactor

— SMRs are expected to be more efficient to build than traditional large reactors. However, this is yet to be proven in practice.

— Compared with a large reactor, an SMR has no economies of scale. SMRs can compensate for this by maximising the economic benefits of serial production.
  - SMRs can potentially draw great benefit from the advantages of serial production because SMRs have more potential for design simplification, and it is expected that the design would not have to be adjusted as frequently to suit local conditions.[3)]
  - For this to work, worldwide harmonisation in policies and regulations would be necessary, because a global market is required to maximise the advantages of serial production.[3)]

It can be difficult to compensate for diseconomies of scale with a FOAK SMR, because serial production has not yet commenced

— The advantages of serial production do not apply to the first SMR, which means the costs per MWh may be higher than those for a traditional Generation III+ reactor.
  - The effects of serial production can therefore only be tested once multiple SMRs of a certain design have been constructed.

Note: (a) See page 59 for an explanation of how this selection was made.

Source: (1) Economics and finance of Small Modular Reactors, Mignacca & Locatelli (2020). (2) Projected costs of generating electricity 2020, IEA (2020). (3) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).

The smaller size of SMRs gives flexibility in terms of location and use, but there is expected to be limited support for multiple reactors spread throughout the country

"For a normal power plant, expensive adjustments often have to be made to the grid infrastructure. Because an SMR has a much smaller capacity, these costs wouldn't apply."

"The safety risks of an SMR are lower, which means you could probably put the power plant closer to a residential area."

"Build a power plant in the right place. For steam, you have to put it close to the user. If you look at industrial hubs, you can design the entire factory in such a way that it can serve all the users in the area."

"The biggest benefit of building multiple SMRs in multiple locations is that it provides flexibility to the network."

"Spreading SMRs around the country does not seem to be an optimal solution. Things like cooling water, environmental impact assessments, etc. would all have to be considered multiple times."

"The Netherlands is very densely populated. Even for a smaller SMR there are only a handful of possible locations."

Due to their small size, SMRs are expected to be easier to integrate into the energy system and to be built closer to consumers...

- The market participants indicated that due to their smaller size, SMRs would be easier to integrate into the energy system. It is possible that fewer adjustments to the grid infrastructure would be required, compared with a large nuclear power plant. SMRs could also be built more easily on sites that are not directly adjacent to the main power grid.
- Due to the smaller size of an SMR and the Generation III+ safety standards applied, SMRs are expected to be easier to place relatively close to an industrial or residential area.[1),2)]

...creating more flexibility in the way the power plants are deployed

- Because SMRs can be built relatively close to industrial and residential areas, opportunities arise for the use of thermal heat in industrial processes or the urban environment.
  - The potential for process heat applications from SMRs is primarily relevant for Generation IV SMRs.[3),4)]
- The market participants indicated that SMRs are flexible and could be deployed relatively easily to provide adjustable power, particularly if several were built. SMRs can therefore help to keep the grid stable.[5)]

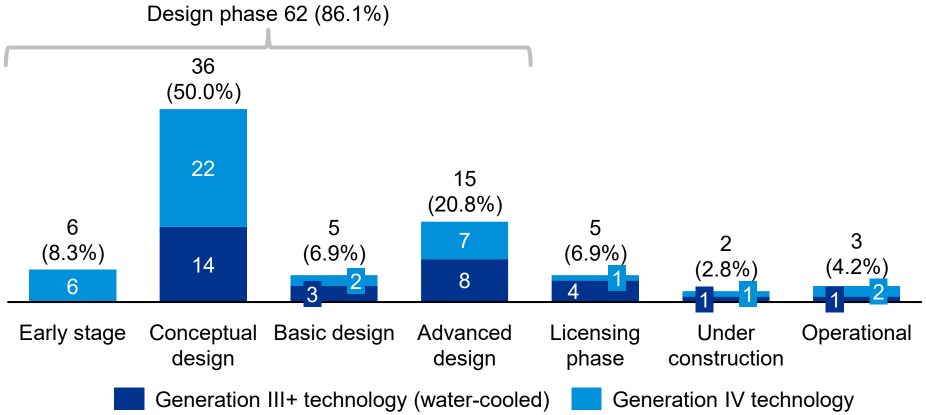
There is expected to be insufficient public support for building multiple SMRs scattered around the country

- For a comparable electricity output, 5-15 SMRs (depending on size) would have to be built to serve as an alternative to a 1500 MW power plant.
- As the market participants explained, the Netherlands is relatively densely populated, which means the number of possible locations for an SMR is relatively low – not only in terms of physical space, but also in terms of environmental space.
- There is also little enthusiasm in the provinces for the arrival of a nuclear power plant (see the 'Nuclear power plant location' chapter on page 133).
- One possibility is to build multiple SMRs in a single location. This could be attractive in terms of financing and load-following capabilities, but the market participants believe it would be sub-optimal in terms of economies of scale compared to a large reactor.

Source: (1) Emergency Planning Zone Sizing for Small Modular Reactors, Nuclear Regulatory Commission (2018). (2) Risk and regulatory considerations for small modular reactor emergency planning zones based on passive decontamination potential, Carless et al (2018). (3) The Future of Nuclear Energy in a Carbon-Constrained World: An Interdisciplinary MIT Study, 2018 (MI). (4) SMR Techno-Economic Assessment Project 3: SMRs – Emerging Technology, National Nuclear Laboratory (2016). (5) Small modular reactors: challenges and opportunities, OECD-NEA (2021).

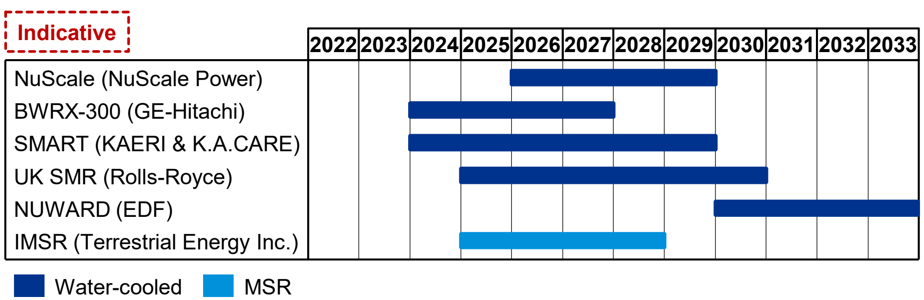
Commercial availability of SMRs is still some time away

SMR designs around the world, by technology type and development phase



Source: Advances in small modular reactor technology developments, IAEA (2020). KMPG analysis.

Expected timeline from the start of construction to the start of operation for the first FOAK reactors for SMR designs currently in the licensing phase[a),b)]



Note: (a) The UK SMR and NUWARD are not yet in the licensing phase; they were added because some market participants mentioned them as being promising. (b) At the request of the Ministry of Economic Affairs and Climate Policy, Chinese and Russian technologies were excluded from this analysis.

Source: (1) Advances in small modular reactor technology developments, IAEA (2020). (2) Advanced Reactors Information System, IAEA (https://aris.iaea.org/sites/overview.html, last accessed on 26 May 2021) (3) Reports and press releases by the designers concerned. KMPG analysis.

There are around 72 SMR designs in development around the world, with 62 (86.1%) still in the design phase[1)]

- Three SMR designs are operational. These include one Generation III+ SMR in Russia that was commissioned in 2020 and two Generation IV demonstration SMRs that were constructed in China and Japan in the 1990s and early 2000s.
- Two SMR designs are under construction. These include one Generation III+ demonstration SMR in Argentina on which construction began in 2014, and one Generation IV SMR in China on which construction began in 2012.
- Five SMR designs are in the licensing phase. This includes one design of a Generation III+ SMR in Russia. The other four designs are described in more detail below.

The first SMRs are expected to become fully operational as FOAK power plants in the period between 2027 and 2033[a)]

- The designs by KAERI, NuScale Power, GE-Hitachi Nuclear Energy and Terrestrial Energy Inc. are in the licensing phase and are therefore the most likely to become commercially available within a relatively short time frame.[b)]
- The market participants also mentioned the UK Rolls-Royce SMR as potentially interesting due to its support from the British government, as well as the NUWARD SMR, which is being developed by EDF.
- The first FOAK SMRs from these developers are expected to become fully operational in the period between 2027 and 2033.[b)]

Note: (a) At the request of the Ministry of Economic Affairs and Climate Policy, Chinese and Russian technologies were excluded from this analysis. (b) See the source list under the bottom left graph.

Source: (1) Advances in small modular reactor technology developments, IAEA (2020). (2) The role of nuclear energy in the energy transition of North Brabant, TNO (2020).

It is recommended that the Netherlands selects a successful developer that can build SMRs in multiple locations, or ensure serial production by itself

The market participants recommended selecting a successful developer who can build SMRs in multiple locations

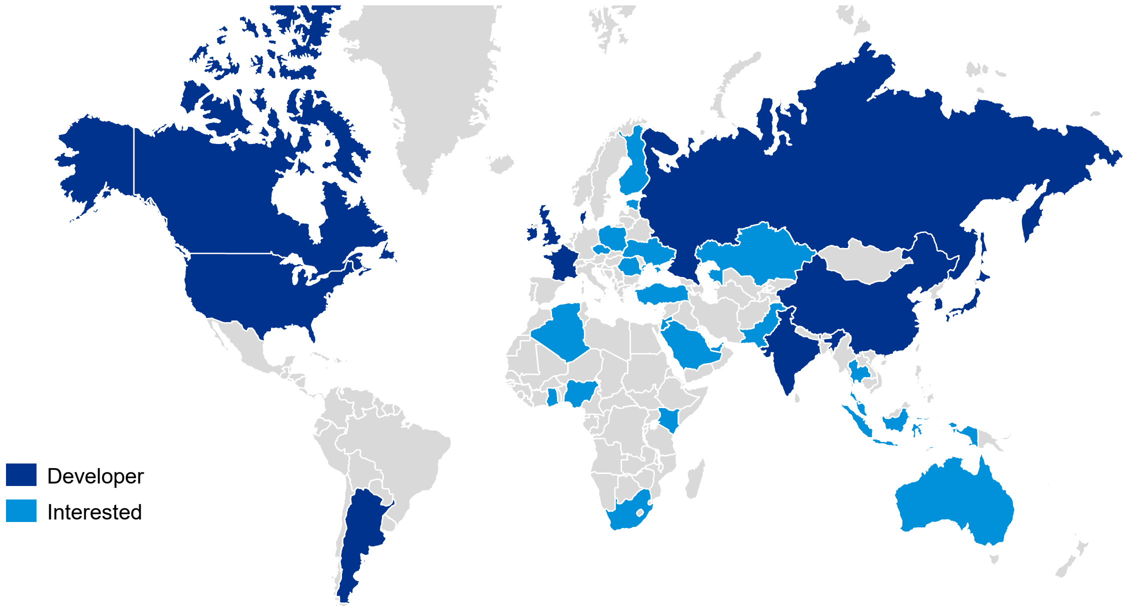
— To reap the benefits of an SMR, it is not enough to choose a proven design; you also have to choose a design that is successful enabling serial production.
  - The promised LCOE be only achieved with serial production (see page 57).

— It may therefore not be possible to choose a design until after the period 2027-2033 (when the first SMRs become operational), because it first needs to be clear which designs are successful enough to allow for serial production.

The Netherlands could also engage in serial production by itself or in collaboration with other countries

— When choosing an SMR design and a developer, the Netherlands could collaborate with other countries, whether in Europe or further afield, to ensure that serial production will be possible.
  - 11 countries are at the forefront of SMR development. In Europe, including France, the UK and Denmark.[1)] The United States and Canada are also frontrunners in this field. Several SMR designs are at various stages of approval with the US nuclear regulator (NRC).[2)]
  - In addition, at least 20 countries have shown an interest in SMRs. In Europe, these include Finland, Estonia, Poland, the Czech Republic, Romania and Ukraine.[1)]

Overview of SMR development around the world



Source: (1) The rise of nuclear technology 2.0 – Tractebel's vision on small modular reactors, Tractebel (2020). (2) Possible role of nuclear in the Dutch energy mix of the future, ENCO (2020).

Financing and guarantees

The government is often directly involved in Generation III+ projects, in combination with a vendor. Large-scale vendor financing for new reactors does not appear realistic...

Financing mix – Completed and ongoing projects

Project	Construction time[a)] *Delay[b)]*	Cost[a)] *Overrun[b)]*	Financing
Flamanville 3[1),3)] *1 × 1,600 MW EPR*	2007-2023 *10 years*	EUR 12.1 billion *EUR 9.4 billion*	The nuclear power plant is being financed and built by EDF.[1)]
Hinkley Point C[2)] *2 × 1,600 MW EPR*	2018-2027 *No delay*	EUR 26.5 billion *EUR 5.8 billion*	EDF (66.5%; also vendor) and the Chinese state-owned company CGN (33.5%).[2)]
Hanhikivi[3),4),5)] 1 × 1,200 MW	2021-2028 *1 year*	EUR 7.0-7.5 billion *EUR ~1.0 billion*	Russian Rosatom (34%; also vendor) and the consortium Voimaosakeyhtiö SF which comprises 44 Finnish shareholders.[5)]
Olkiluoto 3[1),3),5)] 1 × 1,600 MW EPR	2005-2022 *11 years*	EUR 7.7 billion *EUR 5.0 billion*	The consortium Teollisuuden Voima Oyj SF, which comprises 16 Finnish shareholders, and EDF (vendor supplying a turnkey power plant).[5)]
Vogtle 3 & 4[3),5)] 2 × 1,117 MW AP	2013-2022 *5 years*	EUR 15.9 billion *EUR 8.0 billion*	Financed by four government-related energy companies. The US Department of Energy has provided USD 12 billion in loan guarantees.[5)]
Barakah[3),5)] 4 × 1,345 MW APR	2015-2021 *4 years*	EUR ~20.0 billion *No overrun*	Financed by the state-owned company ENEC (80%) and KEPCO (vendor; 20%) supported by export financing.[3)]
Akkuyu[5),6)] 4 × 1,200 MW	2018-2026 *No delay*	EUR ~21.0 billion *No overrun*	Rosatom is the builder, owner (99.2%) and operator of the power plant, but it has agreements with Turkey about energy purchase amounts and prices.[6)]

Existing projects often involve FOAK reactors that are primarily financed by the government and/or the nuclear technology supplier...

- The Generation III+ nuclear power plants that have been built in Europe, the Middle East and North America since 2005, or are under construction, are largely FOAK reactors. By definition, the technology of a FOAK reactor is unproven. This presents risks with regard to lead time and costs, amongst others.
- Generally speaking, private financiers are not prepared to bear FOAK risks. Consequently, existing projects are often primarily financed by the government and/or the nuclear technology supplier (vendor). For vendors, fully or partially financing a FOAK reactor is a way to ensure the technology becomes proven.
  - EDF is the main financial backer of Flamanville 3 and Hinkley Point C. Hinkley Point C is also partly financed by the Chinese state-owned company CGN.[1),2),3)]
  - The Russian state-owned company Rosatom is another key financier. Rosatom is involved in Hanhikivi (33% of the financing, with the rest being private financing from key customers), Paks (fully financed by Rosatom, with a guarantee from the Hungarian government) and the Akkuyu reactor in Turkey (for which the Russian bank Sovcombank has also issued two loans).[3),4),6]

...but market participants expect that vendors will no longer be prepared to provide large-scale financing of new Generation III+ reactor projects

- It is not expected that the financial positions of reactor builders will permit them to finance new large Generation III+ nuclear power plants. In addition, they seem to have primarily provided financing in the past in order to prove the technology. Once the technology is proven and the risk profile of the nuclear power plant has changed, vendors expect the financing to come from other financiers.
  - Only Russian and Chinese vendors (which have state backing) might be able to provide financing, but at the request of the Ministry of Economic Affairs and Climate Policy they were excluded from this market consultation.

Note: (a) Overview of the total costs and construction times, based on 2020 information. (b) The text in red indicates the cost overruns and delays relative to the original estimates.

Source: (1) EDF reports, among other sources. (2) UK government reports, among other sources. (3) OECD NEA reports, among other sources. (4) Hanhikivi 1 design documents submitted to Finnish customer. (5) World Nuclear News articles, among other sources. (6) Rosatom reports, among other sources. KPMG analysis.

Where abridged references are given for sources in the 'Financing and guarantees' chapter, readers may consult the appendices for more details.

…which means other types of financiers could be needed. Such parties would want full commitment from the government and would set various preconditions …

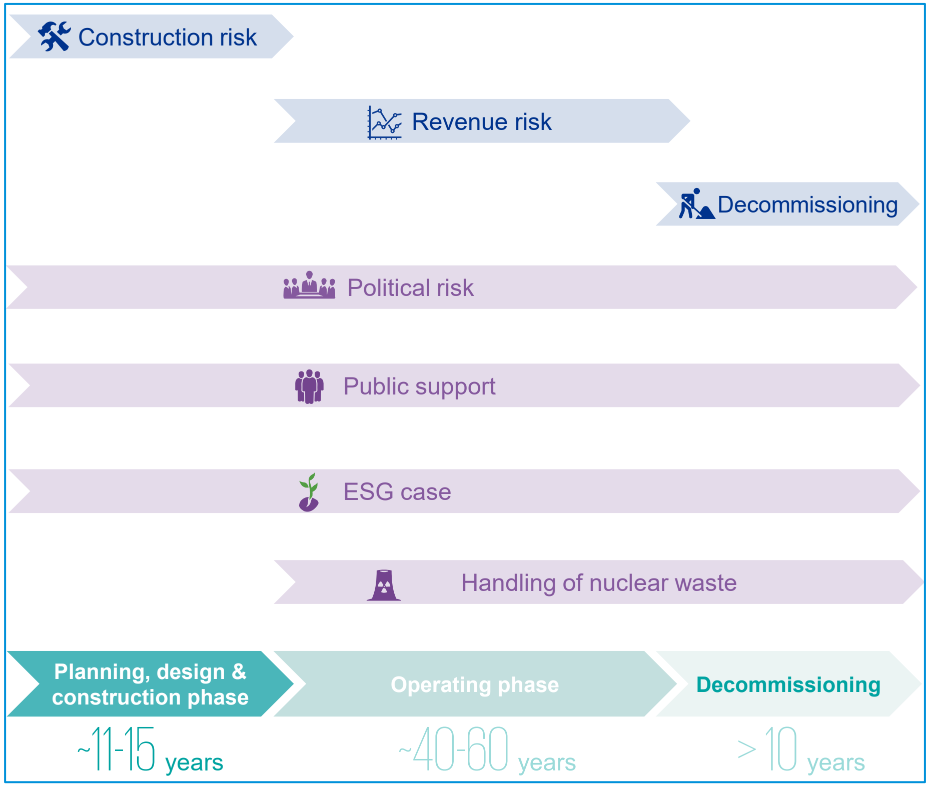
Willingness to provide financing and investment policy of market participants

Type of party	Capacity	Horizon	Government participation	Expected desired guarantees	Other relevant considerations
Pension funds	Mandates up to around EUR 1.0 to 1.5 billion	20-30 years	✓ Pension funds are regularly involved in public-private partnerships	Pension funds are expected to ask for various guarantees covering: revenue (long-term, preferably with a return during construction), *black swan* events (events with a low probability of occurring but with major consequences), licensing risks, decommissioning.	The ESG case is extremely important (partly given the position of pension funds in society), which means a green taxonomy could be required. The same applies to a long-term solution for waste. It is possible that pension funds will only step in once a licence has been issued and the project has begun.
Institutional investors	Mandates up to several billion	5-10 years	✓ Institutional parties generally require government participation	This type of investor is generally expected to want a guarantee covering revenue certainty (including revenue during construction), combined with a guarantee covering decommissioning costs and licensing risks.	Local commitment is often requested (i.e. investment from Dutch financiers). For net-zero investors, the ESG case must stack up to get approval from investment committees.
Vendors/ energy suppliers	Limited	Long-term in existing projects	✓ For new projects, participation by the government or a local party is expected to be desired	Vendors may ask for guarantees covering: investment loss in a prematurely-terminated project, revenue, licensing risks and a government backstop for construction costs. If export financiers (see below) are involved, a loan guarantee would be requested.	Vendor financing could be supplemented with loans or loan guarantees from export financiers. The horizon of vendors is unclear. In existing projects, the vendor often acts as an energy supplier. The main vendors do not operate as energy suppliers in the Netherlands.
Banks (commercial and export banks)	A maximum of around 10-30% of project costs	10-20 years	✓ Banks want the government to participate (possibly up to 70-80%)	Banks want security around the payment of interest and principal. In this context, revenue certainty is important and loan guarantees from the government are expected to be requested, as well as guarantees on reactor completion. Indemnification in the event of nuclear incidents might also be requested.	It is expected that commercial banks would provide financing later in the project (at the end of construction/start of operation), or would only do so with a guarantee from a body such as an Export Credit Agency. Export financing is linked to the involvement of a foreign vendor.

Source: KPMG interview programme 2021.

...and private financiers would primarily accept risks they can control. For the rest, the responsibility would lie with the government

Overview of risks and time frames for a Generation III+ reactor[1), 2)]



Financial risks
Politics and ESG
Phases in a nuclear project

Note: (a) This is an estimate which takes overruns into account, as observed in recent projects in Northern Europe and the United States.

Source: (1) Various, including reports from EDF, Fennovoima and the British government, based on Flamanville 3, Hanhikivi, Vogtle 3 and 4, Hinkley Point C and Olkiluoto. (2) Economics and finance working group report, Canada's SMR Roadmap (2018). (3) Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020). KPMG analysis.

In developing a large nuclear power plant, the government will have to establish a range of preconditions and cover risks to make private financing possible

— Large Western Generation III+ nuclear power plants require investment of around EUR 7.0-13.2 billion[1),a)] with a lead time of approximately 11 to 15 years.[1)]

— The market participants indicated that for the financing of a nuclear power plant, various preconditions will be set by private financiers in the context of political stability and ESG (Environment, Social and Governance):
  - A politically-stable nuclear energy policy and adequate public support are requirements for many private financiers.
  - A properly substantiated ESG case that fits with the investment policy of private financiers is needed for private financiers to be able to invest.
  - As part of the ESG assessment, private financiers will look at the availability of a long-term solution for nuclear waste.

— Private financiers are willing to bear risks they can control, such as ordinary construction risks and operating risks once construction is complete. Private financiers would like the government to shoulder all other risks.
  - This includes revenue risks (given the relatively long construction period and volatile energy market) and so-called 'black swan' risks (low likelihood, major consequences) in both construction and decommissioning. The financing structure in combination with the guarantees to be given will have to provide sufficient cover for these risks.

The risk appetite of private financiers will be different for SMRs than for a new Generation III+ reactor

— SMRs require a relatively lower investment of around EUR 1.4 to 2.7 billion[2)] and a shorter expected construction time of around 4-5 years.[3)]

— The preconditions around politics and ESG are still just as important for SMRs. However, from a financial risk perspective, given the small size and short lead time, private financiers regard SMRs differently.

— In this section, Generation III+ reactors are used as a reference, but in various places the potential for private financing of SMRs is specifically considered.

Political climate, public support and ESG

Stable and consistent political policies on nuclear energy is an important precondition for private financiers

Views of the market participants on the political risk

"Political stability is necessary, partly due to the long lead time."

"The government will have to get involved."

"Is nuclear energy for the long term, or is it a transition technology?"

Recent examples of political policy changes

"Senate agrees to ban coal as a fuel in coal-fired power plants by 2030"

Trouw, 10 December 2019

"Germany compensates energy companies for premature closure of nuclear power plants"

NOS, 5 March 2021

"Stopping biomass subsidies not feasible until 2030"

Parool, 18 December 2020

"Spain loses first arbitration claim over cuts to renewable energy subsidies"

El Pais, 5 May 2017

Source: (1) Trouw. (2) NOS. (3) Het Parool. (4) El Pais. (5) Act banning the use of coal in electricity production (https://wetten.overheid.nl/BWBR0042905/2019-12-20, last accessed on 15 June 2021).

The development of a new nuclear power plant is a long-term project. Partly due to recent examples of policy changes, stable policies and political support are essential for private financiers

— Given the size (in EUR), lead time and relatively long payback period of a reactor project, political support and policies that are stable over the long term (up to 2050) are essential for securing private financing.

— The risk perception of private financiers is fuelled by various recent examples of policy changes in Europe, such as:

- the decision by Germany, in the wake of Fukushima, to close all German nuclear power plants by 2022. This means six nuclear power plants will have to close prematurely. This case has had a significant legal aftermath. In the end, a settlement of EUR 2.4 billion was agreed in March 2021;[2)]
- the Act banning the use of coal in electricity production, as a result of which Dutch coal-fired power plants, including some commissioned in 2015 and 2016, will have to close by 2030;[5)]
- Spain's policy change on sustainable energy tariffs.[4)]

If the government participates, this sends a strong signal. Private financiers may want guarantees around premature termination of the project

— Although broad political support for the development of a nuclear power plant for private financiers is an important requirement, political support alone is not enough. Private financiers (who participate via equity capital) may want to make agreements up front with the government for financial compensation in the event of premature termination (i.e. before the completion of construction or soon after the start of operations), to limit the risks they would face from political uncertainty and policy changes.

— Banks and other providers of loan capital indicate that loan guarantees (covering the payment of both interest and principal) would be requested from the government to limit the risk of a loan not being repaid.

— In addition to formulating stable policies and providing guarantees, the market participants indicated that a strong signal would be sent if the government were to have a financial stake in a Dutch nuclear power plant project. This could be either a majority or minority stake. It would demonstrate commitment to the market and ensure that the interests of the government and private financiers are aligned (to a greater degree).

To mitigate reputational risk and limit the risk of policy changes, broad public support is essential for private financiers

Views of the market participants on public support and reputational risk

"Reputational risk is important to institutional investors."

"Public opinion matters, because support needs to be sufficiently broad. It would help if nuclear energy could be part of the Climate Agreement."

"For private investors, it's important to be sure that the politicians aren't going to change their policies under pressure from public opinion."

"Broad public support is needed, including through collaboration with NGOs."

"To facilitate stable political policies, we need broad public support."

Broad public support is essential for private financiers, partly to protect their reputations. Support also contributes to stable political policies

— The market participants were more or less unanimous in stating that broad public support is needed to make investment in a nuclear reactor possible. Not only could sufficient public support partially mitigate the risk of policy changes (under public pressure), but inadequate public support would make the reputational risk too high for private financiers. This applies to equity investors, but also to banks and other sources of loan capital.

- A good example is Germany, where nuclear energy has been a controversial issue since the 2011 Fukushima disaster, and public pressure caused German financiers to abstain from financing foreign nuclear energy projects.[1)]

The government can contribute by expressing political support, by providing sufficient information and by classifying nuclear energy as a green energy source

— Creating sufficient political support could contribute to public support and vice versa. The government can play an important role in shaping a positive message around nuclear energy, for example by disseminating information about the safety of Generation III+ reactors and providing reassurance about a long-term solution for nuclear waste (see next page).

— The market participants indicated that an EU classification of nuclear energy as a green energy source would help. The Netherlands can lobby at the European level and, in the meantime, formally classify nuclear energy as a green energy source within the Netherlands (see later in this section).

Source: (1) Germany compensates energy companies for premature closure of nuclear power plants, NOS (2021).

Financiers apply strict ESG requirements and critically examine the long-term impact of nuclear projects

Views on ESG (Environmental, Social and Governance)

“ESG is very important for financiers, particularly in the area of waste. So the government could take care of this for private financiers.”

“At a certain point, a policy on the nuclear question is required, and a good ESG case/taxonomy is seen as an important precondition.”

“Long-term storage is important, we don’t want to create environmental problems.”

The ESG case of a new nuclear power plant project must stack up for private investors to obtain approval for an investment in nuclear energy

— In general, private financiers do not face restrictions under investment policies with regard to nuclear energy, unlike those that apply to coal for example. Various financiers indicated that the policy around nuclear energy requires further development.

— However, when making an investment decision, market participants look at the ESG (Environmental, Social and Governance) characteristics of the project. This is broader than the impact on the environment, as it also covers the social impact (including safety, but also elements such as job creation).

— According to the market participants, an investment decision will not get past the investment committee or obtain internal approval if the ESG case does not stack up. For private financing to be possible, detailed and verifiable solutions must be available, covering issues such as:

  - nuclear safety and the impact on the local community: the Dutch government’s assessment of safety matters must be clear (including evacuation plans, for example);
  - environmental aspects, including the impact on water supply and local biodiversity, like the issues that arose for Hinkley Point C where additional measures were taken to protect local fish stocks (at a substantial cost);
  - a long-term solution for nuclear waste (see below).

Partly because of the risk to their reputation, private financiers do not want to be associated with the issue of waste and thus want certainty around a long-term solution for nuclear waste

— The issues around radioactive nuclear waste produced by nuclear reactors are an important subject for many private financiers. Generally speaking, the absence of a clear long-term solution constitutes a barrier in the ESG assessment of an investment in nuclear energy.

— There is broad consensus among private financiers that without a clear and genuine long-term solution for nuclear waste, an investment in nuclear energy would be difficult to justify to investment committees, members and the public. Investors do not want to be involved in a project that could cause long-term environmental problems.

A green EU taxonomy for nuclear energy could increase willingness to provide financing. The Netherlands could also consider introducing its own taxonomy

Recent developments around the taxonomy

"EU comes up with green list for investors, decisions about gas and nuclear energy postponed"

NOS, 21 April 2021

"EU experts to say nuclear power qualifies for green investment label"

Reuters, 27 March 2021

"Brussels bickering over whether to label gas and nuclear energy sustainable"

RTL Nieuws, 20 April 2021

"Nuclear energy a hot potato that the European Commission would rather pass on"

FD, 2 April 2021

Net Zero Asset Managers initiative[1)]

"Wells Fargo is the last of the 'Big Six' banks to make a commitment to climate neutrality."[1),a)]

"Macquarie Asset Management joins Net Zero Asset Managers initiative."[2),a)]

"APG has signed up to the Net Zero Asset Managers initiative. Collectively, the parties to the NZAM initiative represent more than 36% of all managed assets in the world."[3)]

"We're committed to helping increasing numbers of people experience financial wellbeing, and we believe the transition to climate neutrality by 2050 is a major part of that ambition."[4),a)]

Note: (a) Quote from an English-language publication, translated into Dutch by KPMG.

Source: (1) Wells Fargo is the last of the big six banks to issue a net-zero climate pledge, Fortune (2021). (2) Macquarie Asset Management joins Net Zero Asset Managers initiative, Macquarie (2021). (3) APG takes another step towards a carbon-neutral investment portfolio, APG (2021). (4) Getting to net zero, Blackrock (2021). (5) As EU delays taxonomy ruling, experts split on value of green label for nuclear, S&P (2021). (6) Motion by Member of Parliament Erkens et al., 21501-33-864, 10 June 2021. (7) UK government (https://www.gov.uk/govemment/news/chancellor-sets-out-ambition-for-future-of- uk-financial-services, last accessed on 8 June 2021). (8) NOS, 21 April 2021 (https://nos.nl/l/2377637, last accessed on 7 June 2021).

Classification of nuclear energy as a sustainable, green investment at the EU level could help raise interest among private financiers

— For large, institutional parties, it is increasingly important to invest sustainably. To support this goal, a large number of institutional investors have come together to form the Net Zero Asset Managers initiative, which aims to achieve a climate-neutral investment portfolio by 2050.

— Private financiers indicate that an EU decision to classify nuclear energy as a sustainable investment could be an important step. This would ensure that investing in nuclear energy fits in better with sustainable investment mandates, and would create a distinction between 'genuinely green' investments and other investments merely described as sustainable.[8)] Several parties see this as an essential requirement.

— The market participants indicated that a sustainable EU taxonomy for nuclear energy could help generate public support. If a green EU taxonomy also led to more stable political policies, and thus a lower risk profile for the project, this would have a positive effect on the required returns.

However, the EU has postponed its decision, which could prompt the Dutch government to take this step on its own

— The EU has put off making a decision on this issue (and on gas-fired power plants) for the time being, mainly because there are significant differences of opinion between member states on this issue.[5)]

— A number of market participants indicated that the Netherlands could, or should, urge Europe to classify nuclear energy as green.

- A motion[6)] was recently passed in which the government was asked to lobby at a European level, along with a number of other member states, to get nuclear energy included in a green EU taxonomy.

— In addition, the Netherlands, with a view to encouraging private investment in nuclear energy, could consider introducing its own green taxonomy, as the United Kingdom decided to do in November 2020.[7)] However, it is unclear how much value international private financiers would attach to a local taxonomy.

Guarantees and risk appetite of private financiers

In existing FOAK projects, the vendor bears a relatively high proportion of the risk and the government provides revenue guarantees. For a new project, the risks could be shared differently

Risk-sharing for recent FOAK Generation III+ reactors

The existing projects are mostly FOAK projects where the vendor is involved as a financial backer and bears a significant proportion of the construction risks. The benefit of this approach for the vendor is achieving a proven, operational reactor. The expectation of the market participants is that this will not be feasible for new (non-FOAK) projects, and thus financing will have to be obtained from other sources. The market participants anticipate that, in that case, as well as revenue guarantees, the government would have to provide a range of additional guarantees to make private financing possible. This is explained in greater detail in this section.

Risk	Flamanville 3[1)]	Hinkley Point C[2), 3)]	Barakah[3)]	Hanhikivi[3)]	Akkuyu[5)]
Revenue	No specific agreements, market risk borne by EDF.	Covered via a CfD between EDF and the British government.	The government bears the energy price risk (via a PPA signed by the state-owned company EWEC).	Customers bear the risk via a cost-price purchasing obligation.	TETAS (state-owned company) bears 70% of the revenue risk through a PPA.
Construction risk (ordinary)	As vendor and primary financial backer, EDF is responsible for the construction risk.	EDF (as vendor and financial backer) and CGN (as financial backer) bear the construction risk.	KEPCO (as vendor and financial backer) and ENEC (as financial backer) bear the technical construction risk.	Rosatom is delivering a turnkey plant and bears the majority of the ordinary construction risk.[4)]	Rosatom owns 99% of the plant and bears the technical construction risk.
Construction risk (licensing)	As vendor and financial backer, EDF bears the licensing risk.	As vendor and financial backer, EDF and CGN bear the licensing risk.	As vendor and financial backer, KEPCO and ENEC bear the licensing risk.	Rosatom is delivering a turnkey plant and bears the licensing risk.[4)]	As owner, Rosatom also bears the licensing risk.
De-commissioning	The burden of decommissioning will also fall on EDF (as operator of the plant).	EDF and CGN are responsible for the decommissioning plan and for creating the associated fund.	ENEC will set aside money for the fund and draw up a decommissioning plan (at the request of FANR).	Fennovoima will set aside money for the fund and draw up a decommissioning plan (at the request of STUK).	Rosatom will set aside money for the fund and draw up a decommissioning plan (under the supervision of TAEK). Rosatom will take care of the decommissioning.
Role of government	Direct government involvement is limited, and no loan guarantees have been given.	The government bears the energy price risk and has provided a guarantee (of GBP 2 billion).	The government is the main financial backer, has provided loan guarantees to KEPCO and is a party to the PPA.	The government's role is relatively limited. However, the decommissioning will be carried out by the state.	The government is a party to the PPA. The project is part of a bilateral agreement between Turkey and Russia.[a)]

Note: (a) Under this treaty, the Russian government will train 6,000 Turkish workers in Russia to work at Akkuyu.

Source: (1) EDF reports, among other sources. (2) UK government reports, among other sources. (3) OECD NEA reports, among other sources. (4) Hanhikivi 1 design documents submitted to Finnish customer, WNN (2020). (5) Akkuyu nuclear power plant in Turkey, WANO. KPMG analysis.

Private financiers will accept ordinary construction risks, but only to the extent they can control them. Licensing risks should be borne by the government

Views of the market participants on construction risks (CAPEX risks)

“People can agree to bear some of the construction risks, if the design is clear.”

“Ordinary construction risks are fine for a private consortium. But it’s the risks arising from laws and regulations that private parties don’t want to take on.”

“A change in the regulatory framework is a major concern for financiers. We think it’s very important for a consensus to be reached early in the project between the regulator and the financial backers.”

In general, private financiers are prepared to bear ordinary construction risks, but black swan risks must be covered and preferably an existing, approved design should be in place

— Partly due to the substantial cost overruns and longer lead times experienced by existing projects, private parties are expected to take a critical view of estimates of construction costs and construction risks. Despite this, private financiers are willing to bear ordinary construction risks which they are able to control.

— It is worth noting that a proven technology and design may be a fundamental requirement for private financiers. In various cases, FOAK risks have meant that private financing was unable to be obtained, or could only be obtained at a small scale. With an existing design, a well-substantiated cost estimate can be prepared. If an existing design can be used, there are possible learning effects that could improve cost efficiency.

— In addition, various market participants indicated that certain black swan risks should be covered by the government, or that a backstop (i.e. a maximum above which the government covers the costs) should be put in place for construction costs. These risks cannot be estimated in advance by private financiers and could lead to substantial additional costs, and thus a significantly lower return.

In addition, private financiers want a guarantee from the government to cover higher construction costs resulting from licensing risks

— One significant ‘construction risk’ stems from the risk that licensing requirements could change during construction, impacting the design and thus the construction costs and lead time. This is a risk that private financiers will not accept and for which a government guarantee will be requested.

— In addition to the above, various private financiers indicated that they will only become involved once a licence has been obtained, or if the government takes responsibility for all costs in the event that the project is terminated before the licence is issued.

  - Until a licence is issued, there is a risk of losing the investment (if a licence cannot be obtained or the project is terminated) or of substantial additional costs resulting from stricter licensing requirements.
  - In the event of substantial cost increases, the investment may no longer fit within investment mandates and/or returns may fall too low.

Although market operators are willing to create a fund for decommissioning, they would still want a government guarantee to cover increases above the initial estimate and black swan risks

Black swan risks and decommissioning costs

“The margin of uncertainty in decommissioning costs may be even higher than for construction costs.”

“Cost increases related to decommissioning are a risk for the government.”

“The government must cover black swan risks.”

Create a fund up front or build it up over time?

“Provision can be made for decommissioning, provided the business case stacks up.”

“An upfront payment is not an option, the reserve must be built up over time.”

Private financiers are familiar with the requirement to create a fund for decommissioning costs and are willing to do so...

— Decommissioning a nuclear reactor is a process that takes around 15 years. The costs for the immediate decommissioning of European nuclear power plants are estimated at around EUR 0.6 million per MW on average.[1)] Staffing is the highest cost item (around 70%). The estimated costs for decommissioning have a wide margin of uncertainty, with the final duration being a key factor.

— Private financiers have indicated a willingness to set up the required fund[a)] to cover the decommissioning reserve, provided the return from the overall business case remains appropriate, given the risk profile of the project. In this regard, a certain degree of freedom in the investment policy for the decommissioning fund is an obvious advantage.

— In many cases, the decommissioning fund will be built up over time. Private financiers are prepared to do this. If it is requested that the entire decommissioning fund be set up at the start of a project, private financiers are divided on whether this would be feasible. Generally speaking, financiers are not willing to do this, but some market participants indicated that it might be possible, provided the business case for the new nuclear power plant included a sufficient return.

...but risks of cost increases and black swan risks cannot be controlled and require a government guarantee...

— In general, the private financiers indicated that they are not prepared to cover additional costs over and above the initial estimates or costs arising from black swan events (such as a bankruptcy or incident, in which the risk amounts to the shortfall in the decommissioning fund plus the total investment made). A government guarantee would be required for both types of costs, as well as for reimbursement of costs in the event of premature decommissioning due to a policy change.

...and a decommissioning plan must be in place so that private financiers do not face reputational risks

— From a reputational perspective, it is important to private financiers that the licence holder has a sound decommissioning plan in place. If this is not the case, private financiers will run the risk (albeit only far in the future in most cases) of having their name linked to the problematic decommissioning of a nuclear facility.

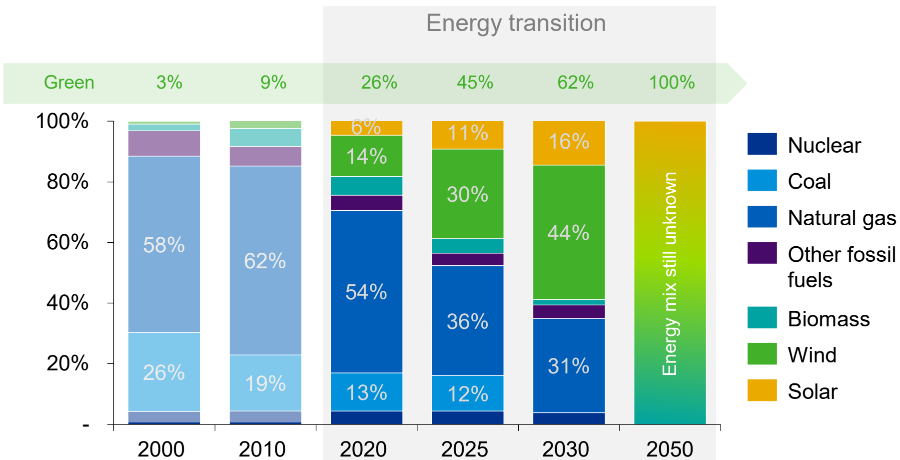
Note: (a) For an explanation of the system and requirements applied in the Netherlands (based on section 15f of the Nuclear Energy Act), please refer to the ‘Decommissioning’ section of the ‘Laws and regulations’ chapter.

Source: (1) The cost of decommissioning nuclear power plants, OECD-NEA (2016).

Returns and cash flows

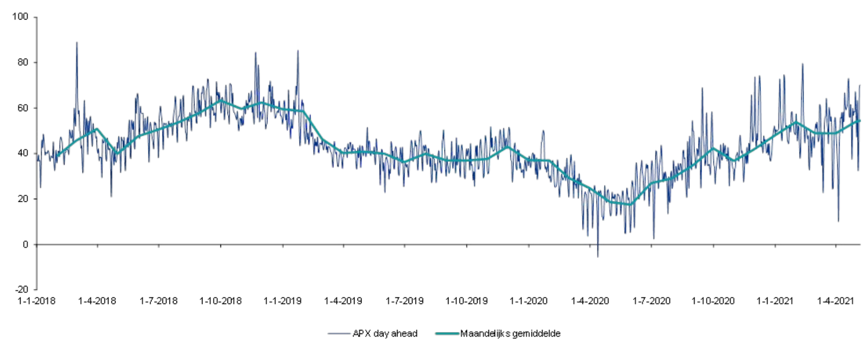
Partly due to the long lead time before the start of operations, the market participants indicated that revenue certainty is required to cover risks and investments

Electricity production mix 2000-2050[1),a)]



Note: (a) Anticipated mix of domestic electricity production excluding energy imports.
Source: (1) 2020 Climate and Energy Outlook. KPMG analysis.

Electricity price volatility graph[2)]



Source: (2) Bloomberg terminal.

The private financiers indicated that revenue guarantees are imperative for private financing

- The future revenue of a nuclear power plant is inherently uncertain. Future revenue streams vary depending on volatile energy prices. In addition, given the lengthy duration of the construction phase, the uncertainty around this issue is high. Market participants are being asked to predict electricity prices over a period of 11-15 years, which is neither possible nor acceptable.
- In addition, actual purchases of nuclear energy depend on priority in the energy mix, or 'merit order'. The position of nuclear energy in the merit order is partly determined by marginal costs, with energy being supplied first by the sources with the lowest marginal costs (solar and wind). Given the anticipated rise of solar and wind energy, along with other sustainable sources, the future use of nuclear power plants is uncertain.
- One of the key elements of an investment decision for a private financier is having a sufficiently clear picture of the required return. Investment in a nuclear power plant is a long-term commitment involving a significant amount of money, with no revenue being generated until after a lengthy construction period.
- In light of this, private financiers require a degree of certainty around long-term future cash flows. They have indicated that a significant level of revenue certainty is required, which is in line with the approach for large infrastructure projects.

Such guarantees can be provided through a range of financing structures

- For existing reactors and those in development, a range of tools have been developed which can provide at least partial revenue certainty to private financiers. These can be divided into three categories:
  - Price guarantees, such as a CfD or PPA, or perhaps a government subsidy (not discussed further in this report).
  - Guarantees on return and size of investment: This can be arranged using an RAB model.
  - Purchase/volume guarantees, such as the Mankala model or a PPA.
- Financing structures are covered in more detail in the next section.

Lead time, size of investment and substantial risks lead to a relatively high return being required compared to ordinary infrastructure projects

Cost structure

“With nuclear it’s about capital expenditure and capital costs because it’s so capital intensive.”

“Reimbursement of capital costs through an RAB for infrastructure projects in the UK works out at around 5% without a bonus, for nuclear it’s around 8-9%.”

“If the government co-finances the project and assumes the risks, an upside should be achievable.”

Financiers require regular market returns, given the risk profile of a nuclear project

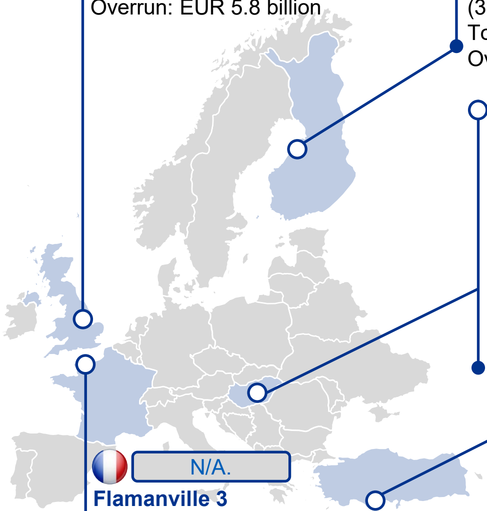
- It is difficult to get an indication of the required return, partly due to the limited involvement of private financiers in existing nuclear projects.
  - The interviews and desk research revealed that the return on equity required by private financiers ranges from around 7-9%[1)] (Hinkley Point C) to around 10-15%. Return requirements depend partly on the project’s risk profile, and partly on the type of private financier.
- To a considerable extent, the returns required by private financiers are determined by the risk profile of a project. If more assurances and guarantees can be given, it is expected that this would lead to a lower required return.
  - A lower required return could potentially lead to a lower LCOE.
- Various factors have an impact on a project’s risk profile, including:
  - certainty around the successful completion of the project (i.e. licensing risk, political climate and policy stability). Political commitment combined with a guarantee in the event of premature termination would mitigate the risk. Financing after licensing involves a lower risk profile;
  - the extent of participation by the government and the guarantees provided. Government participation and the provision of government guarantees would reduce the risk profile;
  - lead time and the expected period between initial investment and first revenue. The longer this period is, the greater the uncertainty. Remuneration during the construction period, as in the RAB model, would have a positive effect; and
  - the financing instrument and collateral position. Equity has a higher risk profile than loans. Loan guarantees from the government or an ECA (export credit agency) could reduce the risk profile of a loan.
- Returns for other instruments, including subordinated loans or export financing, are unknown. The market participants were reluctant to share information and indicated that returns (and interest rates) would be determined on a project-by-project basis.

Source: (1) Hinkley Point C, NAO (2018).

Financing structures

Six financing structures have been identified in the market that could potentially be applied to private financing

Overview of financing structures[1),2),a)]



CfD
Hinkley Point C
United Kingdom
Construction: 2018-2027
Main financial backer: EDF and CGN
Government support via CfD
Total costs: EUR 26.5 billion
Overrun: EUR 5.8 billion

Mankala
Hanhikivi
Finland
Construction: 2021-2028 (incl. one year delay)
Main financial backer: Fennovoima 66% (private)
Russian government involved via Rosatom (33%)
Total costs: EUR 7.0-7.5 billion
Overrun: Approx. EUR 1.0 billion

Government
Paks
Hungary
Construction: 2021-2027 (incl. one year delay)
Main financial backer: Rosatom
Russian government involved via Rosatom (loan facilities)
Total costs: EUR 12.5 billion

N/A.
Flamanville 3
France
Construction: 2007-2023 (incl. 10 year delay)
Main financial backer: EDF
French government involvement via EDF
Total costs: EUR 12.1 billion (2020)
Overrun: EUR 9.4 billion (compared to 2003)

PPA
Akkuyu
Turkey
Construction: 2018-2026
Main financial backer: Rosatom
Russian government involved via Rosatom (99.2%)
Total costs: Approx. EUR 21.0 billion

Partly owing to the FOAK nature of the reactors, many existing projects involve a significant degree of government financing combined with financing by the vendor

- Many existing projects are FOAK projects. In situations where full government financing, as is often the case in China, is not possible, there is generally a combination of (direct) government financing and vendor financing.
- Almost no private financing is involved in existing Generation III+ projects, with the exception of Hanhikivi.

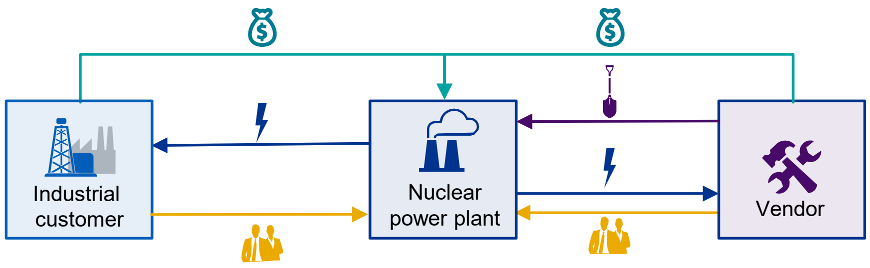
Based on existing projects and ongoing initiatives, a range of financing structures can be seen in the market

- The Mankala model was developed in Finland in the 1970s. It involves local industrial energy customers which are also financial backers of the nuclear power plant. This often occurs in combination with vendor financing. Although this is essentially a private financing model, in practice the parties involved are often regulated entities in which the central government or local/regional authorities have a stake.
- A Contract for Difference (CfD) and a Power Purchase Agreement (PPA) are models that are applied to provide revenue certainty. These models do not explicitly regulate the sharing of other risks. The market participants indicated that in many cases additional guarantees would be requested (from the government) to cover these other risks.
- The United Kingdom is investigating whether the Regulated Asset Base model ('RAB model') could be applied to nuclear energy, in a similar fashion as its current application to large-scale infrastructure projects. The RAB model provides a guaranteed return on the regulated asset base, shares the risks between the financial backers and the government (through measures including the sharing of reasonable costs) and ensures an income stream during construction.
- In this section, the various financing models are described in greater detail, together with an explanation of how risks are shared and the identification of a possible role for the government.

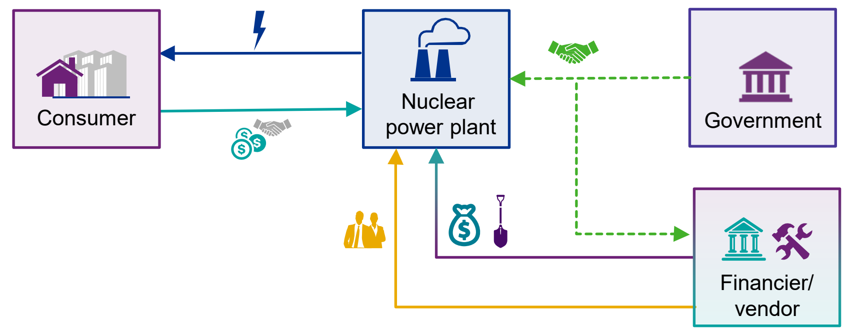
Note: (a) The nuclear power plants presented above all have full or a high degree of vendor financing. Flamanville 3 is the only one with a domestic vendor involved (EDF); in the other examples the vendor is a foreign party.
Source: (1) Reports from EDF, UK government, Rosatom, Fennovoima, MVM and WNN, among other sources. (2) Modern financial models of nuclear power plants, Terlikowski et al. (2019). KPMG analysis.

The Mankala model is a cooperative 'power at cost' model. The RAB model provides an income based on reasonable costs paid for regulated assets

Mankala[1),2)]



RAB[2),3)]



Energy | Construction | Financing | Revenue from energy sales | Stake in power plant | Price agreements

The cooperative Mankala model is a 'power at cost' model in which the investment and (depending on guarantees) a significant portion of the risks are borne by a large number of private parties

— This model, which is only applied in Finland, is one of the examples in which private parties participate in the financing of nuclear energy.

— A consortium is formed by multiple private parties which collectively hold a majority of shares in the nuclear reactor. The private investors meet the needs of the consortium by contributing both equity and debt. Hanhikivi was financed through a combination of vendor financing and export credit, alongside the financing provided by the private participants. The vendor (Rosatom) is obliged to deliver a turnkey reactor, and thus bears the construction risk. The government has not provided any guarantees.[1)]

— The participants are required to purchase the generated power in quantities proportionate to their shares in the Mankala consortium. The parties can then use the energy for their own activities or sell it on the energy market.[2)] How the other risks are shared depends on separate agreements and, potentially, guarantees.

Source: (1) Mankala Principle, Finnish Ministry of Economic Affairs (2018). (2) Modern financial models of nuclear power plants, Terlikowski et al. (2019). (3) RAB for nuclear, Department for Business, Energy & Industrial Strategy (2020). KPMG analysis.

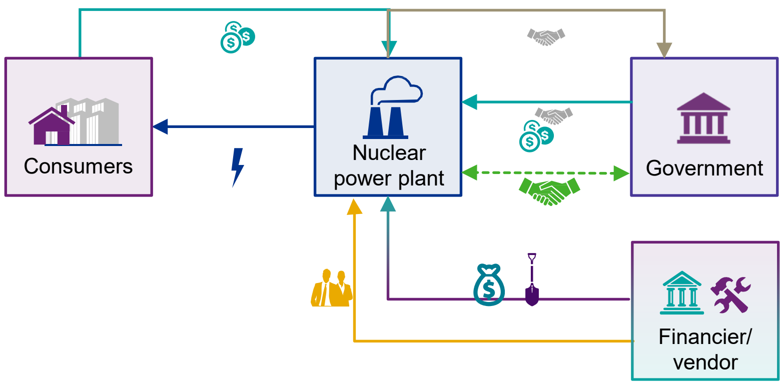
Under the RAB model, revenue is generated even during construction. This must provide a reasonable return to financiers to compensate for the construction and decommissioning risks

— In the RAB model, the construction costs are shared between the private financial backers and the party that pays the RAB fee (e.g. the government). The RAB fee is paid from the start of the project for the so-called 'regulated assets'. The amount of the fee must be high enough to ensure 'reasonable' costs are covered (including depreciation costs on the investment, operating costs and costs related to decommissioning, up to a certain level), while also resulting in a reasonable return on the regulated assets. A regulator (independent third party) determines what 'reasonable costs' are. Costs above the reasonable level are paid for by the private financial backer. This achieves a certain degree of risk spreading.

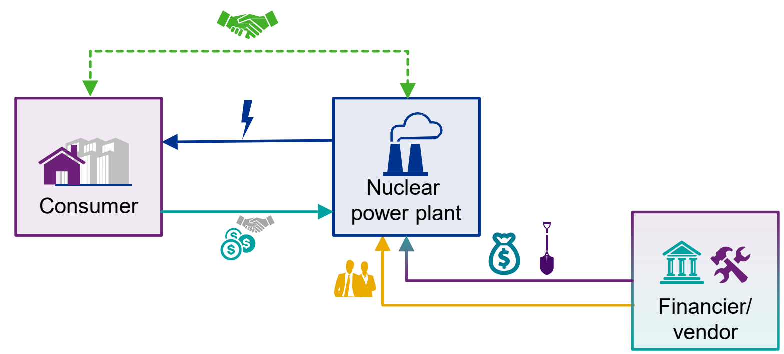
— In the RAB model, construction risks for private financiers are limited. The government can issue a guarantee ('funding cap'), which means investments above a certain amount will be paid for by the government. In this situation the government receives an equity stake in the project in exchange for the investment.

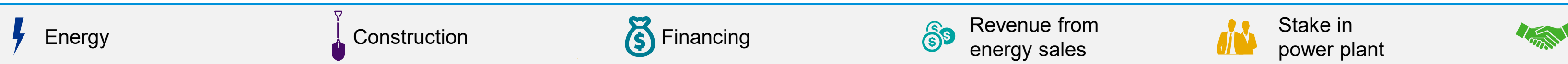
A CfD provides revenue certainty up to a certain 'strike price'. A PPA is a long-term volume and price agreement between an energy supplier and a consumer

CfD[1)]



Power Purchase Agreement ('PPA')[2)]





With a Contract for Difference (CfD), the government guarantees a price per MWh over a long period (30-35 years)[1)]

- A CfD works on the basis of a 'strike price' per MWh which the operator of the nuclear power plant will receive in the future for the energy produced. If the market price is below this level, the other party to the contract (the government) makes up the difference to the benefit of the operator, and if the market price is above the strike price, the other contracting party (the government) benefits.
- The strike price depends in part on the risks borne by private financiers, as well as the share of the investment covered by these parties.
- A CfD only provides revenue certainty. Entering into a CfD does not cover decommissioning risks, licensing risks or certain black swan risks during construction. Based on the interviews, private financiers are expected to ask for additional guarantees.
- An agreement such as the one for Hinkley Point C, where EDF bears the full construction risk and a strike price is in place that takes account of that investment risk, is not seen by the market participants as realistic for future projects.

With predetermined energy purchases at a fixed price, a PPA offers (partial) revenue certainty

- PPAs are the most common form of long-term guarantees in the current energy market. They involve an energy supplier and an energy consumer making fixed agreements in advance about purchases and prices over a 10-15 year period. PPAs generally have an immediate start date, or start within a few years. It is not possible to sign a PPA with a start date more than 11-15 years in the future, because no active market exists.
- Like CfDs, PPAs only provide revenue certainty. The key difference between CfDs and PPAs is that PPAs contain a volume obligation in addition to the price agreements. Because PPAs only cover the revenue risk, additional guarantees are expected to be requested.
- In Turkey (Akkuyu), a PPA was used under which a fixed price agreement for part of the production volume was made with TETAS (a company connected with the Turkish government) for a 15-year period. A comparable agreement does not seem possible in the Netherlands, since there are no state-owned energy companies.

Source: (1) Hinkley Point C, NAO (2018). (2) Akkuyu nuclear power plant in Turkey, WANO (2020). KPMG analysis.

If private financing is sought in addition to government financing, the market participants consider the RAB model and/or a CfD with guarantees to be the most appropriate options

"The security of the RAB model makes it the most attractive to investors. New developments are automatically part of the new asset base."

"Nuclear power plants have to deal with uncertain market purchasing behaviour. Accordingly, you have to use capacity payments or direct subsidies. The RAB model can facilitate these."

"We're not prepared to bear the entire market risk; for that you'd need a CfD, for example, in addition to guarantees during the construction phase. RABs are also attractive."

For private financing of a new, large nuclear power plant, several market participants suggested a RAB model

- The market participants indicated that for a newly-developed Generation III+ nuclear power plant, government financing is expected to be a key component.
- If private financiers can be involved, there are several options for financing structures. The private financiers indicated that the RAB model may be the most attractive. This is mainly due to the fact that income is received even during construction, and there is a relatively high degree of clarity around compensation, risk sharing and returns (see next page).
- Financing based on a CfD meets the desire of private financiers to limit the revenue risk, but based on the interviews with private financiers and other market participants it will only be useful if the government is prepared to provide a range of guarantees.
- The Mankala model (due to a lack of sufficient participants) and PPAs (due to the illiquid market and lack of a state-owned energy company) appear less practical for a Dutch reactor project.

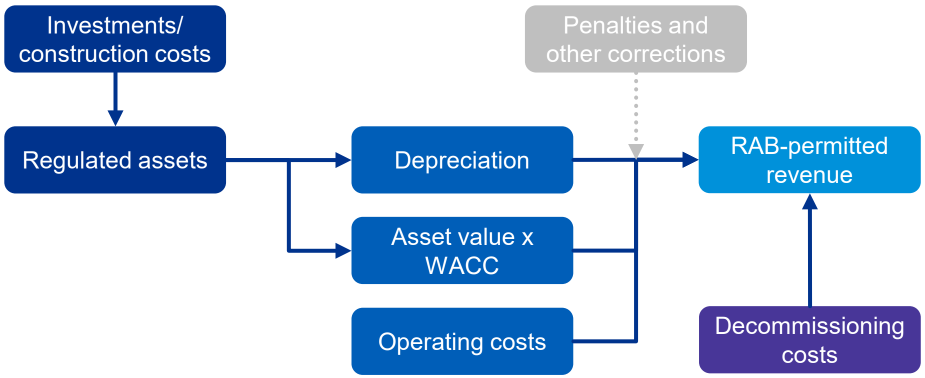
Ultimately, however, choosing a particular structure is the second step, and is of secondary importance. The financing issue starts with the risk appetite of private financiers and the extent to which the government wants to cater to it

- The market participants indicated that for private financing to be possible, there must first be a proven design, a sound ESG case, sufficient public support and stable political policies on nuclear energy. If one or more of these criteria are not met, private financing does not seem realistic.
- In addition, a clear picture is emerging of the desired risk profile for private financiers. Private financiers are willing to bear risks they can control, such as ordinary construction risks, and ordinary operating risks during operation. Other risks must be covered. In all of the models (with the exception of the Mankala model),[1)] this can be structured and will require government involvement. This makes the discussion about structuring secondary, because the government must first decide what level of contribution it is prepared to make.

Source: (1) Modern financial models of nuclear power plants, Terlikowski et al. (2019).

The RAB model may be attractive for private financiers because it allows for returns from the start of construction and ensures a precise distribution of risks

Schematic overview of the RAB model[1)]



Source: (1) RAB for nuclear, Department for Business, Energy & Industrial Strategy (2019).

Views of the market participants on the RAB model

"The benefit of the RAB model is that payments can be made on day one, which means you don't have to endure 10 years of risks without cash flows."

"Part of the RAB fee should be paid by the government in the form of a subsidy."

To meet the needs of private financiers for returns early in the project, many market participants suggested a RAB model...

- Long-term infrastructure projects have, and generally need, a low risk profile. The Regulated Asset Base (RAB) model was developed in the United Kingdom to finance these types of large-scale projects.
- The main benefits of the RAB model for an investor are as follows:
  - Under the RAB model, income is received during the construction phase.
  - The model provides a high degree of certainty with regard to returns by offering a fixed fee (including a return on the regulated assets) based on a reasonable level of costs that includes depreciation on investments, operating costs and decommissioning costs.
  - The possibility of introducing a funding cap – a maximum investment amount to be contributed by financiers, above which additional cost increases will be covered by the government.
- Private financiers and other market participants indicated that the RAB model could potentially be interesting for a Dutch reactor project.

...however, the RAB model has never been applied to a nuclear power plant before, and its application to a Dutch nuclear power plant project would involve significant challenges

- It would be important to assess the feasibility of the project right at the start, since the government would be paying income to private financiers from day one, which would be fully written off if the project is prematurely terminated.
- In contrast to various ordinary infrastructure projects, nuclear power plants earn revenue based on production. This means that, separately from the RAB fee, a financial result (profit or loss) will be recorded on the sale of electricity. At this time, it is not clear how this should be structured and who should receive/bear the result.
- In the market consultation conducted in the United Kingdom, a range of options were mentioned, but no decision has yet been made. This issue will also require further development in the Dutch context.[1)]
- It will be necessary to work out how the RAB fee will be covered. In the United Kingdom, it is currently covered through energy or water bills. This would probably not work in a deregulated energy market. An alternative is to provide a subsidy.[1)]

For SMRs, there is probably a broader range of options for private financing, and private financing could be more appropriate

"Due to its size, in the long term an SMR would probably be easier for private parties to finance."

"For the first SMR(s), government involvement would be more logical."

"Is it acceptable to cover 10 years without cash flow? You should actually build in a modular way, to create a ramp-up."

Given the more limited investment required and shorter lead time, the range of private financing options is probably broader for SMRs than for large nuclear power plants

- The specific characteristics of an SMR mean that private financing based on a RAB model, a PPA or a CfD will probably be possible in the future:
  - The average investment costs (EUR 1.4-2.7 billion)[1)] seem to be lower than for large Generation III+ nuclear power plants and therefore easier for one or a few private financiers to handle.
  - The construction lead time is four to five years on average once a licence is obtained,[2)] which shortens the period in which construction risks must be borne.
  - In addition, the period between the start of construction and the first revenue from sales of electricity is shorter than for large nuclear power plants. This means private financiers would receive a return sooner.
  - As a result, several market participants said that they expect private financing of SMRs to become a possibility in the longer term. They also expect that a number of guarantees, covering things such as black swan risks, would still be relevant for private financiers. After all, these types of risks cannot be controlled by private parties.
- As with large nuclear power plants, the market participants indicated that private financiers are not prepared to bear FOAK risks. If the Netherlands does not wish to wait until a proven design has been built, government involvement and/or vendor financing will be required.

Source: (1) Economics and finance working group report, Canada's SMR Roadmap (2018). (2) Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020).

Financing mix

For a large nuclear power plant, a substantial portion of government financing is inevitable. Private financing options would probably be better for an SMR

“Large projects are too big for private project financing. They could only happen with combined infrastructure funds and government guarantees.”

“It’s possible that a private party could be prepared to bear the market risk for an SMR. But not for a FOAK, and not until the mid-2030s at the earliest.”

“Large Generation III reactors are no longer new, developers already have an approved design. For smaller SMRs, a lengthy period of R&D is required first.”

The market participants expect that for a large nuclear power plant the options for private financing will be limited and the government will have to contribute a substantial proportion of the total financing

- The market participants indicated that private financing without extensive government guarantees would be difficult or impossible to achieve. In addition to various government guarantees, the government is expected to participate in the project and provide a significant proportion of the equity financing. Moreover, apart from the risks, a large nuclear power plant is too big for many private investors and the horizon is too long.
- Given the substantial government contribution, several market participants indicated that it could be appropriate for the government to publicly finance the construction of the reactor (through equity, loans (cheap, possibly 0%) or a combination of the two). Once construction is completed and the power plant is operational, the risk profile would change. The market participants indicated that the government could then consider selling the plant.
- It should be noted that private parties do not only contribute capital, they also contribute knowledge. The involvement of private financiers can also have a disciplining effect. This could be a reason to consider private financing via pension funds, institutional investors and/or a vendor/energy supplier, alongside government investment.

In the long term, the development of an SMR could offer more opportunities for private financing

- Although SMRs are still in development, the development of SMRs could offer opportunities for private financing. The market participants indicated that private financing will only become realistic in Europe once several SMRs have been successfully built and the technology and design have been proven (i.e. after 2030). With SMRs, the FOAK risks should also be borne by the government.
- Due to their smaller size and the shorter lead times required, it is possible that several different types of parties could be interested and a combination of institutional investors and an energy supplier, for example, could be an option.[1)]
- Even in this situation, the government is still expected to have to be involved, by issuing a range of guarantees covering risks that cannot be controlled by private financiers.

Source: (1) Deeds not words: Barriers and remedies for Small Modular nuclear Reactors, Mignacca et al. (2020).

Licensing

In the recent past, cost and time overruns resulting from the licensing process have been a common problem

"The costs incurred in the UK as a result of the tightening of national safety requirements presented significant risks for the developer. Hitachi experienced this first-hand."

"There's no international framework to which each national licensing authority can 100% conform. Until such a framework is created, significant uncertainty will remain."

"Choose an existing design, and don't make/ask for any changes."

"Safety requirements continue to evolve. If they change during construction, it will result in delays, since the licensing authority will be expected to tighten the requirements. There needs to be maximum transparency up front about this issue."

"Fukushima had a big impact in Finland. When something like that happens, the licensing authority has to learn from it and link it to actions. Then the licensing authority comes and has a chat about additional requirements, even while construction is under way."

The specific design requirements for each country and possible changes to the design during construction present significant risks

— The market participants identified a number of risks arising from the licensing process, such as the specific design requirements mandated by each country and possible changes requested to the design during construction which could lead to delays and cost overruns.
  - An example of the former are the specific fire safety requirements for Hinkley Point C as mentioned by the market participants.
  - An example of changes to the design during construction occurred when the Finnish licensing authority made adjustments to the safety requirements during the construction of Olkiluoto 3 in the wake of Fukushima.[1)]
  - Another example of changes during construction came when the American licensing authority introduced new requirements for the Vogtle plant (first to prevent an attack using an aeroplane, and later to protect against tornadoes and earthquakes), seven years after the licence application. This resulted in unforeseen engineering challenges, and it ultimately took nearly two years to comply. The consequences were delays and cost overruns.[1)]

The licensing decision-making process is different in every country, which could create a barrier to entry

— The decision-making model around licensing and investment decisions can also result in high costs and risks, creating a barrier to entry.
  - In the case of Hinkley Point C, according to various market participants the developer spent roughly EUR 1 billion on the design phase before the final investment decision was made by the government. According to the market participants, another EUR 1 billion was spent on preparatory construction work. Various news reports confirm these amounts, giving a range of EUR 1-3 billion.[2)]
  - A similar issue led to Hitachi withdrawing from the Wylfa Newydd project in Wales in 2020, resulting in a write-off of USD 2.8 billion.[3)] The developer had already purchased the land and made preparations, but was then unable to come to an agreement with the British licensing authority (which had imposed a number of additional requirements).

Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). (2) EDF's Hinkley Point seen overrunning budget – Le Monde, Reuters (https://www.reuters.com/article/uk-edf-hinkley-overun/edfs-hinkley-point-seen-overrunning-budget-le-monde-idUKKBN19F0BF, last accessed on 10 June 2021). (3) Hitachi withdraws from UK new-build project, World Nuclear News (https://world-nuclear-news.org/Articles/Hitachi-withdraws-from-UK-new-build-project, last accessed on 10 June 2021).

The market participants therefore advocate transparency, harmonisation and predictability in the Dutch licensing process

The 10 fundamental safety principles of the IAEA

Responsibility for safety	Limitation of risks to individuals	Emergency preparedness and response
Role of government	Protection of present and future generations	Protective actions to reduce existing or unregulated radiation risks
Leadership and management for safety	Prevention of accidents	Optimisation of protection
Justification of facilities and activities		

Source: IAEA Nuclear Security Series No. 20, IAEA (2013).

"In an ideal world, the nuclear sector would have a kind of gold standard which would generally have to be complied with. This would mean there is a uniform framework everywhere in the world."

"The Netherlands can benefit from the hard work of the licensing authority in the United Kingdom."

The advice of the market participants is to create transparency and predictability around the licensing process before and during construction

— According to the market participants, it is important to be clear right at the start about what the procedure is, what requested information must be made available and what the framework is that must be complied with.

— The market participants also expressed a general wish for the licensing authority to not require any additional changes to the design during construction, which would result in extra costs.

  - They would like to see interest groups being allowed to influence policies as little as possible during construction, and would like structural and consistent policies to be established.
  - In addition, they would like clarity around how new insights into safety technology – due to an incident for example, or new technological developments – will be dealt with, and for agreements to be made in advance about how to deal with such insights, should they arise.

— If the government decides to develop a nuclear power plant, the market participants would like to sit down with the ANVS as quickly as possible to get everyone on the same page and start the information exchange process.

To keep costs down, the market participants indicated a strong desire for the Netherlands to align as closely as possible with international standards…

— To keep costs down, the market participants indicated a strong desire for the Netherlands to align as closely as possible with international standards, such as those of the IAEA, and standards developed by other Western countries in response to the construction of a Generation III+ nuclear power plant.

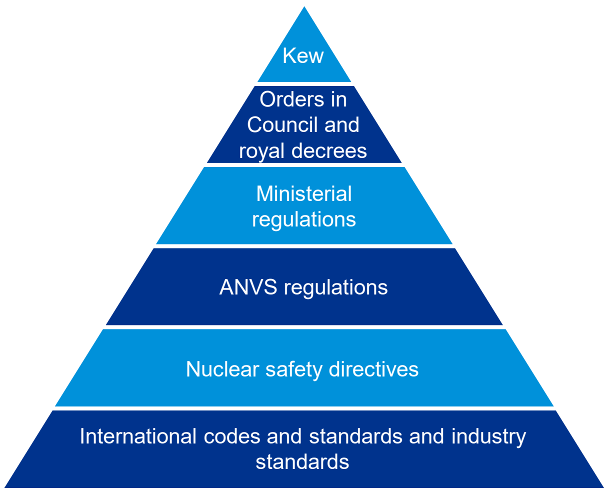
…and to allow the use of as much evidence as possible from the licensing processes in other Western countries

— The market participants indicated that allowing the use of evidence from licensing processes in other Western countries (such as the UK, Finland, the USA and France) could be helpful in reducing lead times and keeping costs down.

— Harmonisation of the licensing process at the European level would also be desirable (see page 90).

As well as requirements from international regulations, the Netherlands has its own design and safety requirements

Structure of the Dutch legal framework, with the Nuclear Energy Act ('Kew') being paramount



Source: 2018 Guide to National Policies on Nuclear Safety and Radiation Protection, ANVS (2018). KMPG analysis.

The Nuclear Energy Act forms the basis of licensing in the Netherlands, with the ANVS being the competent authority

- The Nuclear Energy Act lays the foundations for rules and regulations regarding nuclear safety and radiation protection. It does this by requiring that a licence be obtained for facilities where nuclear energy may be released and/or where fissile materials are stored, and for most actions involving sources of ionising radiation. The Act stipulates that the ANVS may issue these licences and is the competent authority.
- The topics in the Nuclear Energy Act have been developed in greater detail in a number of Orders in Council (in Dutch: 'Algemene Maatregelen van Bestuur'), ministerial regulations and ANVS regulations. See the diagram on the left for an overview of the structure of the Dutch legal framework.[1)]

The ANVS performs assessments using its VOBK Guidelines

- The VOBK Guidelines (Safe Design and Operation of Nuclear Reactors),[2)] published in 2015, set out the details of the stricter safety principles and serve as a guide to ANVS procedures. Using this document, the ANVS assesses licence applications and the information provided. The VOBK Guidelines were compiled based on a combination of German, Finnish and IAEA requirements. They were due to be updated in 2020, but this has not yet happened.
- The VOBK Guidelines use the 'comply or explain' principle. This means that developers have scope to present alternatives, provided they can demonstrate that the right level of safety will be achieved.

Wherever possible, Dutch legislation and policy-making is aligned with international codes and standards, such as current IAEA requirements and guidelines and WENRA reference levels

- The Netherlands has aligned as closely as possible with internationally-accepted principles, recommendations, practices and agreements on nuclear safety.[a)] National circumstances, including the specific Dutch context and policy priorities, sometimes give rise to a specific approach.
- For example, the Netherlands has incorporated the requirements and guidelines set by the IAEA and the reference levels set by the WENRA (Western European Nuclear Regulators Association) into its own regulations.[3)] The Netherlands has also incorporated the Euratom Treaty for nuclear safety and radiation protection into its policies and regulations.[1)]

Note: (a) These were developed with input from and in consultation with the Netherlands, under the leadership of Euratom, IAEA, OECD/NEA, VN3, WHO, ILO, OSPAR, ENSRA, ESARDA, HERCA, EACA, ENSREG and the WENRA.

Source: (1) Laws and regulations, ANVS (https://www.autoriteitnvs.nl/onderwerpen/wet--en-regelgeving, last accessed 10 June 2021). (2) VOBK Guide, ANVS (autoriteitnvs.nl/onderwerpen/nucleaire-veiligheid/handreiking-vobk, last accessed 10 June 2021). (3) IAEA Nuclear Security Series No. 20, IAEA (2013).

The ANVS has indicated that it is open to maximising international harmonisation, but it cannot rule out the possibility of changes occurring during construction

Guidelines on continuous improvement of nuclear safety

"The implementing regulation for Directive No. 2009/71/Euratom on nuclear safety came into effect in 2011. This regulation imposed a number of obligations on nuclear facility licence holders under [...] the Nuclear Energy Act. [...] The purpose of these obligations is to ensure that nuclear facilities comply and continue to comply with the latest technology and scientific understanding."

Source: Guidelines on continuous improvement of nuclear safety, ANVS (2015).

"Each national licensing authority will want to look specifically at the location and at the safety requirements that will apply for that location."

"In Finland, we all saw the effect that Fukushima had on the licensing process."

The ANVS indicated that it will align as closely as possible with international standards and allow the use of as much prior evidence as possible

— The ANVS indicated that it will align as closely as possible with international standards. Designs that comply with those standards can use evidence that demonstrates such compliance in the Dutch context.

— The ANVS stated that the Dutch legal framework is goal-oriented. This offers scope for alignment with foreign design codes and standards in allowing evidence from previous projects.

— The VOBK Guidelines used by the ANVS are expected to align most closely with European licensing requirements, and less with US requirements.
  - For example, the USA has a standards-based framework for radiation protection. If the standard is reached, the design is approved. EU standards indicate that dose optimisation is required even after the standard is reached, which means they could potentially be more stringent.

— In addition, location-specific circumstances must be taken into account at all times (such as an earthquake risk or the likelihood of flooding). In the Netherlands, type approval of a design occurs at the same time as location approval (unlike in the USA).
  - For example, in the Netherlands it might be necessary to specifically examine construction on clay soil, or the fact that a power plant would be built below sea level.
  - Furthermore, the Netherlands is a densely-populated country. This could mean stricter requirements in terms of acceptance of radiation levels outside of the site boundaries.

New insights in the area of nuclear safety could lead to changes in requirements during and after construction, within reason

— In the Netherlands (as in Finland), nuclear facilities are required to make continual safety improvements. New insights can thus lead to new requirements, within reason, before, during and after construction.

— For example, if a nuclear incident occurs anywhere in the world, the ANVS will look at whether it needs to impose additional safety requirements, even if construction is under way. It will ask the licence holder to do the same, given that the latter holds primary responsibility for nuclear safety and for continuously improving it.

— The ANVS therefore cannot rule out the possibility of changes occurring during construction. Such changes must always be made within reason, with the safety gains being balanced against the cost of additional safety-boosting requirements.

The market participants are cautiously optimistic that aligning with other licensing authorities could actually lead to cost savings

"The ANVS is expected to be well capable of properly managing the licensing process, partly based on its experiences with Borssele."

"In practice, nothing is simple. The likelihood of additional requirements being imposed during construction is high."

"Without stable government policies, the licensing process will be uncertain and stressful."

The market participants have a generally positive view of the ANVS's position, but still expect questions, requirements and adjustments that will drive up costs

— In general, the market participants are positive about the framework, procedures and position of the ANVS with regard to the possibility of using evidence from other projects in the Dutch context.

— The market participants expressed appreciation for attempts by the ANVS and others to harmonise with international licensing requirements where possible. However, they also concluded that there is still no certainty for the market participants that the licensing process in the Netherlands can be significantly simplified by using information/evidence already used elsewhere.

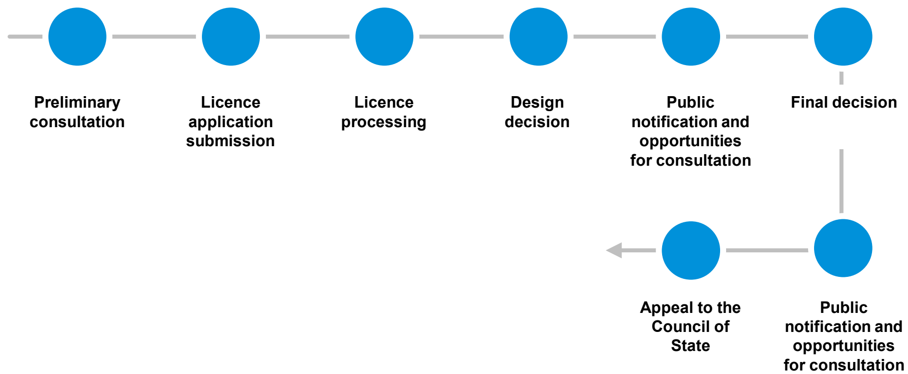
- Location-specific requirements are an example of where significant additional requirements could emerge.

— The market participants are cautious in their expectations about what can actually be achieved in terms of cost savings in the licensing process and during construction. Experience shows that, in practice, additional demands will be imposed and specific adjustments required, particularly with regard to the principle of 'continuous improvement' (see previous page). The ANVS cannot rule this out.

— Stable political policies are another important point raised by the market participants. They observed that the ANVS may have to tighten its requirements as a result of a changing political climate.

The licensing process for a nuclear power plant based on a proven design is expected to take around 3-5 years, which is in line with international processes

Licensing process for a nuclear power plant in the Netherlands



Source: ANVS Licensing Policy (2019). KMPG analysis.

The statutory licensing time frame (from the date of application) is six months, but the entire process including preliminary consultation and procedures is expected to take around three to five years

- The statutory time frame for processing a licensing application for a nuclear power plant (including design decision, public consultation and final decision) is six months. If the application involves an extremely complex or controversial issue, the decision-making time frame may be extended by a reasonable period.
- In practice, this is too short a time frame, given the complexity involved, so the ANVS arranges a period of extensive (though informal) preliminary consultation lasting several years.
  - During this period, there are discussions with the developer and the necessary information is exchanged to permit the submission of an acceptable formal application. During this preliminary consultation, the ANVS clarifies its expectations around substantiating the safety case and the necessary licensing documents.
- Once it receives the licence application, the ANVS has six months to make a decision on whether to grant the licence. The decision may be appealed to the Council of State.
- Other necessary procedures can often be followed in parallel with the licensing procedure under the Nuclear Energy Act. These may include the environmental impact assessment procedure, zoning plan, Nature Conservation Act permit (relating to nitrogen, for example), permits for water extraction and discharge, a Flora and Fauna Act permit and a construction permit. Government coordination is expected to be triggered for some of these applications.
- The anticipated lead time is around three to five years, with three years being expected for a process which is corroborated by previously used evidence and there is no appeal against the permit.
  - A short lead time is contingent on the quality, completeness and maturity of the safety documentation, analyses and reactor design of the initiator.
  - According to the market participants, this lead time is comparable to overseas procedures, such as those in the UK.
- This process only describes the licensing process for a licence to build a nuclear power plant. Further down the track, the developer would have to apply for a licence to operate the nuclear power plant. This procedure would run in parallel with the construction of the facility.

Choosing a Generation IV reactor design, or an SMR, is expected to lead to a longer licensing process, because a (complete) framework is not in place

"It seems logical that Generation IV models that run on uranium will be the first to gain approval anywhere in the world. But it will still take a long time."

"If the Netherlands wants to opt for an SMR, they absolutely must align with other European countries that want to build an SMR. That way they can collectively benefit from the learning effects, including in the area of licensing."

"Generation IV technologies are extremely promising, but we don't yet have any idea how exactly they would work in practice, let alone what requirements licensing authorities would want them to meet."

The licensing process for a Generation III+ SMR is expected to take around five years, during which the reactor technology must be proven…

- Several market participants indicated that certain SMR designs were comparable, in terms of their reactor technology, to known, large nuclear power plants with Generation III+ reactors that have received licences in the past.
- In this situation, since there no significant deviations from the reactor designs with which the ANVS is familiar, the licensing process might take a comparable length of time, with the expectation being that it would be more in the region of five years (depending on how 'conventional' the technologies used in an SMR design are).
- However, there are still no licensed Western examples that can be followed with certainty. Accordingly, it is not certain that legislators and/or the ANVS will not have to develop any additional regulations.
  - However, there is an expectation that the Netherlands could tap into the experience gained by licensing authorities in the USA, Canada and the UK with SMRs developed there.

…but Generation IV reactor technologies are so new that an entirely new licensing framework will have to be established

- Generation IV technologies are so different from the current Generation II and III+ reactors that an entirely new licensing framework is expected to have to be established.[1)] The VOBK Guidelines and the IAEA framework were primarily written for water-cooled reactors (PWRs and BWRs), so only the broad outline can be used for Generation IV technology.
- The IAEA is currently working on accelerated development and on creating support for Generation IV reactors.[2)] Nevertheless, the expectation is that a licensing framework will not be available for another 10-20 years.[1)]
  - The market participants expect that Generation IV models that run on uranium will be the first of this generation to emerge. For expectations around licensing frameworks, see page 96.
- Depending on how many FOAK design choices are made and the extent to which existing regulations, technical codes and requirements are usable, or the extent to which new ones must be developed, the licensing process is expected to take around 10 years.

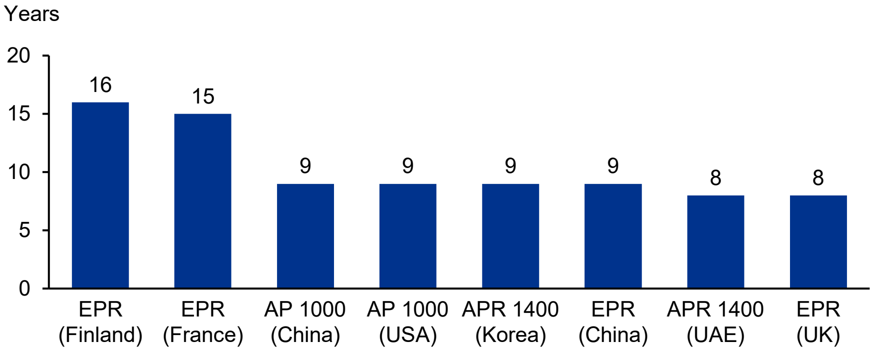
Source: (1) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (2) Next Generation Nuclear Reactors: IAEA and GIF Call for Faster Deployment | IAEA (last accessed on 6 June 2021).

KPMG

Construction time

A Generation III+ nuclear power plant is expected to be able to be built within 11-15 years from the start of the licensing process

Construction times for a selection of recent (FOAK) Generation III+ projects



Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). (2) Plans for new reactors worldwide, World Nuclear Association (https://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx, last accessed on 28 May 2021). (3) Possible role of nuclear in the Dutch energy mix of the future, ENCO (2020).

"A licence for a proven design could be obtained within three years (optimistic) or five years (pessimistic)."

"For construction of our design we now have a timetable of 78 months."

"The construction time is approximately six years. By building more, we may be able to bring this down."

The licensing process for a nuclear power plant based on a proven design would be expected to take three to five years

— The licensing process for a nuclear power plant based on a proven design is expected to take three years in the most optimistic scenario, or five years in a conservative scenario.
  - The variation in the expected time frame for the licensing process is due to the time required for preliminary consultation and the duration of any appeal proceedings (see page 92).

A Generation III+ nuclear power plant with a proven design can be expected to be built in approximately eight to ten years

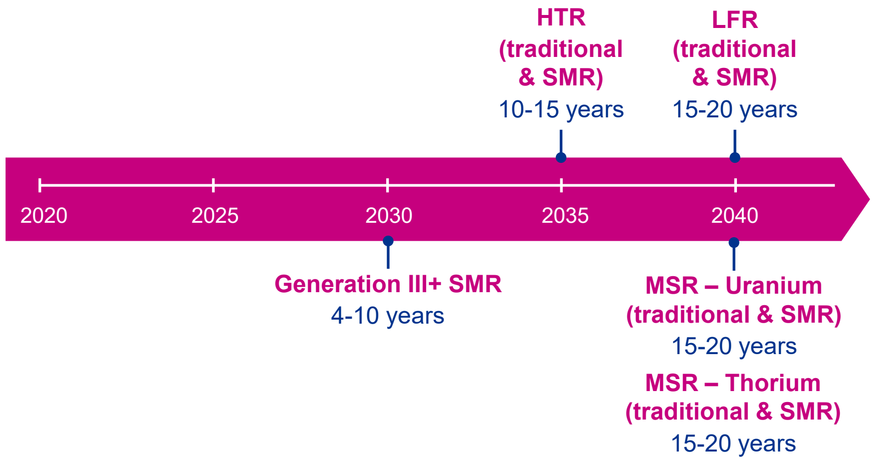
— Based on recent construction projects outside the EU, Generation III+ power plants have a construction time of approximately eight to ten years. The current Generation III+ power plant projects in the EU (France and Finland) are not yet complete, and deviate from this range with expected construction times of 15 and 16 years, respectively.[1)]
  - See page 46 for an analysis of delays with Generation III+ power plants in France (Flamanville 3) and Finland (Olkiluoto 3).

— The market participants said they expect that using the experience gained could reduce the construction time to six to eight years.
  - They also expect to be able to reduce construction times once experience has been built up with licensing and construction. Designs are mature and knowledge about these types of construction projects has been built back up again, as have supply chains.

Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).

A Generation III+ SMR could potentially be completed around 10 years from the start of the licensing process, but a proven design will not be available until 2027-2033 at the earliest

Estimated lead time to availability of a suitable licensing framework[a)]



Note: (a) See notes on the bottom right of the page.

Source: The role of nuclear energy in the energy transition of North Brabant, TNO (2020). KMPG analysis.

"For an SMR, the time between the start of the project and the end is half that of a large reactor. The construction period is less of a grind."

"We expect to be able to build our SMR design in three years."

A Generation III+ SMR is expected to be able to be built within around 10 years from the start of the licensing process. It is not expected that this process can be started before 2027-2033

— The licensing process for an SMR based on a proven Generation III+ reactor design is expected to take around five years (see page 93).

— The expected construction time for a FOAK SMR is around four to five years, and three to four years for subsequent reactors,[1)] but these construction times have not yet been proven.

  - The market participants expect construction times of three to five years for SMRs.

— Generation III+ SMRs are expected to achieve proven operational designs by 2027-2033 at the earliest, most likely in Canada or the USA (see page 59).

— A suitable licensing framework[a)] for a Generation III+ SMR can be created within a comparable time frame of four to ten years if work to create such a framework begins in the near future.[2)]

A Generation IV SMR is expected to be able to be built within around 15 years from the start of the licensing process. It is not expected that this process can be started before 2035-2040

— A licensing process for an SMR based on a Generation IV design is expected to take more time, since there is less knowledge and experience to draw upon with regard to these types of designs. The estimate is around 10 years (see page 93).

— The expected construction time is the same as for a Generation III+ SMR design: three to five years.

— Large-scale commercial implementation of the first Generation IV technologies is expected around 2045 (see page 43). Before that time, 10-20 years will be needed to develop suitable licensing frameworks.

  - The components, systems and structures of these new technologies must be tested with regard to safety and performance. Large-scale experiments will be necessary, with a lead time of approximately five to ten years. This can only be achieved if international governments and the industry work together.[2)]

Note: (a) A licensing framework is a conceptual model against which the components, systems and structures of a design can be tested and evaluated with regard to safety and performance.

Source: (1) Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020). (2) The role of nuclear energy in the energy transition of North Brabant, TNO (2020).

Decommissioning

There is a range of strategies that can be used to decommission a nuclear power plant

Potential advantages and disadvantages of decommissioning strategies

Potential advantages and disadvantages of decommissioning strategies		
	Immediate decommissioning	**Deferred decommissioning**
Advantages	✓ Knowledge and expertise about the specific facility and power plant are available ✓ Most cost-effective way of decommissioning ✓ The site can be used sooner for other purposes	✓ Less high-level radioactive material and radiation ✓ Possible synergy benefits due to the simultaneous decommissioning of several power plants ✓ More time to amass sufficient funding
Disadvantages	× Higher radioactive exposure during decommissioning means that extensive safety requirements must be put in place × More high-level radioactive waste must be removed and processed	× More maintenance and inspections during the deferral period × Laws and regulations can change and/or the cost of decommissioning could increase in the intervening period × New, qualified staff may have to be recruited

Note: This is a selection of the potential advantages and disadvantages of immediate and deferred decommissioning of nuclear power plants.

Source: The cost of decommissioning nuclear power plants, OECD-NEA (2016).

"In the Netherlands, nuclear power plants must be decommissioned immediately. Deferred decommissioning is not an option. Everything must be cleared away until only a 'green field' remains, which can be used for other purposes."

A choice can be made between immediate and deferred decommissioning of the nuclear power plant

- Decommissioning a nuclear power plant is a specialist task that requires a relatively large amount of preparation and planning.
- Broadly speaking, there are two strategies for decommissioning a nuclear power plant:
  - With immediate decommissioning, after the power plant is shut down, all parts of the nuclear infrastructure are cleaned and/or removed so that the site can be returned to its original state as quickly as possible.[1),2),3)]
  - With deferred decommissioning, the final dismantling of the plant is postponed (usually by 40-60 years). A state of 'safe confinement' is created and the site is kept secure in the interim.[1),2),3)]
- The potential advantages of deferred decommissioning include the fact that radioactive radiation decreases over time, and that this strategy allows more time (if required) to amass adequate financial resources. On the other hand, with immediate decommissioning the site can be used sooner for other purposes.[1)]

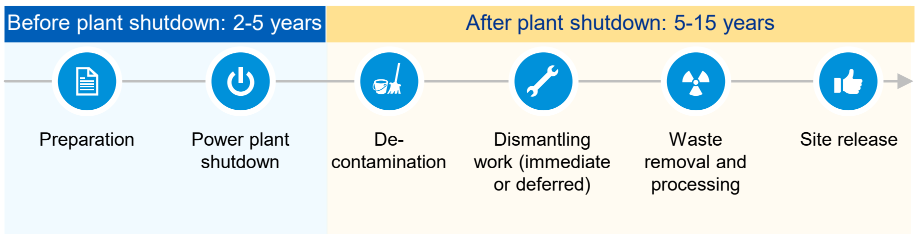
In the Netherlands, nuclear power plants must be decommissioned immediately after normal operations end

- The Nuclear Installations, Fissionable Materials and Ores Decree states that a nuclear power plant licence holder must immediately commence decommissioning and dismantling of the power plant once normal operations end.[4),5)]
- In the Netherlands, creating a state of 'safe confinement' and applying a waiting period before starting the actual decommissioning is not permitted.[4),5)]

Source: (1) The cost of decommissioning nuclear power plants, OECD-NEA (2016). (2) Decommissioning of nuclear power plants, research reactors and other nuclear fuel cycle facilities, IAEA (2018). (3) The decommissioning process, IAEA (2006). (4) Nuclear Installations, Fissionable Materials and Ores Decree. (5) Removal of energy installations (Part II): Nuclear installations, van Beuge (2016).

Decommissioning a nuclear power plant is a lengthy and complex process that can take up to 20 years (in the case of immediate decommissioning)

Process for decommissioning a nuclear power plant



Note: (a) The actual lead time can vary significantly depending on the size and condition of the nuclear power plant, the desired end state and local laws and regulations. The lead times in this diagram are based on immediate decommissioning.

Source: (1) The decommissioning process, IAEA (2006). (2) The cost of decommissioning nuclear power plants, OECD-NEA (2016). KPMG analysis.

"Recent decommissioning operations at nuclear power plants in Germany have had an average lead time of around 15 years, including preparation time."

"Decommissioning a nuclear power plant requires good preparation. For example, you have to get a permit for the decommissioning work, which can take quite a long time."

Depending on the size of the power plant and the target end state, the decommissioning process can take up to 20 years

— The actual decommissioning lead time depends on factors including the size of the power plant, the desired end state and local laws and regulations.[1),2)]

— Before the plant is shut down and the decommissioning can begin, permits must be applied for and contracts signed with decommissioning specialists. This preparation period can last for two to five years.[1)]

— The actual decontamination and dismantling work takes place after the plant is shut down. The facilities are cleaned and radioactive waste is removed and disposed of. This period can last for five to fifteen years.[1)]

— Experience from recent decommissioning operations at German nuclear power plants shows that immediate decommissioning can take 15 years on average (around four years of preparation, a four-year cooling-down period and seven years for the actual dismantling).

In the Netherlands, the preparation for decommissioning must be done before the plant becomes operational

— Dutch laws and regulations state that nuclear power plant licence holders must already have a decommissioning plan in place (including financial underpinning) when nuclear operations begin.[3),4)]

— The initial preparations for decommissioning have thus already been made before the plant even comes online.

Decommissioning must be done as quickly as possible, until only a 'green field' remains

— In the Netherlands, it is prohibited to shut down and/or decommission a nuclear power plant without a permit. The licence holder must apply to the ANVS for the permit and, as part of the application, demonstrate how safety will be ensured and harm prevented during the decommissioning work.[3),4),5)]

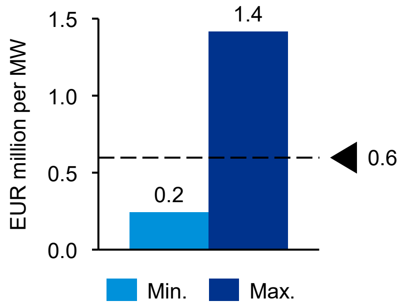
— In the Netherlands, it has been agreed that decommissioning work must be completed as quickly as reasonably possible, and that the end result must be a 'green field', suitable for alternative purposes.[3),4)]

Source: (1) The cost of decommissioning nuclear power plants, OECD-NEA (2016). (2) Decommissioning of nuclear power plants, research reactors and other nuclear fuel cycle facilities, IAEA (2018). (3) Nuclear Installations, Fissionable Materials and Ores Decree. (4) Removal of energy installations (Part II): Nuclear installations, van Beuge (2016). (5) The Nuclear Energy Act.

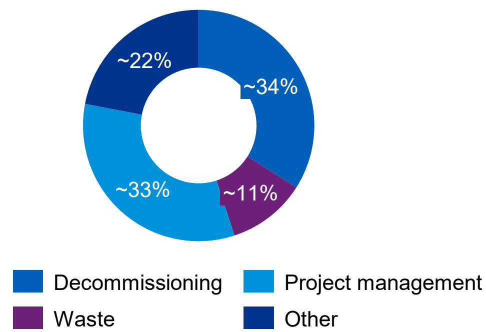
The average costs of immediate decommissioning are estimated at around EUR 0.6 million per MW

Potential costs for immediate decommissioning

Range of potential decommissioning costs (EUR million per MW)



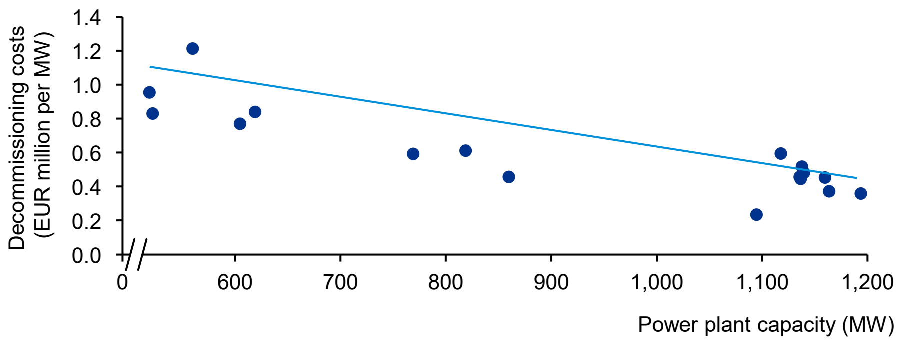
Breakdown of potential decommissioning costs



Note: (a) These costs are based on estimates for future decommissioning from decommissioning plans, supplied as part of an OECD-NEA survey. Nuclear power plants with a capacity of <160 MW were not included in the calculations.

Source: (1) The cost of decommissioning nuclear power plants, OECD-NEA (2016). KMPG analysis.

Relationship between potential immediate decommissioning costs and nuclear power plant capacity



Note: (a) These costs are based on completed decommissioning operations and estimates for future decommissioning operations for nuclear power plants in the United States.

Source: (1) The cost of decommissioning nuclear power plants, OECD-NEA (2016). KPMG analysis.

The average potential costs of immediate decommissioning are estimated at around EUR 0.6 million per MW

- Worldwide, only 16 nuclear power plants have been fully decommissioned since 2016.[1)] The availability of figures and information about the decommissioning process based on practical experience is limited. In most cases, only estimates of lead times and the associated costs for the decommissioning process are available.
- The costs of immediate decommissioning of European nuclear power plants are estimated at around EUR 0.6 million per MW on average.[1)] The actual costs of decommissioning depend on a range of factors including the decommissioning strategy, the lead time, wage costs and the size of the power plant.
- Research into the relationship between decommissioning costs and the capacity of nuclear power plants suggests that the decommissioning of a smaller plant is relatively expensive. The costs per MW decrease as the capacity of the plant increases.[1)]

In the Netherlands, decommissioning costs are paid by the licence holder, which must be able to show that it has sufficient financial resources for the task

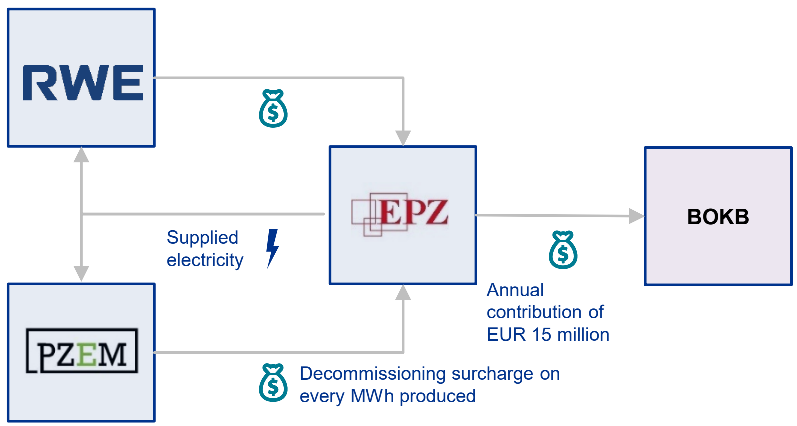
- In the Netherlands, it is stipulated that the licence holder must bear the costs of decommissioning. In this regard, laws and regulations state that the nuclear power plant licence holder must have sufficient capital at the time the plant shuts down to be able to finance the immediate decommissioning of the nuclear power plant.[2),3)]
- Every five years, the decommissioning plan and financial collateral must be approved by the government.[2),3)]
- The financial collateral may be provided through the creation of a fund, by means of a bank guarantee, or by providing any other suitable security that covers the decommissioning costs.[2),3)]

"In addition to construction costs, decommissioning costs make up a significant portion of the total costs for a nuclear power plant."

Source: (1) The cost of decommissioning nuclear power plants, OECD-NEA (2016). (2) The Nuclear Energy Act. (3) Removal of energy installations (Part II): Nuclear installations, van Beuge (2016).

In the Netherlands, there is a preference for financial collateral in the form of a fund

Overview of the formation of the Borssele nuclear power plant decommissioning fund



Source: (1) 2019 Annual Report, EPZ (2019). (2) Removal of energy installations (Part II): Nuclear installations, van Beuge (2016). KPMG analysis.

> *"For the purpose of decommissioning a nuclear power plant in the Netherlands, the owners set up a fund and the decommissioning is financed with the capital built up in the fund."*

> *"Every five years, the decommissioning plans and the plans for financing the decommissioning are submitted to the government. These plans must set out how and when the decommissioning will take place and how it will be financed."*

In practice, decommissioning in the Netherlands is financed via a decommissioning fund

— In the Netherlands, fund creation is preferred over other forms of collateral. Creating a fund into which money is periodically deposited provides the greatest degree of certainty because the money is actually set aside.[1)]

— The fund can be built up gradually over the operational service life of the nuclear power plant.[1),2),3)] The fund can be held in cash, shares, bonds or other types of investments.[1)]

— A choice can be made to set up a fund that is protected from the risk of the licence holder going bankrupt (fenced fund structure). The fund is thus legally separated from the licence holder's other assets and liabilities.[1),3)]

  - For example, EPZ has set up an independent fund (BOKB) from which the decommissioning of the Borssele nuclear power plant will be financed. EPZ's customers are charged a decommissioning surcharge on every MWh produced. Every year, EPZ pays this income to the foundation which was set up in 2012 and is legally separated from EPZ's normal business operations. The foundation then invests this money.[3)]

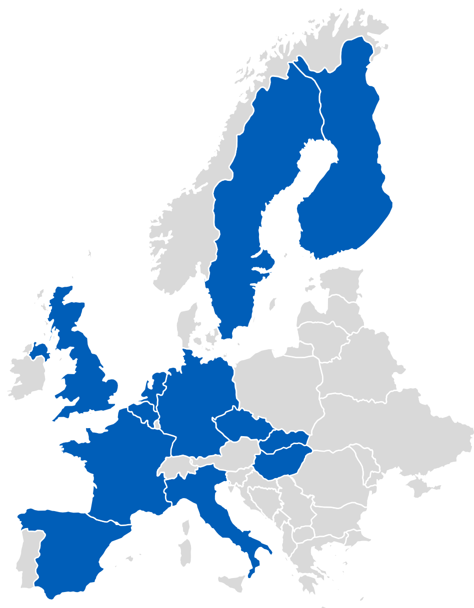
— The government can attach conditions to the decommissioning fund to ensure that the state will have access to the amount lodged as security if the licence holder fails to meet its obligations for any reason. For example, a first lien can be established on the fund in favour of the state.[2),3)]

— If, despite having the fund and conditions in place, the licence holder is unable to pay all of the decommissioning costs, it is unclear who will pay instead.[1),2),3)]

Source: (1) Financial Collateral under the Nuclear Energy Act, KPMG (2005). (2) The Nuclear Energy Act. (3) Removal of energy installations (Part II): Nuclear installations, van Beuge (2016).

The Dutch system of financing decommissioning via a decommissioning fund is in line with international best practice

Overview of the formation of decommissioning funds in the EU



Source: (1) The cost of decommissioning nuclear power plants, OECD-NEA (2016).

"Creating a fund to finance decommissioning is common. Some form of fund is used in many European countries."

In other countries, comparable systems are used to finance the decommissioning of a nuclear power plant

— Creating a fund to build up financial collateral for decommissioning nuclear power plants is standard practice in OECD countries. However, there are differences between and within countries in terms of the rules for fund creation and the procedures for setting these rules.[1),2)]

— Funds are generally built up over the service life of a nuclear power plant (although in some cases a shorter period may be used), through regular contributions to externally-managed funds. Certain aspects may vary, such as the degree of independent management and/or the extent to which the licence holder can influence investment policy.[1),2)]

— The rules around fund composition (the extent to which the fund must be held in cash, shares, bonds or other types of investments) also differ markedly between countries.[1),2)]

— In most cases, the funds are regularly audited by a government body or independent authority.[1),2)]

There is no preference for an alternative model for providing financial collateral, other than through a fund

— An alternative model for safeguarding the financial collateral that is used in some countries is to maintain a reserve for decommissioning costs on the balance sheet of the licence holder (against cash and cash-like assets). The financial assets are managed internally and are thus not separated from the licence holder's other assets and liabilities.

— The market participants expressed a preference for the creation of a fund, indicating that this is more robust, and less exposed in the event of bankruptcy.

Source: (1) Financial Collateral under the Nuclear Energy Act, KPMG (2005). (2) Removal of energy installations (Part II): Nuclear installations, van Beuge (2016).

The market participants would like to see additional guarantees from the government to cover risks over which they have little control and which have major financial consequences

"The actual decommissioning costs are extremely difficult to predict. In our opinion, the risk of unforeseen cost increases related to decommissioning must be borne by the government."

"In the event of bankruptcy where not enough money has been set aside, it's not clear who will pay the decommissioning costs."

"Black swan risks should be covered by the government."

The market participants would like to see a guarantee from the government to cover decommissioning costs in the event of premature bankruptcy of the operator

— The market participants indicated that in the context of decommissioning, the premature bankruptcy of the operator/licence holder is seen as a major risk.

— If the operator goes bankrupt, the shareholders would lose their investment, and might also have to bear the cost of shortfalls in the decommissioning fund.

— The market participants indicated that there is insufficient clarity at present about the extent to which shareholders can be held liable for shortfalls.

The market participants indicated that the risk of unforeseen cost increases related to decommissioning must be borne by the government

— Decommissioning costs are difficult to predict in advance. Some market participants indicated that in some cases, the margin of uncertainty for decommissioning costs is higher than for construction costs.

— Decommissioning is the natural end of the life cycle of an asset. The technical, financial and compliance uncertainties associated with decommissioning may decrease as countries around the world gain more decommissioning knowledge and experience.

- In 2021, COVRA will start designing the necessary future decommissioning and waste infrastructure and will make calculations/estimates of the investments that will be required. The results of this study could be considered in the estimates for the required decommissioning fund.

— Possible interim amendments to laws and regulations and changes to waste handling costs are expected to inject a degree of uncertainty into the actual decommissioning costs.

— In general, market participants indicated that they are not prepared to cover additional costs over and above initial estimates.

They also require a guarantee to cover black swan risks

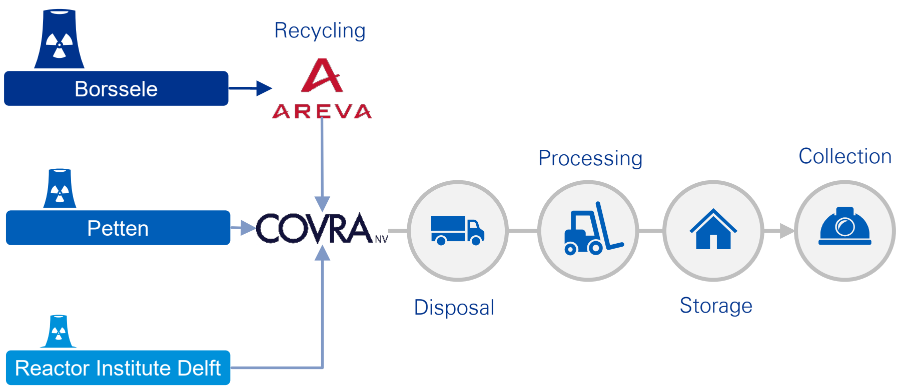
— The market participants indicated that, in general, they are not prepared to cover the risks and consequences of black swan events (such as an incident). A government guarantee is required, as well as the reimbursement of costs for decommissioning before completion of the construction phase (for example if the government decides to cease construction of the power plant in response to an incident).

KPMG

Waste

The Dutch system of central processing and storage of nuclear waste for the medium term is viewed positively by the market participants

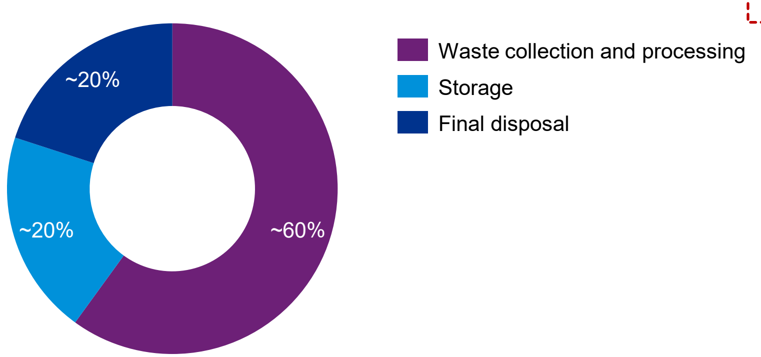
Handling of nuclear waste in the Netherlands by COVRA



Source: 2019 Annual Report, COVRA (2019).

Estimated breakdown of COVRA's fee for handling nuclear waste

Indicative



Source: KPMG interview programme (2021).

In the Netherlands, nuclear waste is handled centrally by COVRA

— Through COVRA, a 100% state-owned company, the Netherlands provides medium-term storage of nuclear waste for approximately 100 years. COVRA will realise a final disposal solution around 2130. COVRA is the only recognised organisation in the Netherlands that is allowed to collect, process and store radioactive waste.[1)]

— Radioactive waste from the Borssele nuclear power plant and the research reactors in Petten (HFR) and Delft (HOR) is stored in COVRA's high-level radioactive waste treatment and storage building (HABOG).[1)]

— The market participants indicated that a central storage facility such as COVRA, which is fully funded through contributions from its waste management services, is a good solution. Most European countries have some form of centralised processing and storage of nuclear waste.

COVRA charges a fee, in return for which it accepts the nuclear waste and takes full responsibility for it

— When waste is transferred to COVRA, a fee is charged that covers its services throughout the waste management chain, up to and including final disposal. The long-term management risk is therefore borne by COVRA.[1),2)]

— The financial risks of waste handling are also assumed by COVRA, including final disposal. This means that the producers of nuclear waste do not bear any risks, nor do they have to set aside a reserve for unforeseen higher costs for nuclear waste handling. This is important for private financiers.

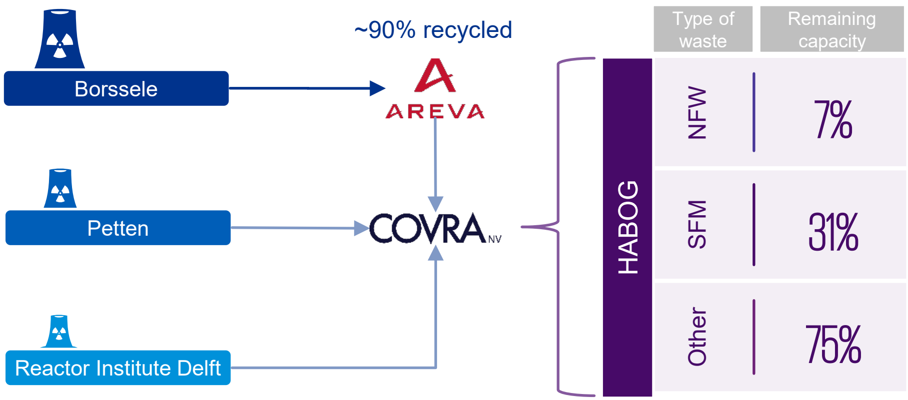
"The Netherlands must continue with COVRA as a 100% state-owned company in line with the legal obligation for waste storage."

"Producers of nuclear waste receive a single invoice from COVRA, with which they pay for collection, processing, storage and final disposal of waste. This is unique in Europe."

Source: (1) 2020 Annual Report, COVRA (2020). (2) KPMG interview programme (2021).

COVRA's current storage capacity is designed for the expected waste flows from current and planned reactors...

Handling of nuclear waste in the Netherlands (COVRA)[1) a) b)]



Note: (a) The HABOG is the building for high-level radioactive waste. (b) NFW stands for nuclear fission waste, SFM stands for spent fissile materials.

Source: (1) 2019 Annual Report, COVRA (2019).

"The amount of high-level radioactive waste produced in the Netherlands is very small, and up to 90% of it is recycled in France."

"With its current expansion of capacity, COVRA can store nuclear waste from Borssele until the nuclear power plant is shut down."

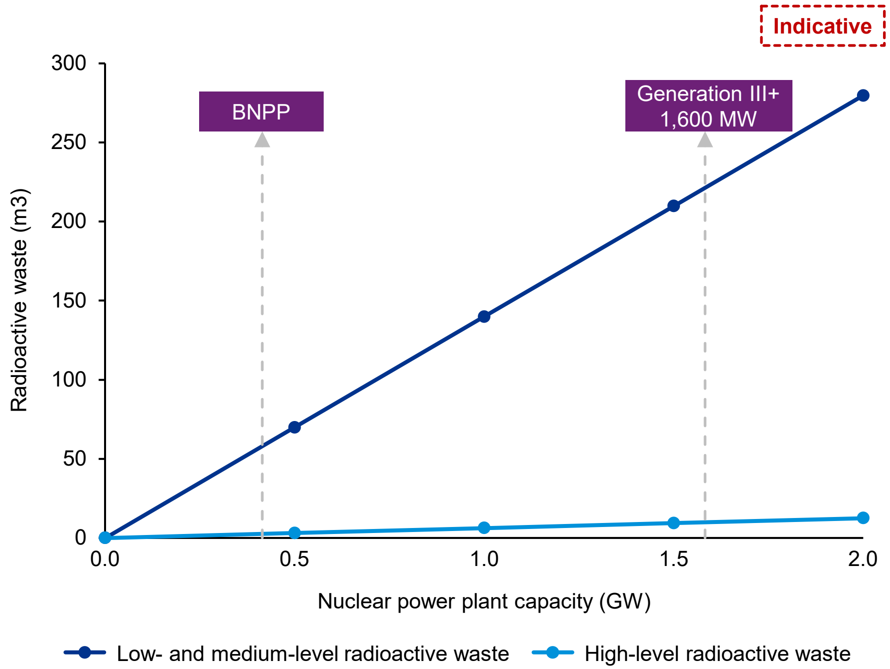
COVRA regularly expands its storage capacity, ensuring it has sufficient capacity to store all currently-expected waste

- COVRA has 20 hectares of land, which currently hold five storage buildings. Some of the storage is designed for low- and medium-level radioactive waste and some for high-level radioactive (nuclear) waste.[1)]
- High-level radioactive waste from Borssele, the HFR in Petten and the research reactor in Delft is stored in the high-level radioactive waste treatment and storage building (HABOG).[1)]
- Spent fissile materials from Borssele go to France first, for reprocessing. Around 90% is reused in France. The remaining 10% comes back as waste.
- At present, around 110 m3 of high-level radioactive waste is stored in the HABOG. On average, an additional 4.5 m3 or so arrives each year (with 70% of that coming from Borssele). The remaining storage capacity of this building is relatively limited, with 7% remaining for nuclear fission waste and 31% for spent fissile materials.[1),2)]
- Work is under way to expand the HABOG. The current capacity is being expanded by 50 m3 of additional storage capacity for high-level radioactive waste.[1),3),4)]
- Once this expansion is complete, there will be sufficient capacity to store nuclear waste from Borssele until its planned closure in 2034, possibly enough for a further extension of operations, and sufficient capacity available for waste from the possible new Pallas reactor in Petten.[1),5)]

Source: (1) 2020 Annual Report, COVRA (2020). (2) 2019 Annual Report, COVRA (2019). (3) COVRA application for revised licence, COVRA (2014). (4) Storage building for high-level radioactive waste being expanded (https://www.covra.nl/nl/organisatie/nieuws/uitbreiding-habog/, last accessed on 15 June 2021). (5) KPMG interview programme (2021).

…but it appears that upscaling to be able to process and store additional radioactive waste from a new nuclear power plant is quite possible

Total expected annual production of radioactive waste by a nuclear power plant



Note: (a) For all reactors, the quantity of fission products is approximately proportional to energy production. This means that the quantity of radioactive waste is proportional to the capacity of the reactor. The Borssele nuclear power plant produces around 3 to 3.5 m3 of high-level radioactive waste per year, and around 70 to 75 m3 of low- and medium-level radioactive waste per year. Extrapolating this volume, a Generation III+ reactor with a capacity of 1,600 MW could generate 10 to 11.5 m3 of high-level radioactive waste and 230 to 250 m3 of low- and medium-level radioactive waste per year. (b) In the above graph, the average of the range is presented. (c) BNPP: Borssele Nuclear Power Plant, EPR: European Pressurised Reactor

Source: (1) KPMG interview programme (2021). (2) KPMG analysis.

If a new nuclear power plant is built, capacity will have to be expanded again

— COVRA indicated that building a new nuclear power plant would mean its capacity would have to be expanded.[1)]
  - A Generation III+ reactor with a capacity of 1,600 MW could generate an additional 10 to 11.5 m3 of high-level radioactive waste per year. Over the assumed service life of 60 years, this could amount to 600 to 700 m3 of additional high-level radioactive waste in total.[a)]
  - A nuclear power plant also produces low- and medium-level radioactive industrial waste, which also has to be processed and stored by COVRA. This could potentially be around 230 to 250 m3 per year for a Generation III+ plant with a capacity of 1,600 MW. Over the assumed service life of 60 years, this could amount to 14,000 to 15,000 m3 of additional low- and medium-level radioactive waste in total.[a)]

— Because COVRA's storage capacity has a modular setup, a further expansion of capacity would be relatively simple from a technical point of view. However, it is expected that an additional industrial plot would have to be purchased for low- and medium-level material. There does appear to be sufficient space, but public support would be required.[1)]

"The storage capacity has a modular setup, so this would be relatively simple from a technical point of view."

Notes: (a) The Borssele nuclear power plant produces around 3 to 3.5 m3 of high-level radioactive waste per year, and around 70 to 75 m3 of low- and medium-level radioactive waste per year. Extrapolating this volume, a Generation III+ reactor with a capacity of 1,600 MW could generate 10 to 11.5 m3 of high-level radioactive waste and 230 to 250 m3 of low- and medium-level radioactive waste per year (indicative KPMG analysis).

Source: (1) KPMG interview programme (2021).

According to the market participants, underground (geological) final disposal is the only real and technically feasible long-term solution for radioactive waste...

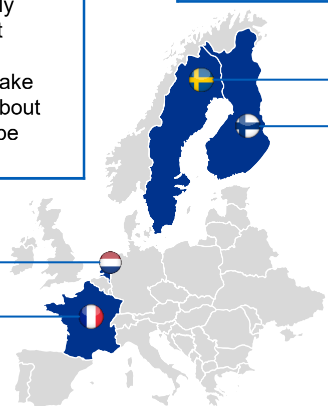
Overview of concrete projects in Europe for underground final disposal

The Netherlands

In the Netherlands, the Final Disposal of Radioactive Waste (OPERA) research programme has studied the underground final disposal of radioactive waste. The results of this study were published in early 2018. The conclusion is that all Dutch radioactive waste can be safely stored in deep clay and/or salt deposits. Final disposal in the Netherlands is anticipated to take place in 2130, so a decision about the definitive site will need to be made around 2100.

Sweden

In Sweden, a geological final disposal facility for radioactive waste will be created in granite layers at a depth of 500 metres. Construction of the facility, near the Forsmark nuclear power plant, will start in 2025 and take 10 years.



Finland

In Finland, work is under way on the construction of Onkalo, a storage facility for radioactive waste at a depth of around 450 metres. The radioactive waste will be stored in a number of tunnels, which have been dug in granite layers. The work is expected to be completed around 2022. Waste will begin to be stored there in around 2025.

France

In France, there are plans for an underground final disposal facility for radioactive waste. Final disposal is planned for Cigeo, a storage facility in clay deposits at a depth of 500 metres. Construction of Cigeo will start around 2025.

Source: (1) Final disposal, COVRA (https://www.covra.nl/nl/radioactief-afval/eindberging/, last accessed on 15 June 2021). (2) Cigeo, Andra (https://international.andra.fr/solutions-long-lived-waste/cigeo, last accessed on 15 June 2021). (3) Final repository for long-lived waste, SKB (https://www.skb.com/future-projects/the-last-repository/, last accessed on 15 June 2021). (4) Developing the First Ever Facility for the Safe Disposal of Spent Fuel, IAEA (2019). (5) KPMG interview programme (2021). KPMG analysis.

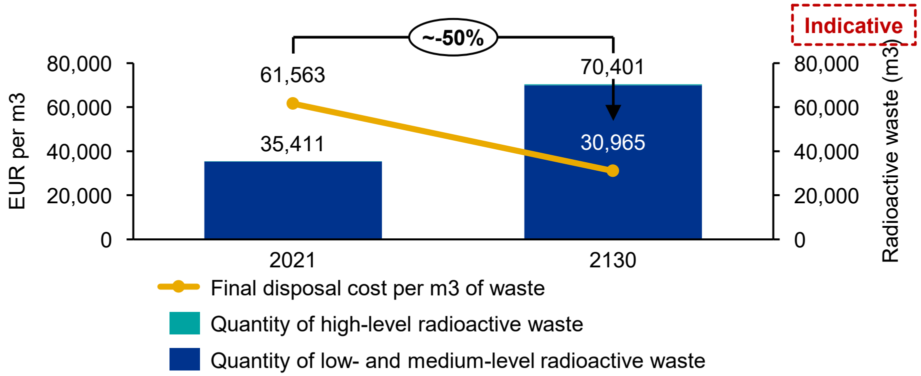
Underground final disposal is (almost) a proven technology

- There is currently one underground final disposal facility for radioactive waste in operation. Since 1999, United States military nuclear waste has been stored in salt deposits in New Mexico.[1)]
- In Europe, no underground final disposal facility for high-level, long-lived radioactive waste is currently in operation. However, work is being done in Finland, Sweden and France to create final disposal facilities. These projects are at various stages of readiness. It is expected that the first final disposal facility for high-level radioactive waste in Europe will become operational in Finland in around 2025.[2),3),4)]
- According to COVRA research, final disposal in the Netherlands is certainly possible. The Netherlands has sufficient suitable salt and clay deposits where final disposal could be achieved at a depth of 500 metres.[5)]

Source: (1) Final disposal, COVRA (https://www.covra.nl/nl/radioactief-afval/eindberging/, last accessed on 15 June 2021). (2) Cigeo, Andra (https://international.andra.fr/solutions-long-lived-waste/cigeo, last accessed on 15 June 2021). (3) Final repository for long-lived waste, SKB (https://www.skb.com/future-projects/the-last-repository/, last accessed on 15 June 2021). (4) Developing the First Ever Facility for the Safe Disposal of Spent Fuel, IAEA (2019). (5) KPMG interview programme (2021).

...but will not be realised in the Netherlands until 2130 for technical and economic reasons

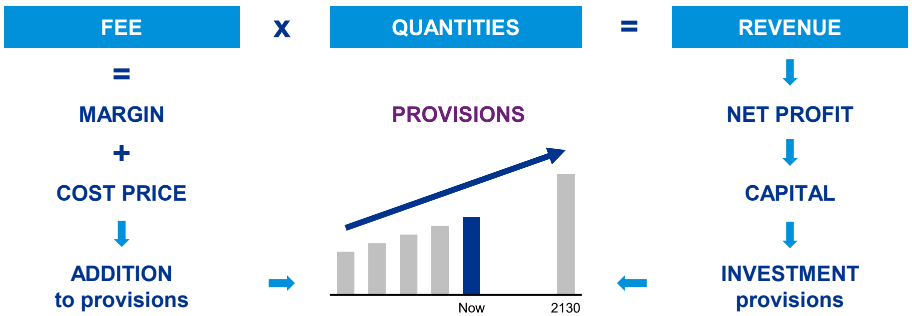
Potential reduction in the cost of final disposal per m3 of radioactive waste in the Netherlands



Note: Costs of final disposal per m3 are based on a cost estimate for final disposal in the Netherlands of EUR 2.18 billion (estimate from the OPERA research programme). Quantities of high-, medium- and low-level radioactive waste in 2130 are based on COVRA estimates, assuming a situation in which all radioactive waste is sent for final disposal, the Borsselle nuclear power plant closes in 2034 and the Pallas reactor in Petten is built. A potential new nuclear power plant is not included in the analysis.

Source: (1) 2020 Annual Report, COVRA (2020). (2) Inventory of radioactive waste in the Netherlands, COVRA (2014). (3) KPMG analysis.

Growth in COVRA provisions for final disposal



Note: Because final disposal is not expected to be carried out before 2130, COVRA must create provisions for this long-term financial obligation. The provisions are supplemented with the addition of part of the cost price for COVRA's services and further additions from the proceeds of investments, and increase by around 4.3% per year.

Source: 2020 Annual Report, COVRA (2020).

Delaying final disposal until 2130 appears to be a government decision made on technical and economic grounds

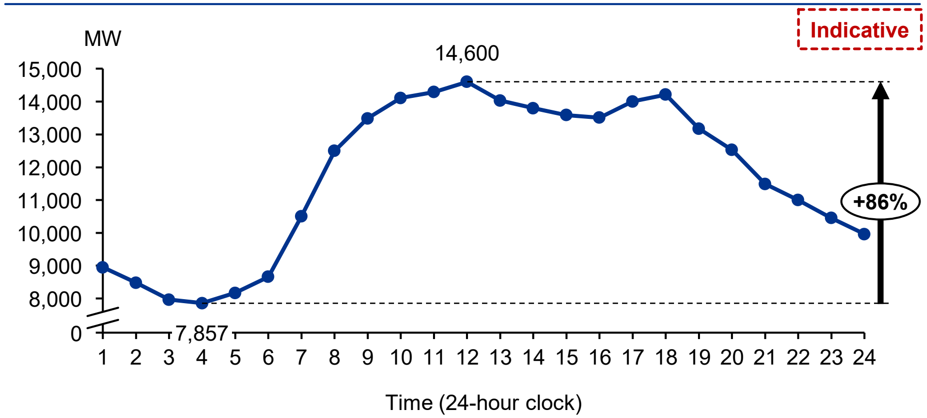
- The Dutch government has decided that radioactive waste should be stored for at least 100 years before proceeding with final disposal. Geological final disposal is anticipated in around 2130. In around 2100, a decision will have to be made about the location of the final disposal facility.[1),2)]
- According to COVRA, final disposal could technically be carried out sooner; this is a political, technical and economic calculation in the context of the Dutch radioactive waste policy.[3)]
  - The period of at least 100 years is based on the fact that the volume of waste could grow over that period (the Netherlands produces relatively little waste), meaning that the costs per unit would fall.[3)]
  - Technical advancements in that time might also mean that the waste could be stored in a more efficient manner.[3)]
  - The period can also be used to allow the final disposal fund, which is funded by the waste handling fee, to appreciate.[3)]
  - Finally, the period allows for the opportunity to investigate and perhaps develop options for international collaboration.[3)]
- A dual strategy will be followed for final disposal. A national route to final disposal will be developed, but the possibility of collaborating with other European member states to create a final disposal facility is not being excluded.[1),2)]
- The expectation of the market participants is that a joint European final disposal facility is unlikely for political reasons and regulatory differences. COVRA expects that when the geological final disposal facilities in Finland, Sweden and France have been operational for some time, an initiative will emerge for an international solution for smaller countries.
  - This could either be a joint initiative, or be connected with one of the final disposal facilities that will be well-established by that time.[3)]

Source: (1) Final disposal, COVRA (https://www.covra.nl/nl/radioactief-afval/eindberging/, last accessed on 15 June 2021). (2) National report for the Council Directive 2011/70/EURATOM, ANVS (2016). (3) KPMG interview programme (2021).

Options for deploying a nuclear power plant

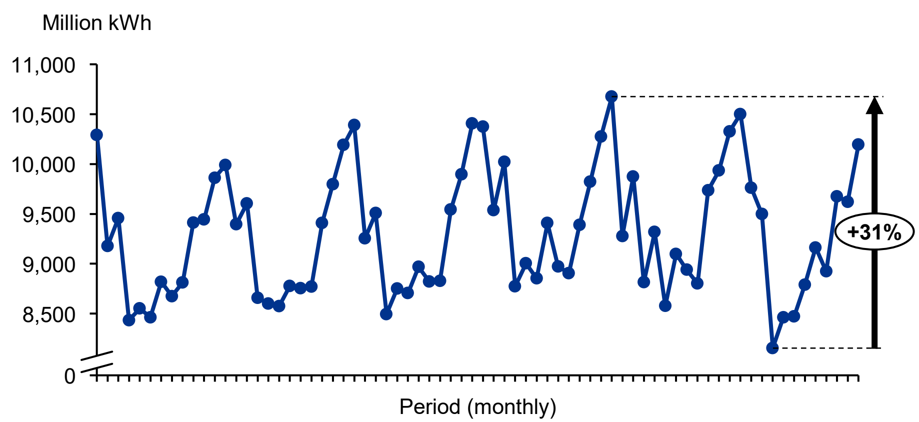
Essentially, a nuclear power plant can be deployed as a baseload or as a load-following power plant

Daily variation in electricity consumption in the Netherlands (by hour)[a)]



Note: (a) Pattern of daily electricity consumption in the Netherlands on a typical autumn day.
Source: Market and flexibility, CE Delft (2016). KPMG analysis.

Seasonal variation in electricity consumption in the Netherlands (2015-2020)



Source: Electricity balance sheet supply and consumption, Statistics Netherlands (2021). KPMG analysis.

Electricity grids have a base load and a peak load

— The base load is the minimum electricity supply required in the network for a specific period. The peak load is the maximum electricity supply required in the network for a specific period.

— The need for baseload and adjustable (peak) power stems from the variations in electricity and energy consumption.
  - Electricity consumption in the Netherlands follows a characteristic pattern and typically peaks around midday. The difference between the minimum and maximum consumption on a typical autumn day can be as high as 86%.[1)]
  - Seasons also have a sizeable influence on base load and peak load. Electricity consumption can be up to 31% higher in winter months.[2)]

A nuclear power plant can be deployed to cover both the base load and the peak load

— A nuclear power plant can be used to supply the base load, which means the plant will operate continuously.

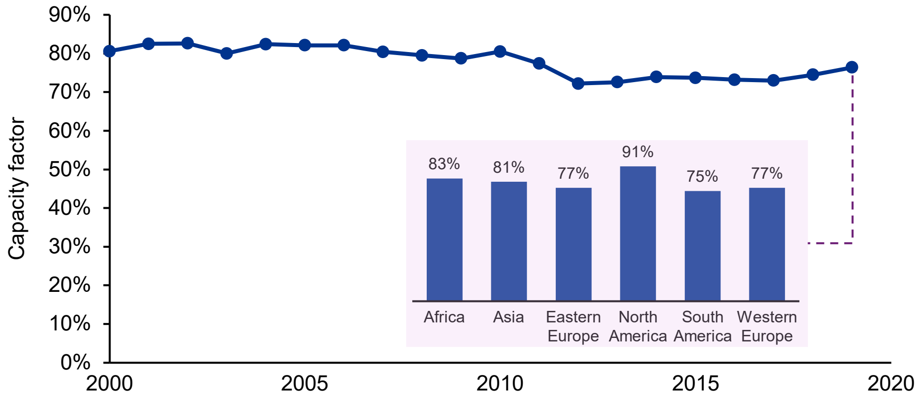
— A nuclear power plant can also be operated in load-following mode to cover the peak load, in which case the plant supplies power only when other sources are supplying insufficient energy.

— Alternatively, it can be used as a combination of the two.

Source: (1) Market and flexibility, CE Delft (2016). (2) Electricity balance sheet supply and consumption, Statistics Netherlands (2021).

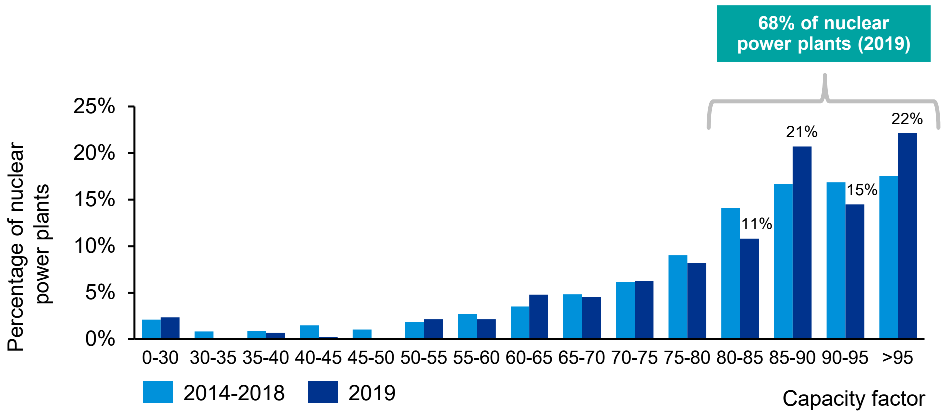
In other countries, nuclear power plants are generally used as baseload power plants

Average capacity factors for nuclear power plants around the world



Source: (1) World nuclear performance report 2020, World Nuclear Association (2020). KPMG analysis.

Percentage of power plants per capacity factor category



Source: World Nuclear Performance Report, World Nuclear Association (2020). KPMG analysis.

High capacity factors indicate that nuclear power plants are generally used as baseload power plants and largely operate continuously

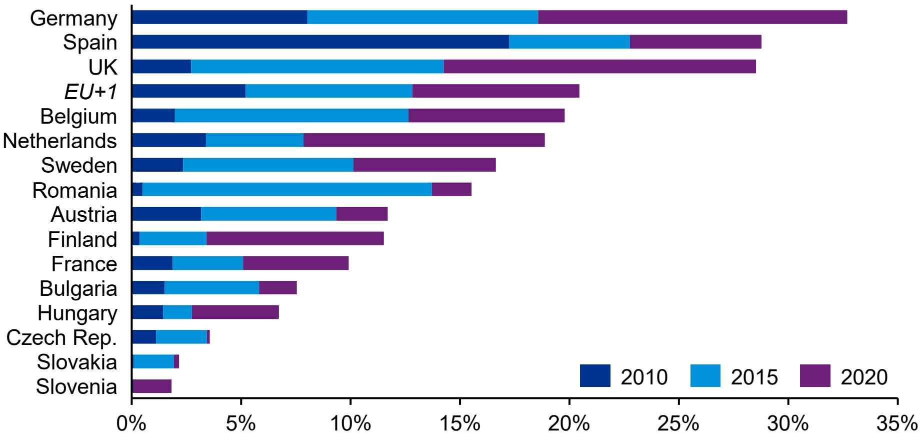
- The market participants indicated that most power plants operate to cover the base load, because this is the most cost-effective option (see page 115).
- Over the past 20 years, the average capacity factor of nuclear power plants in all countries combined has been around 80%.[1),2)]
- In 2019, 68% of power plants around the globe had a capacity factor of >80%. This picture is comparable to previous years.[1)]
  - Capacity factors in North America are above 90% on average. Almost without exception, power plants in North America are deployed to cover the base load (the exception being the Columbia Generating Station (CGS, 1170 MW, Richland, Washington).[1),3)]
  - Capacity factors are lower in Europe, because a number of countries use nuclear power plants fully or partially in load-following mode (see next page).[1)]
- High capacity factors indicate that nuclear power plants have a high degree of reliability and can operate continuously.[1)]

"Most power plants operate to cover the base load."

Source: (1) World Nuclear Performance Report 2020, World Nuclear Association (2020). (2) Power Reactor Information System, IAEA (https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendinAverageLoadFactor.aspx, last accessed on 1 May 2021). (3) Can nuclear power and renewables be friends?, Ingersoll et. al. (2015).

Due to the rise in solar and wind energy, nuclear power plants are increasingly operated as load-following power plants

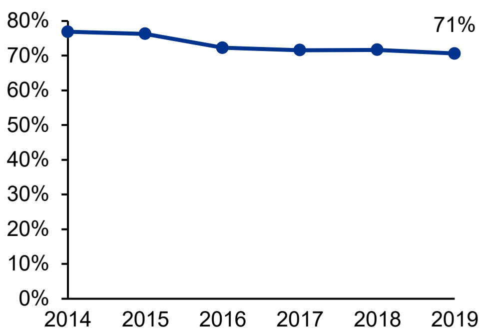
Share of solar and wind energy in electricity production

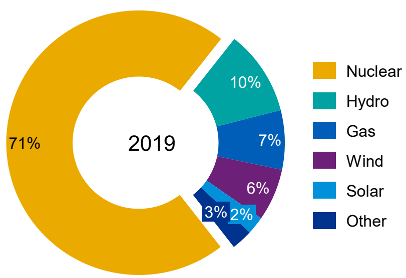


Note: EU countries with nuclear energy. The share of solar and wind energy in electricity production for the United Kingdom (UK) is also shown. EU+1 refers to the EU and the UK.

Source: EU Power Sector in 2020, Ember (2021).

Share of nuclear energy in energy production in France





Source: Power reactor information system, IAEA (https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=FR, last accessed on 1 May 2021). KPMG analysis.

It appears that nuclear power plants are increasingly being used to provide adjustable power, particularly due to the strong growth in renewable energy sources

— Renewable energy sources are experiencing strong growth. The share of solar and wind energy in electricity production in the EU rose by around 20% in 2020.[1)]

— Renewable sources, particularly solar and wind, have an unpredictable production profile, which means flexibility in power generation is needed to balance supply and demand. In some countries, nuclear power plants are increasingly being operated in load-following mode, which means nuclear power plants are sometimes switched on and off several times a day, depending on the specific demand and available supply.[2),3)]

- Germany (and to a lesser extent Belgium and Sweden) is an example of a country with a relatively large share of solar and wind energy where nuclear power plants are regularly operated in load-following mode.[2),3),4)]

Nuclear power plants can be used to provide adjustable power even when nuclear energy has a relatively large share of the energy mix

— In some countries, the share of nuclear energy in the energy mix is so large that as well as covering the base load, it also has to provide adjustable power to be able to balance varying demand (see also page 120) and supply.

- France is an example of a country where nuclear energy has a relatively large share (71%) in the energy mix and where nuclear power plants are regularly operated in load-following mode.[2),3),4)]

"With the increase in renewables, you're seeing nuclear power plants increasingly used to provide adjustable power."

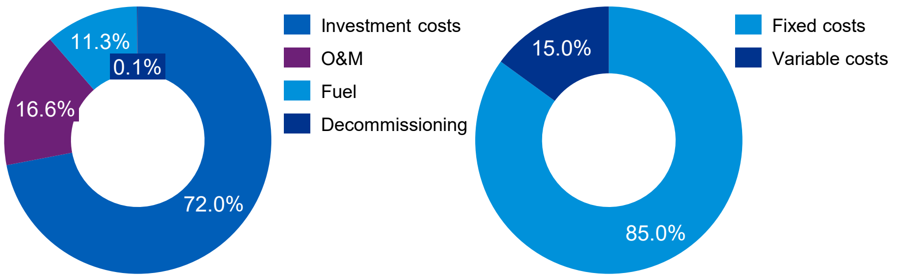
"In Germany for example, where they have a lot of solar and wind, nuclear power plants are used as a backup."

Source: (1) EU Power Sector in 2020, Ember (2021). (2) World Nuclear Performance Report, World Nuclear Association (2020). (3) Non-baseload operation in nuclear power plants, IAEA (2018). (4) Additional costs for load-following nuclear power plants, Elforsk (2012).

Base load

The market participants recommended operating a Dutch nuclear power plant to cover the base load, as this is the most cost-effective option

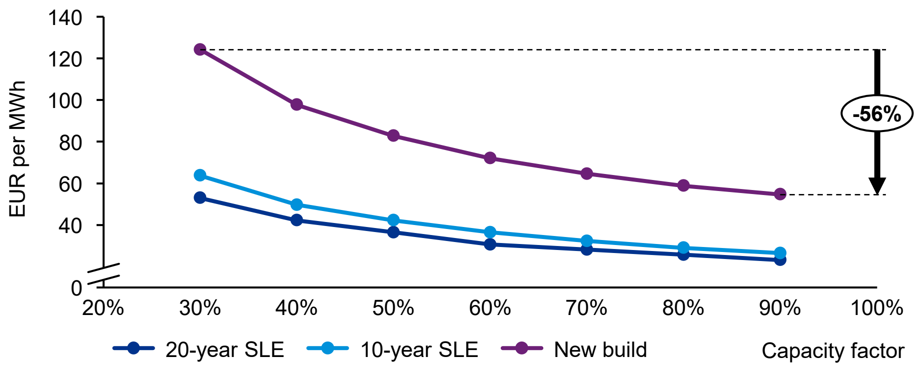
Breakdown of the total cost of a nuclear power plant



Note: 'Total cost' means all costs relating to the financing, construction, operation and decommissioning of a nuclear power plant.

Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).

LCOE of nuclear energy compared to capacity factor



Note: SLE stands for service life extension.

Source: (1) Projected Costs of Generating Electricity 2020 Edition, IEA & OECD-NEA (2020). KPMG analysis.

"Because uranium is so cheap, you should run a plant continuously. This is by far the most economical option."

The market participants indicated that covering the base load is the most cost-effective method of using a nuclear power plant

— Building a nuclear power plant is relatively capital-intensive, while the cost of operating it is relatively low.

- Investment costs make up 72% of the total cost of a nuclear power plant. These are largely fixed costs, incurred during construction of the plant.[1)] The cost of a Western Generation III+ FOAK reactor is estimated to be between approximately EUR 4,826 and 8,122 per kW (including budget overruns, see page 38). O&M (operation and maintenance) costs are also largely fixed costs.
- However, operating costs are relatively low. Variable fuel costs make up only around 11% of the total cost.[1)] Because of the low price of uranium, fuel costs vary from 0.4 euro cents per kWh to 1.2 euro cents per kWh.[2)] Running the plant for more hours only results in a small increase in operating costs.

— Accordingly, in principle a nuclear power plant is more profitable when it operates continuously.

This means a nuclear power plant can supply cheaper electricity (LCOE) at a higher capacity factor

— For the abovementioned reasons, nuclear power plants can supply cheaper electricity when they operate continuously. The relatively high fixed investment costs will then be spread across more productive hours, resulting in a lower LCOE. This makes nuclear power plants more competitive.

— The LCOE of nuclear power plants can decrease by as much as 56% when the capacity factor increases from 30% to 90%.[2)]

"A nuclear power plant has particularly high fixed costs, only a small percentage is variable."

Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).
(2) Projected Costs of Generating Electricity 2020 Edition, IEA & OECD-NEA (2020).

In addition, continuous operation is more in line with the technical characteristics of a nuclear power plant

"It's much cheaper and more efficient to deploy a nuclear power plant to cover the base load, because it means the plant is operating continuously."

"Older nuclear power plants in particular are primarily built to be used as baseload power plants and work best when run at full capacity."

"Constantly scaling a nuclear power plant up and down results in more wear and maintenance and is therefore very expensive. So you're better off letting the plant run continuously."

The market participants indicated that it is technically simpler and more efficient to operate a nuclear power plant continuously

— Nuclear power plants work most efficiently at a stable temperature. It is much easier to maintain a constant temperature in the reactor when fewer adjustments are made to the capacity, i.e. if the plant is operated continuously, rather than being frequently switched on and off.[1)]

— Furthermore, operating a nuclear power plant to cover the base load is a more efficient use of nuclear fuel.[1)] See page 122 for more information about the extra fuel costs incurred when operating nuclear power plants in load-following mode.

— In addition, with a constant load and continuous use of the reactor there is less wear, so that fewer inspections and less maintenance are required.[1)] See page 122 for more information about the extra maintenance required when nuclear power plants are operated in load-following mode.

Older nuclear power plants in particular have limited flexibility characteristics

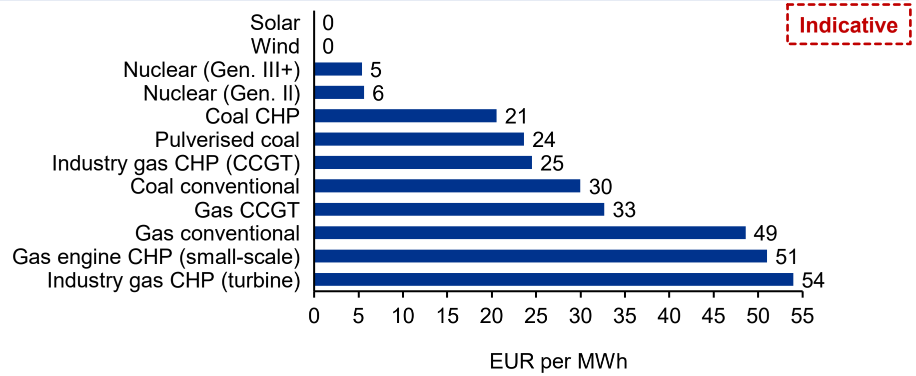
— Nuclear power plants have limitations in the extent to which their capacity can be quickly switched on and off.
  - Modern nuclear power plants can handle load variations of 50-100% of rated capacity, at a rate of 1-5% per minute.[2),3)] See also page 121 for a more detailed explanation of the flexibility characteristics of nuclear power plants.

— In addition, older nuclear power plants in particular have limitations in the extent to which capacity can be scaled down for extended periods.[3)]

Source: (1) Non-baseload operation in nuclear power plants, IAEA (2018). (2) Load following capabilities of nuclear power plants, Sustainable Nuclear Energy Technology Platform (2017). (3) Nuclear energy and renewables, OECD-NEA (2012).

However, in a deregulated market, nuclear energy competes with solar and wind, and at times of peak production may be superseded based on merit order

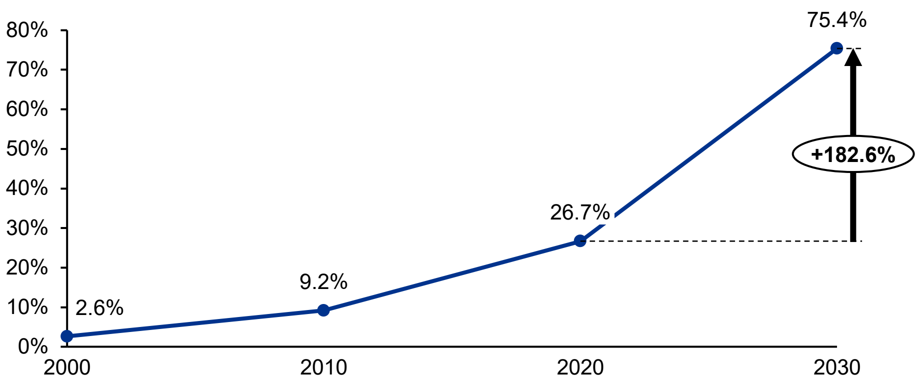
Marginal costs in the Netherlands (EUR/MWh)



Note: (a) Technologies with an installed capacity of >500 MW. Marginal costs based on the current situation in the Netherlands, as set out in the Netherlands 2020 scenario in the Energy Transition Model. Nuclear (Gen. III+) has been added to the model.

Source: Energy Transition Model.

Share of renewable sources in electricity production, 2030 forecast



Source: 2020 Climate and Energy Outlook, PBL (2020). KPMG analysis.

The market participants indicated that the marginal costs of nuclear energy are higher than those of renewable sources, which means that without government intervention nuclear would be superseded at times of peak production by solar and wind energy

- In the deregulated Dutch energy market, electricity is traded on the basis of merit order (the order in which production capacity is used). Supplies are ranked on the basis of price (marginal costs). The supply with the highest marginal costs is the first to become unprofitable and is scaled down at times of peak production when there is more supply than demand.
- Nuclear energy has lower marginal costs than fossil fuel alternatives, but not as low as the marginal costs for wind and solar energy.[1),2)]
- Accordingly, wind and solar energy would push nuclear energy (and energy from fossil fuels) out of the market at times when they are able to produce large amounts of electricity (in favourable conditions, i.e. when there is a lot of sun or wind) and there is not enough demand to use peak production.

The market participants expect that this situation will occur more frequently in the future due to the expected increase in the share of renewable sources in total electricity production

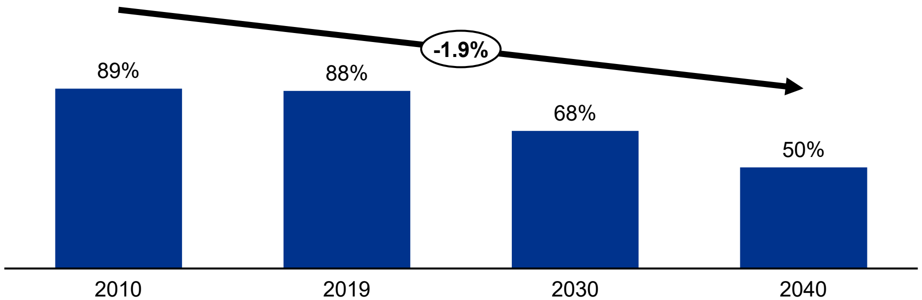
- The market participants expect that the share of renewable sources in electricity production will continue to increase, meaning that peak production times are expected to occur more often.
  - Forecasts show that the share of solar and wind in electricity production in 2030 may be as high as 75%.
  - Accordingly, solar and wind energy will regularly (and to an increasing extent) be able to fully meet electricity demand.[3),4)]

Source: (1) Energy Transition Model. (2) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (3) 2030 electrification and demand profile, TenneT (2020). (4) Systemic impact of nuclear power plants, in Climate-neutral energy scenarios in 2050, Kalavasta, Berenschot (2020).

> *"The current merit order is a major problem for nuclear energy because it's pushed out of the market by solar and wind."*

If the government wants a nuclear power plant to be able to operate continuously, government intervention is expected to be necessary

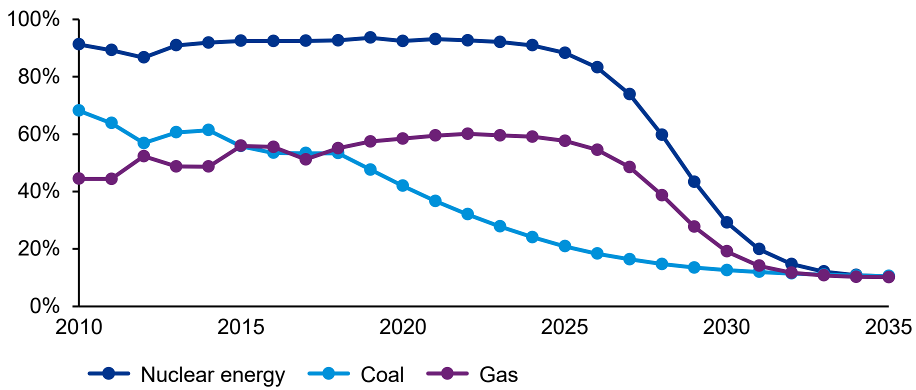
Capacity factors of a nuclear power plant in the Netherlands, 2010-2040 forecast



Note: (a) The 2010 and 2019 figures are the capacity factors of Borssele. The 2030 figure is a forecast by TenneT based on factors such as developments in the energy mix, assumed generation capacity, fuel and CO_2 costs. The 2040 figure is an estimate by the newspaper Het Financieele Dagblad.

Source: (1) Power reactor information system, IAEA (https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=FR, last accessed on 1 May 2021). (2) Monitoring Security of Supply 2020, TenneT (2020). (3) Nuclear hydrogen, Het Financieele Dagblad (2020). KPMG analysis.

Capacity factors for coal, gas and nuclear energy in the USA, 2010-2035 forecast



Note: (a) The figures from 2020 onwards are forecasts by RethinkX.

Source: Rethinking Energy, RethinkX (2021).

The operation of nuclear power plants is expected to continuously decline in the future

— Due to the growth of renewable sources and the merit order effect (see previous page), the market participants indicated that they expect the number of operational hours of nuclear power plants to continuously decline in the future.

- A forecast by the grid operator TenneT shows that by 2030, nuclear power plants in the Netherlands might only be able to manage a capacity factor of around 68%.[1)] Het Financieele Dagblad estimates that by 2040, a capacity factor of only 50% will be able to be achieved due to the significant increase in renewable sources.[2)]
- Capacity factor forecasts for fossil fuels and nuclear energy in the USA predict that capacity factors could fall to around 10% by 2035.[3)]

If the government wants a nuclear power plant to be able to operate continuously, government intervention in the market is expected to be necessary

— If the government wants a nuclear power plant in the Netherlands to operate all the time and be deployed to cover the base load, it will have to issue a price guarantee (perhaps in the form of a CfD) to allow the plant to produce power below cost.

— The market participants indicated that such a price guarantee could be issued in a range of ways, such as in the form of a CfD or through an SDE++ subsidy.

Source: (1) Monitoring Security of Supply 2020, TenneT (2020). (2) Nuclear hydrogen, Het Financieele Dagblad (2020). (3) Rethinking Energy, RethinkX (2021).

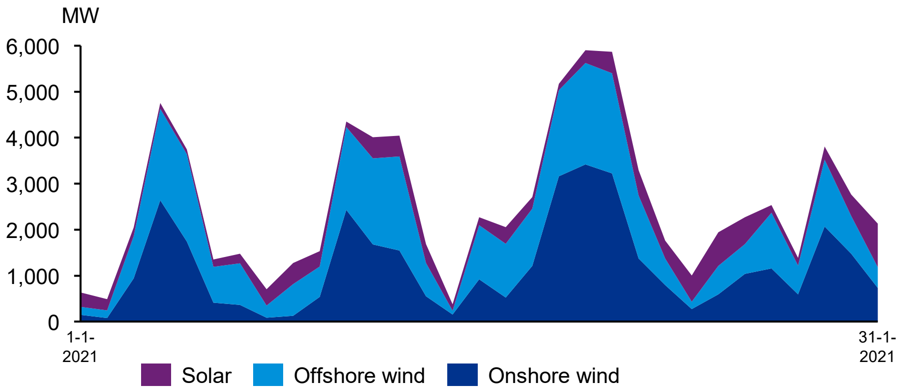
"Prices must be regulated to enable a nuclear power plant to operate continuously. If you want an example, look at France and the UK, where electricity from nuclear energy is sold at agreed prices so that the plants can operate continuously and remain competitive."

"The government must intervene in the merit order. Nuclear energy is the only carbon-neutral source that doesn't receive any support."

Load following

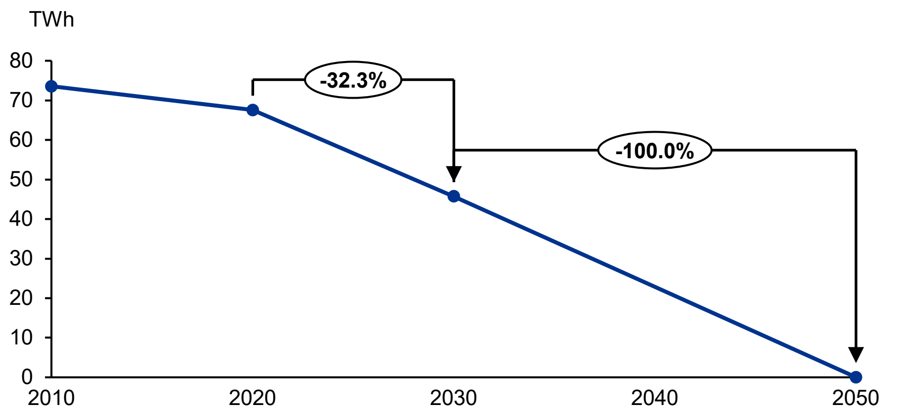
In the future, the Netherlands will need carbon-free adjustable power. A nuclear power plant could be used to provide it

Production capacity of solar and wind in the Netherlands, January 2021



Note: (a) Instantaneous production capacity on a daily basis for the month of January 2021.
Source: Energy generation (https://energieopwiek.nl/, last accessed on 1 May 2021). KPMG analysis.

Electricity production from natural gas, 2050 forecast



Source: (1) 2020 Climate and Energy Outlook, PBL (2020). (2) 2050 Exploration, Gasunie (2018). KPMG analysis.

Electrification and the rise of renewable energy sources mean that sufficient flexibility in power generation will be needed in the future

— Forecasts show that electricity consumption in the Netherlands will increase sharply between 2030 and 2050. The expectation is that renewable energy sources (solar and wind) will represent an increasingly larger share of the electricity supply.[1),2),3)]

— Due to the unpredictable production profile of wind and solar, greater investment in adequate load-following capabilities and flexible supply is expected to be necessary in the future. Load following and flexible supply will ensure that electricity supply and demand remain in balance despite the varying supply of electricity from wind and solar.[2)]

— TenneT indicated that 24-27 GW of adjustable power could be required by 2030.[4)] Netbeheer Nederland expects that the need for load-following power plants in 2050 will be nearly twice as high as current capacity.[3)] The current adjustable power capacity is around 22 GW.[5)]

In the Netherlands, adjustable power is traditionally provided by gas-fired power plants, which according to policy projections are going to be phased out

— In the Netherlands, adjustable power is traditionally provided by flexible gas-fired power plants. These can be switched on and off relatively quickly (see next page) and the typical capacity factor varies from 30-70%.[6)]

— The Netherlands wants to transition to a low-carbon energy supply, so fossil fuels (including natural gas) will be phased out between 2030 and 2050. Policy projections show that electricity production based on natural gas could decrease by around 32% by 2030 before being fully phased out by 2050.[1),7)]

Various alternatives to natural gas are available to provide carbon-free adjustable power, including nuclear energy

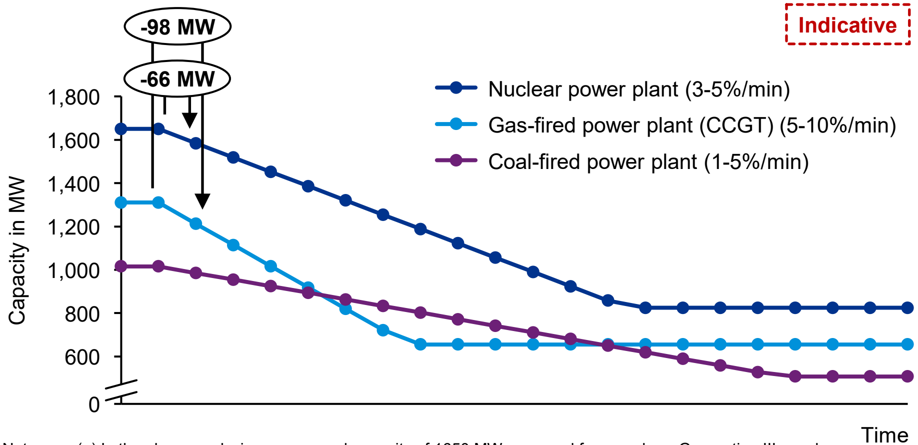
— Forecasts by Netbeheer Nederland, Gasunie and others show that hydrogen and green gas could be carbon-free alternatives to natural gas.[3),6)]

— The market participants indicated that nuclear energy could also potentially be used to provide carbon-free adjustable power. The market participants stated that modern power plants in particular possess considerable flexibility and could thus play a role in the production of hydrogen.

Source: (1) 2020 Climate and Energy Outlook, PBL (2020). (2) Scenarios for a climate-neutral energy system, TNO (2020). (3) The energy system of the future, Netbeheer Nederland (2021). (4) 2020 electrification and demand profile, TenneT (2020). (5) Monitoring Security of Supply 2020, TenneT (2020). (6) Conversion of primary energy carriers, Delft University of Technology (2019). (7) 2050 Energy Mix, Gasunie (2018).

Modern nuclear power plants are capable of providing adjustable power, but are not as effective in this role as gas-fired power plants

Adjustable power capacity of peak load power plants



Note: (a) In the above analysis, an assumed capacity of 1650 MW was used for a modern, Generation III+ nuclear power plant. For the capacity of a coal-fired power plant, an average was taken of the four remaining power plants in the Netherlands. The capacity of a CCGT gas-fired power plant is based on the Vattenfall Magnum plant (three units) (the most recently-constructed plant in the Netherlands). (b) The above graph is based on the average flexible capacity of the different types of power plants. (c) 50% of the rated capacity is used as a lower limit.

Source: (1) Load-following with nuclear power plants, Lokhov (2011). (2) Non-baseload operation in nuclear power plants, IAEA (2018). (3) Technical and economic aspects of load following with nuclear power plants, OECD, NEA (2011). (4) Load following capabilities of nuclear power plants, Sustainable Nuclear Energy Technology Platform (2017). (5) Nuclear energy and renewables, OECD, NEA (2012) (6) Memorandum of amendment to the Act banning the use of coal in electricity production, Ministry of Economic Affairs and Climate Policy (2021). (7) Nuon opens Magnum gas-fired power plant in Eemshaven, Vattenfall (https://group.vattenfall.com/nl/newsroom/archive/nieuws/2013/nuon-opent-magnum-gascentrale-in-de-eemshaven, last accessed on 1 June 2021). KMPG analysis.

"It has been demonstrated in various countries that from a technical point of view, nuclear power plants are highly suitable for use in the supply of adjustable power."

"Although many things are technically possible, there are significant constraints on the load-following capabilities of nuclear power plants."

Most modern nuclear power plants can handle load variations of 50-100% of capacity, at a rate of 3-5% per minute

— A modern nuclear power plant (assuming a net capacity of 1,650 MW) can increase or decrease production by 3-5% of the rated capacity per minute, or around 66 MW. If necessary, this can be done several times a day.[1),2),3)]

- Nuclear power plants in countries such as France, Germany, Belgium, Finland and Switzerland have been proven in practice to possess significant capacity for flexibility.[2),4)] Reactors in France, for example, can be adjusted twice a day, within half an hour, by up to 80% of the rated capacity.[5)]
- The European Utility Requirements state that new (Generation III+) nuclear power plants must be able to increase and decrease output by up to 50% of their capacity per day, at a rate of 3-5% per minute.[1),3)]

— This makes nuclear power plants more flexible than coal-fired power plants, but not as flexible as gas-fired power plants (CCGTs). CCGT gas-fired power plants can increase and decrease output by up to 10% of their capacity per minute, or approximately 100 MW, and have a shorter start-up time than nuclear power plants.[2),4),6)]

However, there are indications that using a nuclear power plant to provide adjustable power may place a greater burden on the plant (than if it were covering the base load), resulting in slightly higher wear and maintenance

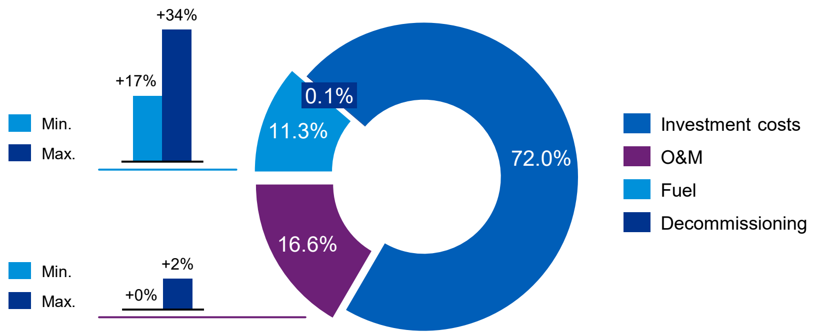
— Because most modern nuclear power plants have flexibility characteristics (incorporated in their designs and/or added later through essential modifications), the impact on the plant of operating in load-following mode is relatively limited.

— However, there are indications that operating a plant in load-following mode leads to higher wear and more maintenance, particularly with regard to the control valves.[2),3),7)] See also the next page for a further explanation of the cost perspective.

Source: (1) Load-following with nuclear power plants, Lokhov (2011). (2) Non-baseload operation in nuclear power plants, IAEA (2018). (3) Technical and economic aspects of load following with nuclear power plants, OECD, NEA (2011). (4) Load following capabilities of nuclear power plants, Sustainable Nuclear Energy Technology Platform (2017). (5) Global Performance Report 2020, World Nuclear Association (2020). (6) Nuclear energy and renewables, OECD, NEA (2012). (7) Additional costs for load-following nuclear power plants, Elforsk (2012).

Using a nuclear power plant to provide adjustable power is considered less cost-effective, which means the government would have to provide a subsidy

Potential increase in the total cost as a result of using a nuclear power plant to provide adjustable power



Note: (a) 'Total cost' means all costs relating to the financing, construction, operation and decommissioning of a nuclear power plant. (b) As well as additional O&M and fuel costs, deployment of a nuclear power plant can lead to additional investment and staffing costs; the amount of these is unknown, and was therefore not included in the above graph.

Source: (1) Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020). (2) Non-baseload operation in nuclear power plants, IAEA (2018). (3) Load-following operating mode at NPPs and incidence on O&M costs, Bruynooghe et al. (2010). (4) Additional costs for load-following nuclear power plants, Elforsk (2012). KMPG analysis.

"Constantly scaling a nuclear power plant up and down results in more wear and maintenance, among other things, and is therefore more expensive. So you're better off letting the plant run continuously."

"The cost of electricity is much higher when the plant can't operate at full capacity, and this will be reflected in a higher LCOE."

Using nuclear power plants to provide adjustable power can result in additional costs, making them less profitable

— Although a certain amount of flexibility of use is incorporated into the design of most modern nuclear power plants, there are indications that operating a plant in load-following mode results in higher costs.
  - Slightly higher maintenance costs, partly due to more wear and more inspections.[1),2)] O&M costs can work out around 2% higher.[1),3)]
  - Higher fuel costs due to a less-efficient use of fuel (the fuel cycle is more difficult to plan). Fuel costs can be around 17-23% higher for Boiling Water Reactors (BWRs) and around 25-34% for Pressurised Water Reactors (PWRs).[1),4)]
  - Staffing costs may also be higher, because adjusting power output creates more work. More training would also be required. It is not known what the additional staffing costs would be.[1)]

— When nuclear power plants are operated in load-following mode, the average cost of the electricity produced increases, partly because the high fixed investment costs must be spread out over fewer productive hours.

— The LCOE increases by around 10% when the capacity factor falls from 80% (base load) to 70% (load following).[5)] See also the graph on page 115, which shows the LCOE of nuclear power plants in relation to the capacity factor.

To make flexible operation profitable, the government would have to provide a subsidy to compensate for the lower production hours

— The market participants indicated that, for the above reasons, a nuclear power plant could be less profitable if deployed to provide adjustable power.

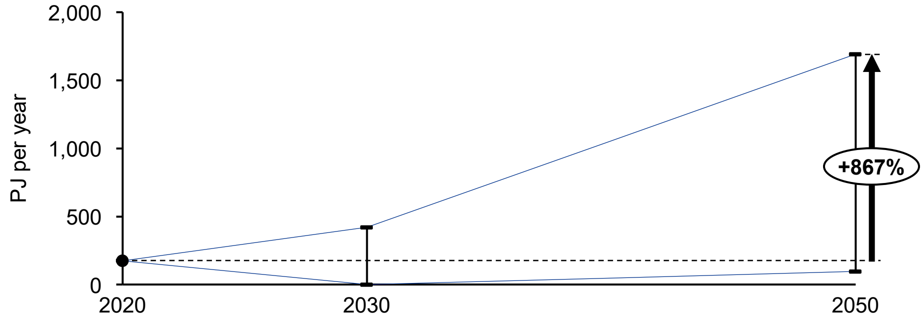
— In particular, a subsidy would be required to compensate for the lower production hours in order to make the nuclear power plant profitable.

— The market participants indicated that if flexibility in power generation is desired, it would be better to build several small SMRs than one large nuclear power plant (see also page 58). This would give more flexibility with upscaling and downscaling as well as more security when production issues occur than a single nuclear power plant.

Source: (1) Non-baseload operation in nuclear power plants, IAEA (2018). (2) Technical and economic aspects of load following with nuclear power plants, OECD, NEA (2011). (3) Load-following operating mode at NPPs and incidence on O&M costs, Bruynooghe et al. (2010). (4) Additional costs for load-following nuclear power plants, Elforsk (2012). (5) Projected costs of generating electricity 2020 edition, IEA & OECD-NEA (2020).

When used to provide adjustable power, surplus nuclear energy could be used for hydrogen production to improve the profitability of nuclear power plants

Hydrogen demand, 2020-2050 forecast



Note: (a) The graph shows a range for the potential total demand for hydrogen in the Netherlands. The range is based on several underlying scenario studies. Because future demand for hydrogen is difficult to predict, the range is relatively broad.

Source: Hydrogen in the Netherlands, TNO (2020). KPMG analysis.

"If you have overcapacity in a situation with high production from solar and wind, you could use nuclear capacity for hydrogen production."

"You can run a plant at full capacity if you produce both electricity and hydrogen."

"Using a nuclear power plant to generate hydrogen would be pointless because it's too expensive."

Hydrogen may play a key role in the transition towards a carbon-neutral energy supply

— Projections show that demand for hydrogen could rise to as high as 1,700 petajoules per year by 2050. Conservative forecasts are based on around 100 petajoules per year.[1] The actual future demand for hydrogen is difficult to predict.

A number of market participants indicated that nuclear power plants could be used for hydrogen production, which could improve their profitability

— Nuclear power plants can produce hydrogen when other technologies (with lower marginal costs) are producing sufficient electricity. This would mean the nuclear power plants would have to scale down less often.

— Although the technology has not yet been proven on a large scale,[2),3)] several market participants indicated that nuclear power plants are particularly well-suited to hydrogen production.

- In contrast to many other technologies, nuclear power plants produce both electricity and heat. Both can be used for hydrogen production. Because high temperatures (750-1,000 degrees Celsius) are required in most cases for hydrogen production, several Generation IV reactors (HTRs, AHTRs, and to a lesser extent MSRs) will be suitable for producing hydrogen using heat.
- Hydrogen produced in nuclear power plants is carbon-free.

— In many cases, the production of hydrogen in nuclear power plants requires only minor modifications, alongside investments in equipment such as electrolysers. The exact extent of these modifications/investments will be different for each plant.[4)]

It's not clear whether hydrogen produced in nuclear power plants will be able to compete with other forms of hydrogen

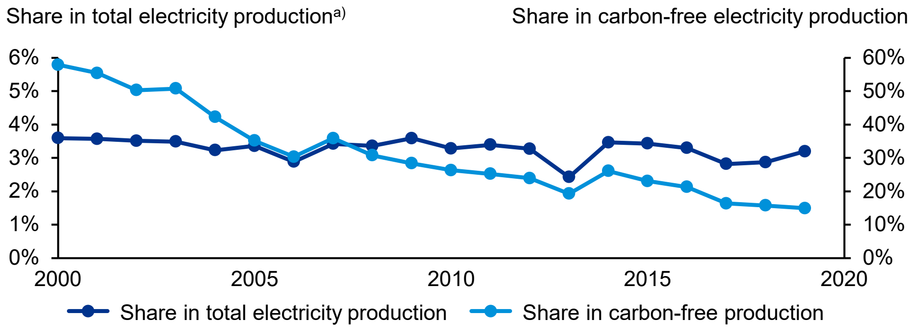
— Some market participants and studies indicate that hydrogen produced from nuclear energy may not be able to compete with other technologies, while other projections predict that new-generation nuclear power plants built from around 2030 will be able to supply relatively cheap hydrogen.[2),5),6)]

Source: (1) Hydrogen in the Netherlands, TNO (2020). (2) The role of nuclear energy in the energy transition of North Brabant, TNO (2020). (3) Hydrogen production and uses, World Nuclear Association (https://www.world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.aspx, last accessed on 1 June 2021). (4) Hydrogen production using nuclear energy, IAEA (2013). (5) Missing link to a livable climate, Catalyst (2020). (6) Systemic impact of nuclear power plants in climate-neutral energy scenarios in 2050, Kalavasta, Berenschot (2020).

Borssele

The Borssele nuclear power plant has around a 15% share in the carbon-neutral electricity production of the Netherlands

Share of Borssele in electricity production



Note: (a) Total electricity production including imports.
Source: 2020 Climate and Energy Outlook, PBL (2020).

Borssele nuclear power plant specifications

Reactor type	PWR (Generation II)
Net electrical capacity	482 MW_e
Thermal capacity	1,366 MW_t
Capacity factor[a)]	85.9%
Start of construction	1969
Commissioning	1973

Note: (a) Average capacity factor (electricity production achieved as a percentage of maximum production capacity in a specific period) 2009–2019.
Source: Power Reactor Information System, IAEA (https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=423, last accessed on 1 May 2021).

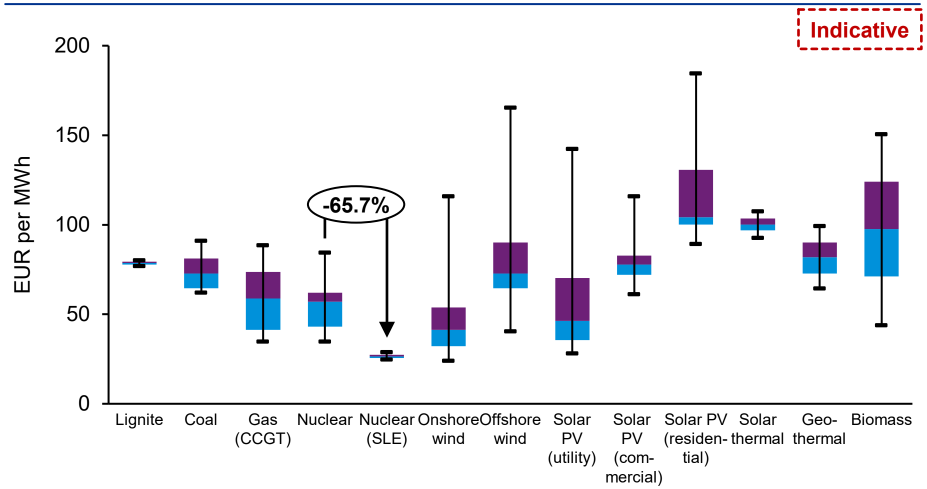
The Borssele nuclear power plant appears to be used primarily to cover the base load, but can also be used to provide adjustable power when required

- Borssele is a Generation II Pressurised Water Reactor (PWR) with a net capacity of 482 MW.[1)]
- The average capacity factor of the nuclear power plant over the period 2009-2019 was 85.9%.[1)] This means that the plant operates for more hours than an average foreign nuclear power plant that covers the base load (around 80%).[2)]
  - A nuclear power plant never operates at 100% capacity. Every year, maintenance, replacement of spent fissile material, and a variety of minor faults result in loss of production.
- TenneT has signed agreements with EPZ about the mandatory and voluntary adjustment of power output to resolve transmission restrictions. TenneT sometimes asks EPZ to temporarily switch off the Borssele nuclear power plant, particularly at times of peak wind power production.[3),4)]
- Until 2004, the nuclear power plant generated more than 50% of the carbon-free electricity in the Netherlands. By 2019, this share had dropped to around 15%. This was mainly due to the rise of solar and wind energy.[5)]
- Borssele has a relatively stable share of total Dutch electricity production, at around 3%.[5)]

Source: (1) Power reactor information system, IAEA (https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=423, last accessed on 1 May 2021). (2) World Nuclear Performance Report, World Nuclear Association (2020). (3) KPMG interview programme (2021). (4) Reserve capacity supplied for other purposes, TenneT (https://www.tennet.org/bedrijfsvoering/Systeemgegevens_voorbereiding/Aangeboden_reservevermogen_Overige_Doeleinden/index.aspx, last accessed on 15 May 2021). (5) 2020 Climate and Energy Outlook, PBL (2020).

The market participants recommended extending the service life of Borssele for financial reasons and to maintain the knowledge/value chain in the Netherlands

LCOE of new build versus service life extension



Note: (a) The graph shows the range and spread of LCOEs of individual plants by technology (data from 243 power plants in 24 countries). The figures are the expected LCOEs for 2025. The real discount rate is 7%. For nuclear energy (and various other technologies), an average capacity factor of 85% was assumed. (b) The LCOE can vary markedly within and between technologies. In addition, the LCOE can vary markedly between regions/countries. (c) SLE stands for service life extension.

Source: (1) Projected costs of generating electricity 2020 edition, IEA & OECD-NEA (2020). KPMG analysis.

"Extending the service life of a nuclear power plant is a much cheaper means of energy production than building a new plant."

"By keeping Borssele running, you keep the nuclear infrastructure in the Netherlands alive."

The market participants indicated that after a service life extension, a nuclear power plant could produce cheaper energy than a new plant

— The market participants stated that extending Borssele's service life could be appealing from a financial point of view, but that this would depend on commercial agreements and the necessary technical maintenance (see following pages).

— Several studies have indicated that electricity generated in nuclear power plants following a service life extension may have a lower LCOE than electricity from new nuclear power plants (more than 65% lower in some cases).[1),2)]

— Furthermore, the investment required to extend the service life is less than for a new build.

- The capital costs of a service life extension for Generation II water-based reactors generally vary between approximately EUR 414 per kW and EUR 910 per kW. The service life is generally extended for 10 to 20 years.[2),3)]
- The cost of a Western Generation III+ FOAK reactor is estimated to be between approximately EUR 4,826 and EUR 8,122 per kW (including budget overruns, see page 38).

Extending the service life of the Borssele plant would give the Netherlands flexibility to add nuclear energy to the energy mix now or in the future

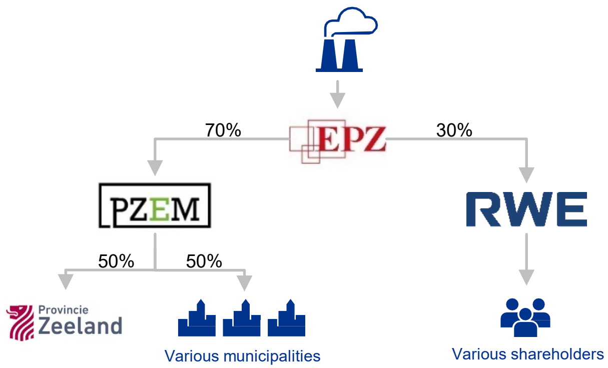
— Partly because of Borssele, the Netherlands possesses specific knowledge about supplying nuclear energy (such as radiation protection and licensing).[4)]

— The market participants emphasised that it is important to maintain the knowledge and expertise currently present in the Netherlands (both with parties in the value chain and with the regulator ANVS). This gives the Netherlands flexibility to add nuclear energy to the energy mix now or in the future.

Source: (1) Projected costs of generating electricity 2020 edition, IEA & OECD-NEA (2020). (2) Nuclear power in a clean energy system, IAEA (2019). (3) The economics of long-term operation of nuclear power plants (OECD (2012). (4) Nuclear knowledge infrastructure in the Netherlands, Technopolis (2016).

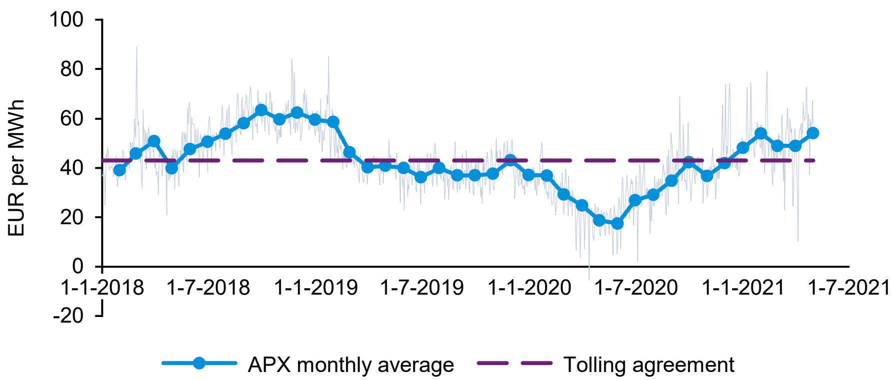
If the service life is extended, it will be necessary to review Borssele's financing and ownership structure

Ownership structure of the Borssele nuclear power plant



Source: (1) 2019 Annual Report, EPZ (2019). (2) PZEM Annual Report, PZEM (2020). (3) 2020 Annual Report, RWE (2020). KPMG analysis.

Wholesale electricity price



Source: Bloomberg (2021).

The nuclear power plant is subject to commercial risks, since market prices sometimes fall below the cost price and Borssele does not have a guaranteed minimum purchase price

- EPZ is the operator of the Borssele nuclear power plant. EPZ is owned by the German energy company RWE and the Zeeland company PZEM.
- RWE and PZEM buy electricity from the Borssele nuclear power plant at a fixed price of EUR 43 per MWh, under a tolling agreement. EPZ therefore receives a cost-plus price for the electricity produced.[1)]
- RWE and PZEM sell the electricity on the open market. Because the market prices of electricity are sometimes lower than the cost-plus purchase price the two organisations pay, at those times they make a loss on their stake in the power plant.
- If the service life is extended, it is expected that the shareholders will not be willing to continue to bear these commercial risks.

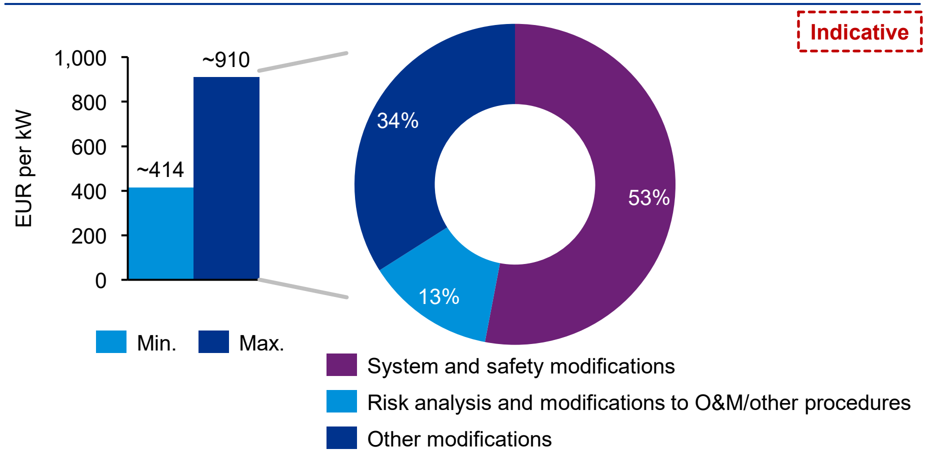
A government stake or a CfD have been suggested as options to remove and/or cover risks

- The market participants indicated that the government could take a stake in the nuclear power plant, thereby taking on the operating and commercial risks.
- Furthermore, under a CfD a guaranteed strike price per MWh would be agreed for the electricity produced. If market prices were below the strike price, the government would make up the difference for the benefit of the operator/shareholders. See the 'Financing and guarantees' chapter on page 61 for a further explanation of how a CfD works.
- An SDE++ subsidy could also be offered.

Source: (1) Advice on financial issues in the Province of Zeeland, Jansen Temporary Committee (2017).

Safety aspects are an important precondition of extending the service life of the Borssele plant

Breakdown of investment costs for a nuclear power plant service life extension



Note: (a) This breakdown of the investment costs involved in a service life extension is an average of the range of cost components indicated by the IAEA.

Source: Nuclear power in a clean energy system, IAEA (2019). KPMG analysis.

“Costs for safety modifications for a service life extension vary widely and depend on the specific context.”

“In our country, a service life extension for a Generation II nuclear power plant would mean bringing it as close as possible to the safety level of a Generation III plant. We believe that would make it expensive.”

Note: (a) See the next page for more details about legally-required and other necessary modifications as well as the associated process steps for a service life extension of the Borssele plant.

Source: (1) Possible extension to the operations of the Borssele nuclear power plant, ANVS (https://www.autoriteitnvs.nl/onderwerpen/ mogelijke-verlenging-bedrijfsvoering-kerncentrale-borssele, last accessed on 31 May 2021). (2) Nuclear power in a clean energy system, IAEA (2019). (3) ANVS. (4) Borssele safety benchmark, Borssele Benchmark Committee (2018).

Borssele would have to undergo a safety evaluation before its service life could be extended

- To keep the Borssele nuclear power plant operating for longer, the Nuclear Energy Act would have to be amended and the current licence would have to be modified.[a)]
- For operations to continue after 2033, the underlying safety report would have to be updated. In the safety report, the licence holder must demonstrate that the nuclear power plant can meet the technical safety requirements.[1)]
- A service life extension could involve high investment costs, partly due to the necessary modifications.
  - The capital costs of a service life extension for Generation II water-based reactors generally vary between approximately EUR 414 per kW and EUR 910 per kW,[2)] which for Borssele works out at roughly EUR 199-439 million.
  - More than 50% of the costs are for system and safety modifications,[2)] which for Borssele would work out at roughly EUR 106-233 million.
  - The actual cost of a service life extension largely depends on the type of reactor, the length of the extension, location-specific safety requirements and country-specific requirements.[2)]

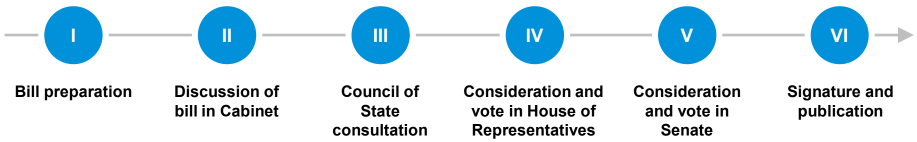
The market participants indicated that they do not anticipate any issues around safety in relation to a service life extension

- The market participants said that Borssele has a safe, modern design.
- The plant has also undergone a number of safety adjustments over the years. In response to regular safety evaluations its systems have been made safer and/or expanded, such that some market participants now describe Borssele as a Generation II+ nuclear power plant.
- The safety of Borssele was confirmed by the Benchmark Committee (the committee that produces a report every five years about the safety of the Borssele nuclear power plant), which indicated that the plant is in the top 25% of the safest pressurised-water nuclear power plants in the Western world.[4)]

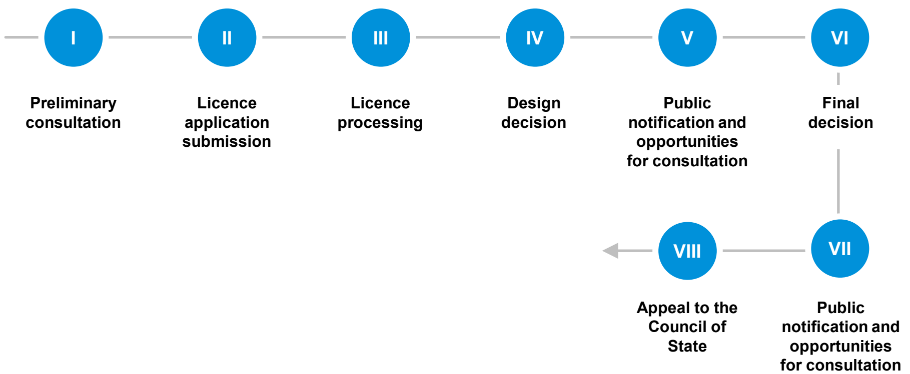
For now, the government and EPZ have agreed that Borssele should shut down by the end of 2033 at the latest. A service life extension would require an amendment to the Nuclear Energy Act

Process for possible statutory and licence amendments for a Borssele life cycle extension

Legislative process



Licensing process



A service life extension would require an amendment to the Nuclear Energy Act

- The Dutch government and the owner EPZ have agreed that the nuclear power plant in Borssele should shut down by the end of 2033 at the latest.
- After 31 December 2033, no more nuclear energy may be released in the Borssele nuclear power plant. This is laid down in the Nuclear Energy Act.
- This means that for the plant to remain in operation after 2033, the Nuclear Energy Act will have to be amended.[1),2)]

The Borssele Nuclear Power Plant Covenant would also have to be amended

- The Explanatory Memorandum to the Act states that the inclusion in the Act of a deadline for closure of the plant is connected to the agreement about the service life of the plant, as contained in the Borssele Nuclear Power Plant Covenant.
- This means that, if the plant is to remain in operation after 2033, along with the Nuclear Energy Act, the Covenant will also have to be amended.[1),3)]

To keep the Borssele nuclear power plant operating for longer, the current licence would also have to be modified

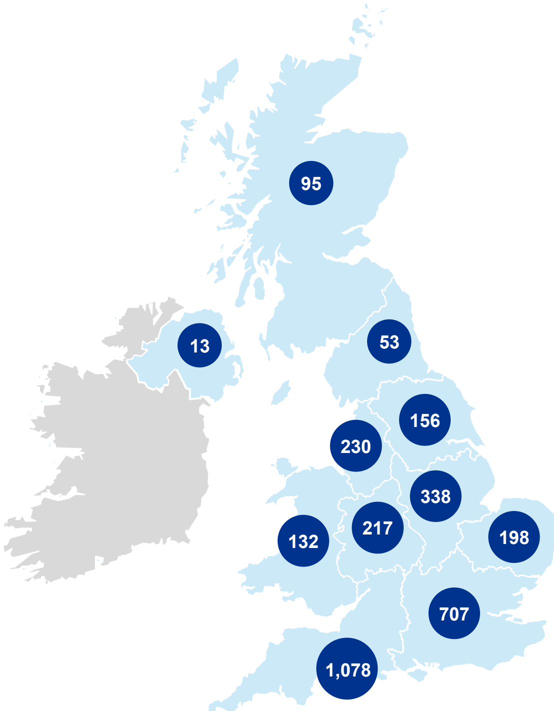
- Part of the current licence for Borssele is an underlying safety report. For operations to continue after 2033, the underlying safety report would have to be updated. In the safety report, the licence holder must demonstrate that the nuclear power plant can meet the technical safety requirements. For operations to continue after 2033, the licence holder must supplement the safety report and demonstrate, using a safety analysis and ageing calculations, that safety can be guaranteed after 2033.[1)]
- The new safety report must be assessed and approved by the ANVS. Depending on the outcome, this may require a modification to the licence.[1)]

Source: (1) Possible extension to the operations of the Borssele nuclear power plant, ANVS (https://www.autoriteitnvs.nl/onderwerpen/ mogelijke-verlenging-bedrijfsvoering-kerncentrale-borssele, last accessed on 1 May 2021). (2) The Nuclear Energy Act. (3) Borssele Nuclear Power Plant Covenant, Government Gazette (2006).

Impact on the local economy

The market participants indicated that they expect that construction of a nuclear power plant in the Netherlands could make a positive contribution to the Dutch economy

Number of local suppliers in the United Kingdom involved in the construction of Hinkley Point C



Source: How construction of Hinkley Point C is supporting companies in Britain, EDF (https://www.edfenergy.com/energy/nudear-new-build-projects/hinkley-point-c/for-suppliers-and-local-businesses/built-in-britain, last accessed on 22 April 2021).

"60% of the construction is civil engineering, which you can procure locally. That already produces 3,000 FTEs per plant during construction."

Local suppliers could be involved during the construction phase. Estimates range from around 20% to 80% of the total work

— Construction of a 1,000 MW nuclear power plant would require approximately 12,000 direct working years.[1)]

— The market participants indicated that large numbers of local suppliers could potentially be involved in the construction phase of a nuclear power plant. The proportion of local suppliers would depend on local knowledge and expertise, regulations and the financing structure, among other factors. Estimates by the market participants range from around 20% to 80%.

- In the construction of Hinkley Point C, approximately 64% of the work was contracted out to local companies.[2)] The market participants expect that a comparable percentage will be achieved for Sizewell.
- Partial financing through foreign export credit can result in lower levels of local procurement, since a higher level of procurement from the country concerned is often a condition of financing.

— Locally-contracted work is primarily civil engineering work. The market participants indicated that approximately 60% of the construction of a nuclear power plant consists of civil engineering work. Support activities such as catering, security, equipment, etc. could also be procured locally.

- Around 3,000 local suppliers were involved in the construction of Hinkley Point C.[2)]

— It is likely that less work would be procured locally if an SMR were to be built, because the intention would be for a significant amount of construction to take place in a factory.

Any necessary capacity, knowledge or skills not available locally could be imported, subject to conditions

— The market participants indicated that, in theory, any capacity, knowledge or skills that are not immediately available can be imported, but this depends on local legislation such as labour laws.

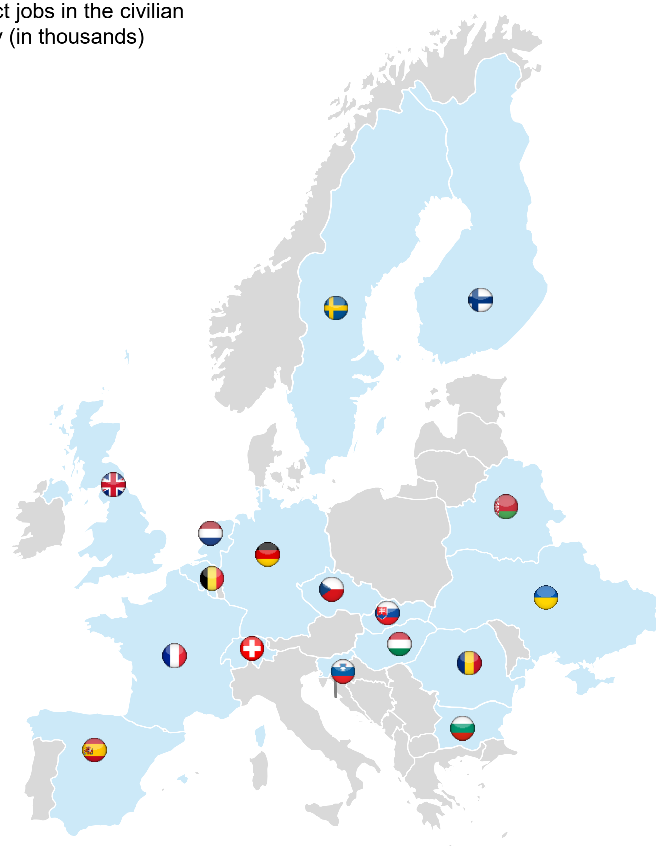
Source: (1) Measuring employment generated by the nuclear power sector, OECD-NEA & IAEA (2018). (2) How construction of Hinkley Point C is supporting companies in Britain, EDF (https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/for-suppliers-and-local-businesses/built-in-britain, last accessed on 30 May 2021).

After commissioning, a nuclear power plant could continue to contribute to the local economy and boost employment

Job creation in European countries that operate nuclear reactors[a)]

Number of direct jobs in the civilian nuclear industry (in thousands)

- 180.1
- 43.7
- 29.4
- 26.9
- 24.1
- 21.2
- 17.2
- 12.5
- 11.2
- 6.5
- 6.3
- 5.4
- 3.8
- 2.0
- 2.0
- 1.5-3.1
- Unknown[b)]



Key: Country that operates one or more nuclear reactors.

Note: (a) Situation in 2019. (b) The nuclear reactor was opened recently, so the exact number of jobs is not yet known.

Source: Info graphics, FORATOM (2020).

A nuclear power plant contributes to the local economy and boosts employment throughout its service life

— The operation of a 1,000 MW nuclear power plant would require an average of around 600 full-time jobs per year, based on a 50-year service life. Over the entire service life of a nuclear power plant of this size, around 1,000 indirect jobs[a)] would be created.[1)]

— In 2019, European nuclear power plants (118,019 MW in total)[2)] generated around 392,300 direct jobs in the civilian nuclear industry. They also generated around 786,500 indirect jobs, which means a total of around 1.2 million jobs were created.[3)]

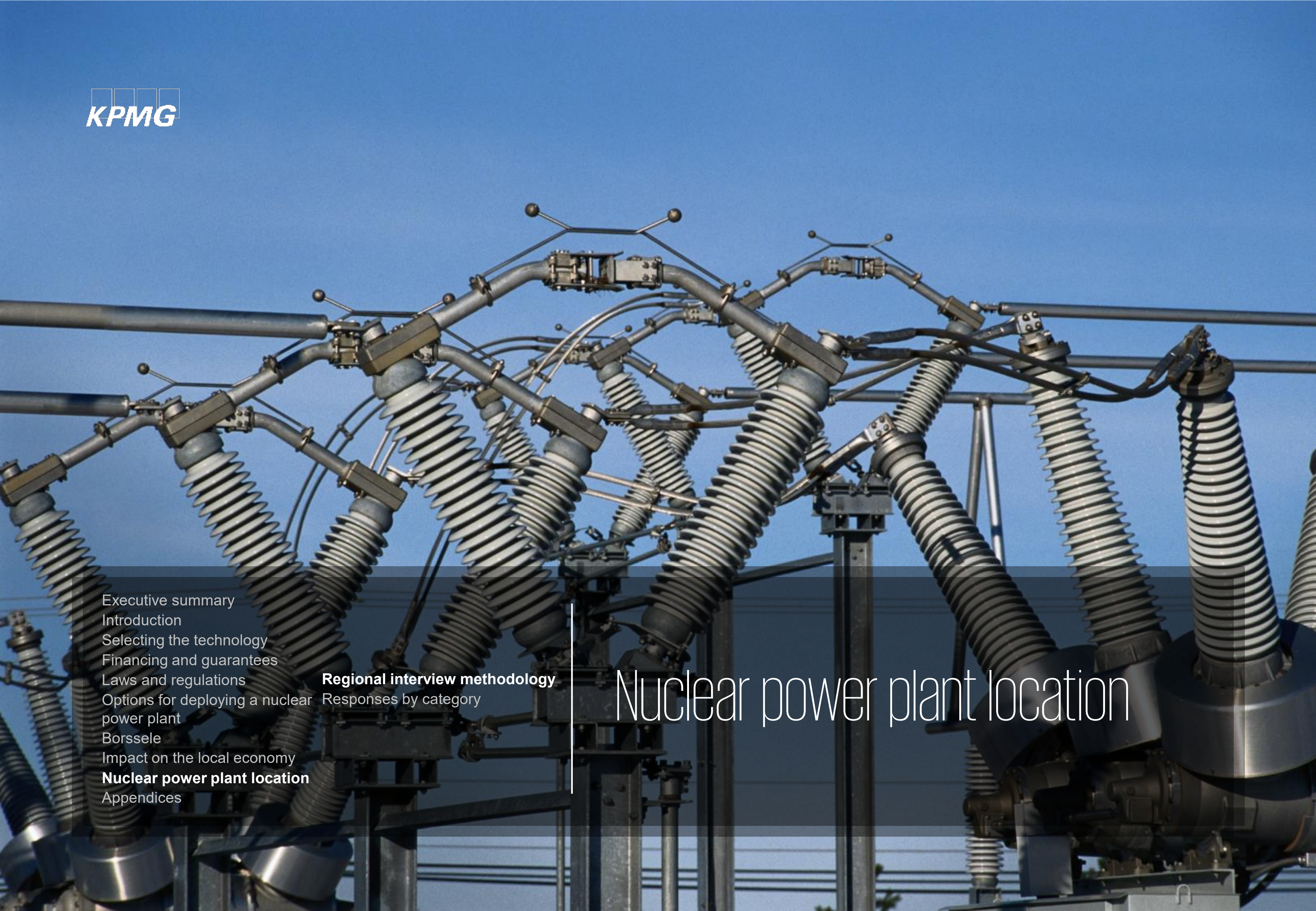
The jobs created would be mainly well-paid, highly-skilled jobs

— The market participants indicated that the jobs created by a nuclear power plant would be mainly well-paid, highly-skilled jobs. For some regions outside the Randstad region of the Netherlands, this could be a significant consideration.

- More than 500 people work directly for the Borssele nuclear power plant, and the plant also supports around 500 indirect jobs.[4)]
- Estimates of the total number of direct jobs in the Dutch nuclear sector vary, partly due to a definition issue. Nuclear Netherlands puts the number at around 1,500,[5)] FORATOM at around 2,000 (see the graphic on the left) and a Technopolis study assumes around 3,100 with an annual revenue of around EUR 1 billion.[5)]

Note: (a) Indirect jobs are jobs created in related economic sectors due to the activities of the nuclear industry, and jobs created as a result of spending by direct employees and by employees in the related economic sectors.

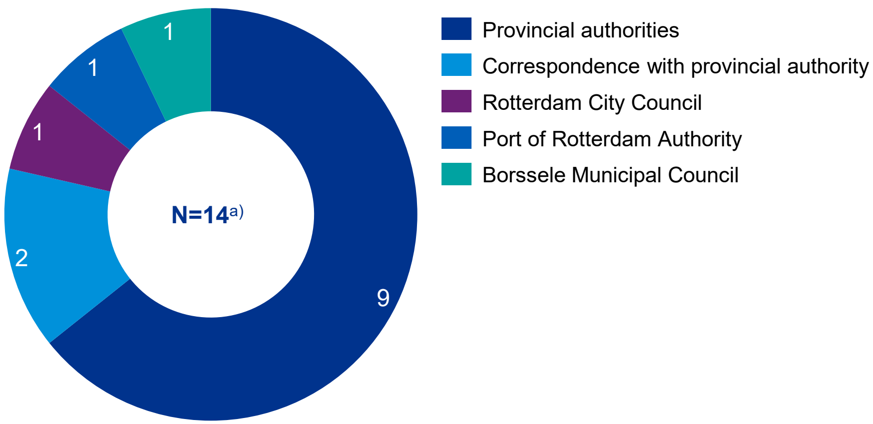
Source: (1) Measuring employment generated by the nuclear power sector, OECD-NEA & IAEA (2018). (2) Nuclear energy needed to achieve CO_2 targets, Nuclear Netherlands. (3) Info graphics, FORATOM (2020). (4) EPZ. (5) Nuclear knowledge infrastructure in the Netherlands, Technopolis (2016).



Nuclear power plant location

To answer the third question, "In which region is there interest in the construction of a nuclear power plant?", provincial authorities and two municipal authorities were interviewed

Schematic overview of the interviewed regions



Note: (a) The total number of organisations interviewed is 14, with the Borssele Municipal Council being present at the interview with the Zeeland provincial authority. These two organisations were therefore recorded jointly as a single response on page 140.

Source: (1) Nuclear power plant locations – Letter from the Minister of Economic Affairs, House of Representatives (1986). (2) Third Electricity Supply Structure Plan, House of Representatives (2009). (3) Motion by Member of Parliament Beckerman et al. ruling out Groningen as a nuclear power plant site (4 March 2021).

In terms of a possible location for a new nuclear power plant, the study considered more than just the locations identified by the government

— In the nuclear energy safeguard policy, Eemshaven, Maasvlakte I and Borssele were identified as potential locations for the use of nuclear energy.[1)] The policy was endorsed in the Third Electricity Supply Structure Plan.[2)] Eemshaven was recently ruled out following a motion in Parliament.[3)]

— The nuclear energy safeguard policy states that no developments may take place that would prevent or seriously impede the construction of nuclear power plants in these locations. The policy does not make any statements about the actual construction of nuclear power plants. It also does not necessarily mean that these regions have any interest in a new nuclear power plant.

— New technological developments (including in the area of safety) mean that other regions may also be worthy of consideration.

— For these reasons, following the Dijkhoff motion the Ministry of Economic Affairs and Climate Policy asked that all regions be approached.

A multi-step approach was chosen, with municipal authorities being approached only if there was reason to do so, based on identified locations and/or the response from the provincial authorities

— First, all provincial authorities were approached for an interview, then the relevant municipalities were selected for additional interviews based on the outcomes of the conversation with the associated provincial authority. This included the three potential locations for nuclear power plants that had already been identified.

— Following the first round of interviews with provincial authorities, contact was made with Borssele Municipal Council (representatives of which were present at the interview with the Zeeland provincial authority), Rotterdam City Council and the Port of Rotterdam Authority.

— No interview took place with Eemshaven, based on the Beckerman motion[1)] and the interview with the Groningen provincial authority (see page 145).

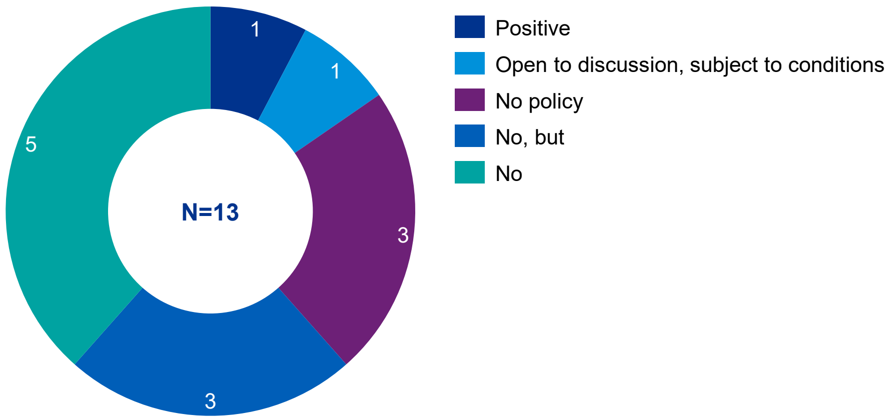
— No interviews took place with provincial authorities from Drenthe, Flevoland or Friesland, but written responses were received in two cases (see page 145).

— In addition, Rijkswaterstaat and TenneT were approached for feedback on the availability of cooling water and electricity infrastructure. No independent technical and/or planning research was performed.

Responses by category

The results of the interviews were categorised and validated by the organisations. The expectation is that there is one location that is the most promising

Schematic overview of responses from the interviewed organisations to the question of whether there is interest in the construction of a nuclear power plant



Note: (a) N=13, since the responses from the Borssele Municipal Council and the Zeeland provincial authority were merged. The results from Rotterdam City Council and the Port of Rotterdam were also counted as one.

The results of the interviews were divided into a number of categories and validated by the interviewed organisations

- This chapter sets out the results of the interviews with the regions. The relevant passages were submitted to the interviewed organisations for validation.
- The responses were divided into a number of categories ('positive', 'open to discussion, subject to conditions', 'no policy', 'no, but' and 'no'), and are described further on pages 140-146.
- In addition, a number of general, recurring themes that were discussed in several interviews are described on page 137. These are themes that were mentioned as considerations in several interviews, but not in all.

Based on the interviews, two possible locations can be defined, with one more promising than the other

- Based on the interviews and relevant preconditions, one possible location emerged where one or more large nuclear power plants and/or SMRs could be built: the municipality of Borssele in the province of Zeeland. This location has local support, appears most promising from a cooling water perspective, and seems to have no problems with grid connections.
- There is another location, in the province of North Brabant, where a nuclear power plant could possibly be built at some point in the future. The challenges for that location relating to local support, cooling water and integration appear to be more significant than for the possible location in Zeeland.

Based on the interviews, building multiple nuclear power plants (SMRs) in multiple locations in the Netherlands does not appear feasible

- The expectation of the regional authorities and market participants is that there would be insufficient public support for this option, even if the SMRs are situated on the site of a coal-fired power plant that has been shut down.
- However, multiple SMRs could potentially be built at a single location (see also page 58).

Local support, integration into spatial planning, innovation and job creation are key considerations for provincial authorities

"The densification of our environment and the increasing number of spatial challenges make this a difficult decision."

"Regardless of the decisions we make now, it's essential to remain open to innovations and innovative technologies that arise out of the energy transition."

"You must invest not only in development, but also in public debate."

"We should not exclude future technologies such as thorium in advance."

"The creation of new, high-quality jobs as the result of a project such as this is very appealing."

In the interviews with provincial authorities, a number of recurring themes emerged which are important in considering whether there is interest in the development of a nuclear power plant in the province[a)]

— **Local support**, among both politicians and residents, is broadly considered to be critical. Without local support, the construction of a nuclear power plant is considered neither achievable nor desirable. Support may be expressed through opinion polls, positions set out in policies, or statements by municipal or provincial councils.

— The provincial authorities indicated that fitting a nuclear power plant into **spatial planning** in several different parts of the country would be an enormous challenge, given urbanisation, areas becoming more densely populated, protected natural reserves, and many potentially suitable locations already being earmarked for other purposes.

— The importance of continuing to innovate and pursuing **new technologies and developments** is considered critical by the provincial authorities. In some cases, the provinces that were neutral or only mildly opposed to a nuclear power plant in their region indicated that they could be receptive to new developments. The thorium reactor was frequently mentioned as a possible new technology that could be considered after 2040.

— The relationship between nuclear energy and the **Regional Energy Strategies** was also raised. The integration of nuclear energy is seen as challenging, because RESs opting for a different solution/strategy have already been formulated. After 2030, there may be more scope in a number of provinces for nuclear energy as a carbon-neutral alternative.

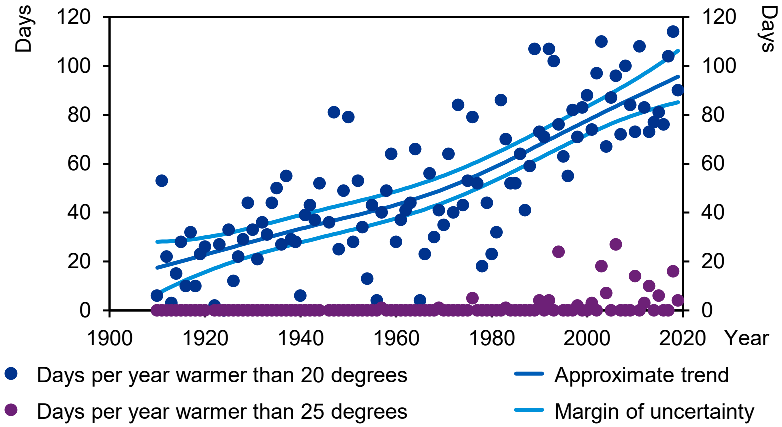
— **Local job creation, the impact on the business climate and the acquisition and maintenance of knowledge** were cited in multiple interviews as positive aspects that should be considered when making a decision.

Technical preconditions such as cooling water and electricity infrastructure are also important. These are explored in more detail on the following pages.

Note: (a) The themes listed were not all mentioned or discussed in every interview. The text on this page sets out a number of themes that recurred so frequently in the interviews that they could be taken as general topics.

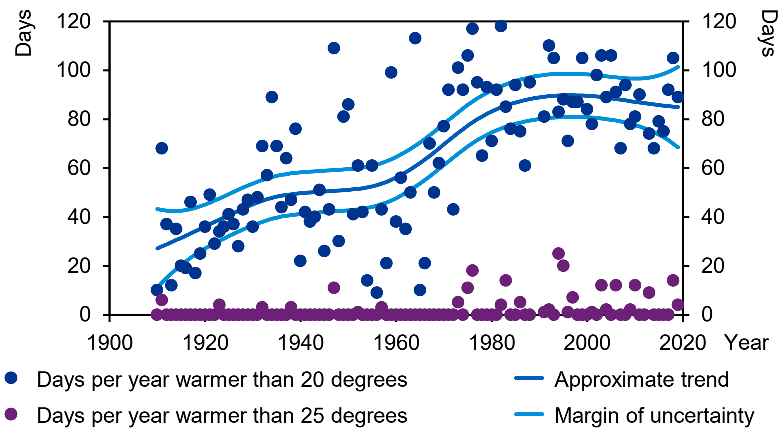
For any potential location, the availability of cooling water is essential, and from that perspective a location near the sea would probably be the most viable

Number of days with high water temperature, Rhine at Lobith



Source: (a) Surface water temperatures 1910-2019, Compendium for the Living Environment (www.clo.nl/nl056605, last accessed on 20 June 2021).

Number of days with high water temperature, Meuse at Eijsden and Borgharen



Source: (a) Surface water temperatures 1910-2019, Compendium for the Living Environment (www.clo.nl/nl056605, last accessed on 20 June 2021).

Locating a nuclear power plant next to a river, the IJsselmeer or another inland waterway is expected to be difficult

— In relation to the discharge of cooling water, surface water temperature is the most restrictive precondition for a new nuclear power plant. This is already the case now, and it is expected to become more restrictive in the future due to climate change. The effect on fish from the intake of cooling water is another possible issue to consider.

— Given their small volume, regional bodies of surface water (smaller bodies of water, overseen by a water board) cannot be considered for this purpose. Of the large bodies of water, the IJsselmeer is also not a desirable location, given its poor through-flow and the maximum permitted rise in water temperature.

— In addition, nearly all of the large rivers in the Netherlands face challenges relating to surface water temperature and are not expected to have sufficient thermal capacity to serve as cooling water for a large nuclear power plant.

— If an SMR is selected, it can be investigated whether it could be located at the site of a coal-fired power plant that is to be disconnected, to take advantage of the thermal capacity of the cooling water that would be freed up. However, given the restrictive situation in terms of surface water temperature and the fact that each new initiative (even if it replaces an existing power plant) must be assessed against the legal framework, it cannot be taken for granted that there will be scope at such sites for the use of cooling water.

If a decision is made to build a new nuclear power plant, it seems that a coastal location offers the most opportunities for integration.

— However, when the exact location is known it will be necessary to examine specifically the precise local effects of the cooling water on the ecology (particularly the consequences of cooling water intake on fish and the consequences of the heat discharge on the ecosystem).

This is an explicitly broad assessment of the overall picture, based on general information and principles. Assessing the effects on water quality for licensing purposes will, in due course, require specific and careful ecological consideration for each potential location.

For any potential location, a site close to the main power grid with little congestion would be preferable, particularly for a large nuclear power plant

Map of the Dutch power grid, 2020[1)]

For a large nuclear power plant, high grid capacity is required. A location close to the main power grid would be the most cost-effective with relatively easy integration

- The market participants indicated that for a large nuclear power plant (1,200–1,500 MW), a strong grid infrastructure would be required.
- The Netherlands has good grid infrastructure, with the main power grid (380 kV, the red line in the image on the left) able to handle capacity of up to 2,500 MW per high-voltage corridor.[a)]
- The market participants indicated that situating a large nuclear power plant along the main power grid is obvious. Such a location is expected to require minimal infrastructure investment and relatively easy integration, since little to no new infrastructure would have to be built.
  - The key figure for the cost of a standard double-circuit connection is approximately EUR 10 million per kilometre.[2)]
- With large nuclear power plants, local congestion must be considered, for example near landing locations for offshore wind energy (white dotted lines).
- SMRs have more flexibility because of their lower power output (10-300 MW) and the ease of integrating them into the grid is comparable to that of smaller coal-fired power plants (such as the former Maasvlakte power plants).

Neither of the two potential locations is expected to face congestion challenges

- At Borssele, there appears to be capacity for one or two large nuclear power plants (1,200-1,500 MW) due to the already-planned expansion of the 380 kV grid (red dotted line). The potential electrification of local industry could offer even more capacity.[b),c),3)]
- There also appears to be sufficient transmission capacity in West Brabant (Moerdijk/Geertruidenberg) due to the same planned expansion.[4)]
- For both locations, the relationship with and dependence on possible future developments applies on both the production side and the demand side, in addition to what has already been taken into account.

Note: (a) Based on a dual-circuit 4 kA connection not set out in a loop. These four kiloamperes correspond to 2,635 MVA (approximately 2,500 MW). In principle, with a dual circuit, twice this capacity would be available, but to ensure a single fault reserve, the connection may only be loaded to half the rated capacity. With a dual corridor, in principle, four times this capacity would be available, but the connection may only be loaded up to three times this capacity. (b) After the expansion, there will be approximately 6,500 MW of grid capacity. Taking offshore wind (around 3,500 MW) and the current Borssele nuclear power plant (around 500 MW) into account, there will be 3,000 MW left over. Possible future developments (on both the production side and the demand side) above this capacity demand, particularly from offshore wind, could have consequences for grid capacity. (c) If two nuclear power plants were connected, a new transformer station would have to be built, to ensure that an outage at the station would not result in disruption to the electricity supply. TenneT applies the rule of thumb of a maximum of 5.5 to 6 GW of production capacity per station.

Source: (1) Map of the Dutch power grid as at 30 October 2020, TenneT TSO BV (2020, reproduced with consent). (2) The energy system of the future: Comprehensive Infrastructure Survey 2030-2050, Netbeheer Nederland (2021). (3) TenneT. (4) Why not turn the Amercentrale into a nuclear steam generator, instead of demolishing it?, AD (17 January 2021).

The following regions gave a positive response to the question of whether there was interest in the construction of a nuclear power plant

“Zeeland is comfortable with the idea of a new nuclear power plant”

Omroep Zeeland, 5 March 2021

“Nuclear energy can play a supplementary, supporting role in the decarbonisation of the Dutch energy and raw materials supply”

Study conducted by eRisk Group on behalf of the Zeeland provincial authority into the possible role of nuclear energy, December 2020

Participant: Zeeland and Borssele Municipal Council

Key considerations:

— The provincial authority has had positive experiences with the existing nuclear power plant and is a supporter of keeping nuclear energy in the energy mix. There is therefore broad political support for building a nuclear power plant.

— The population has a positive opinion and there is broad public support. The local population is accustomed to living in the vicinity of a nuclear power plant and has not experienced any significant problems with it.

— A great deal of local knowledge and expertise with regard to nuclear energy is already present and there is a desire to maintain it, along with the existing value chain. Creating/maintaining high-value local jobs is also a key driver.

Other considerations:

— The region considers the current financing/ownership structure of the Borssele nuclear power plant to be extremely inequitable and undesirable, and will make improving this structure a condition of any new plant in the region.

— The provincial authority expects a future increase in the electrification of local industry, which could absorb additional local supply in the grid.

The following organisations gave a response of 'open to discussion, subject to conditions' to the question of whether there was interest in the construction of a nuclear power plant

"The generation of nuclear energy is welcome. We're also exploring the potential of thorium"

Administrative Agreement 2020-2023

"The role of nuclear energy in the transition of North Brabant"

Report by the Netherlands Organisation for Applied Scientific Research (TNO), 1 February 2020

Participant: North Brabant

Key considerations:

- The Administrative Agreement (2020-2023) indicated that nuclear energy is welcome. The provincial authority indicated that it expects nuclear energy to play a role in the energy mix after 2030, up to 2050, which could help achieve CO_2 targets.
- At the time of our request for written verification, there were discussions in North Brabant about the formation of a new governing coalition.

Other considerations:

- North Brabant is a crowded province (with many closely-packed interests and challenges), making it difficult to identify a suitable location.
- According to the provincial authority, there could be opportunities in relation to knowledge acquisition and research, whereby knowledge about nuclear energy could be connected to or supported by existing knowledge infrastructure in North Brabant, and could, in the long term, contribute to the use of nuclear energy in the energy mix.
- North Brabant commissioned TNO to conduct an exploratory study into the possible role of nuclear energy in the province of North Brabant. The resulting report suggested that if the province was interested in building a nuclear power plant, it should support the development of Generation IV technologies such as thorium.

Source: (1) Administrative Agreement 2020-2023: "Our Brabant: Intelligent and Decisive, Together". (2) The role of nuclear energy in the energy transition of North Brabant, TNO (2020).

The following regions indicated that they have no policy on the matter, in response to the question of whether there was interest in the construction of a nuclear power plant

"The Overijssel provincial authority is organising an online exchange of knowledge about nuclear energy and thorium MSRs, initiated by a number of groups within the provincial council"

PS Overijssel, 21 October 2020

"Municipalities in the province are not enthusiastic about nuclear energy generation"

RTV Utrecht, 16 November 2020

Participant: Overijssel

Key considerations:

— The provincial authority has no formal policy on nuclear energy. The provincial authority indicated that the policy on the location of a nuclear power plant is up to the government.

Other considerations:

— The innovation and development of new technologies as part of the energy transition has the attention of the provincial authority. In particular, it is interested in the development of thorium and SMRs.

Participant: Utrecht

Key considerations:

— The provincial authority has no formal policy on nuclear energy. The provincial authority indicated that the policy on the location of a nuclear power plant is up to the government.

— At the request of the Provincial Council, a study was conducted into how the municipalities of Utrecht view nuclear energy. From the responses, it appears that the majority of municipalities have no formal policy on the matter, have no interest in nuclear energy, or cannot take a position at this stage.[1)]

Other considerations:

— Given the density of urban areas and infrastructure and the presence of a variety of nature reserves, the provincial authority expects that integration would be extremely difficult.

Participant: South Holland

Key considerations:

— The provincial authority has no formal policy on nuclear energy. In accordance with the Nuclear Energy Act, nuclear energy falls under the jurisdiction of the central government. Consequently, it is for the central government to develop a policy on the matter. If the government chooses South Holland (in relation or in addition to the already-identified potential location of Maasvlakte II) as a possible location for a nuclear power plant, the provincial authority will be involved in the spatial planning process.

Other considerations:

— The provincial authority indicated that space is extremely scarce – not only in terms of physical space, but also in terms of environmental space.

Source: (1) Request for opinions on nuclear energy among the municipalities of the province of Utrecht, Utrecht provincial authority (2021).

The following regions gave a response of 'no, but' to the question of whether there was interest in the construction of a nuclear power plant (1/2)

"A nuclear power plant in Gelderland? Not a single municipality would put its hand up right now"

De Stentor, 21 April 2021

Participant: Gelderland

Key considerations:

- Key considerations: There is currently no interest in the building of a nuclear power plant. The Provincial Council has also indicated as such.
- No thought has been given yet to formulating a policy beyond 2030. The provincial authority will follow the national policy for the period after 2030.

Other considerations:

- The provincial authority has approached the municipalities of Gelderland to identify their views on the issue. This survey has not yet been fully completed, but initial responses show that the majority of municipalities have no formal policy on the matter, have no interest in nuclear energy, or cannot take a position at this stage.

"The residents of North Holland don't need to worry about a nuclear power plant being built in their backyard"

Noordhollands Dagblad, 12 November 2018

Participant: North Holland

Key considerations:

- There is no interest in the building of a nuclear power plant. This was confirmed by a motion in 2018[1)] and is still endorsed.
- Developments in the area of new technologies such as thorium will be monitored.

Other considerations:

- The provincial authority supports the development of the Pallas reactor for medical isotopes.

Source: (1) 'No new nuclear power plant in North Holland', motion number M46-2018 (2018).

The following regions gave a response of 'no, but' to the question of whether there was interest in the construction of a nuclear power plant (2/2)

"The Limburg provincial government sees no reason at present to investigate the idea of a nuclear power plant in Limburg"

1Limburg, 3 March 2021

Participant: Limburg

Key considerations:

— The province of Limburg does not currently see any reason to investigate a potential location for a conventional (Generation III+) nuclear power plant in Limburg. After all, the central government has already identified a number of locations along the coast for potential new nuclear power plants. If the Main Energy Structure Programme shows that these identified locations do not provide sufficient room for the necessary nuclear energy capacity, the central government must make a decision about an additional location. If at that time the central government thinks an additional location would be desirable, the provincial government will consider the issue.

— The provincial authority will monitor research into new, smaller forms of nuclear energy and molten salt reactors that use thorium, primarily with a view to securing regional security of supply.

Other considerations:

— Given its border location, for the province of Limburg it is essential to maintain good relations with neighbouring regions. A potential site for a conventional nuclear power plant on the border would involve an additional, complicating dimension.

The following regions gave a response of 'no' to the question of whether there was interest in the construction of a nuclear power plant (1/2)

"Outcry in Groningen after Mark Rutte's statements about a nuclear power plant in Eemshaven"

EenVandaag, 1 March 2021

"Until now, Drenthe politicians never saw nuclear energy as a serious option"

RTV Drenthe, 13 November 2019

"Flevoland doesn't want a nuclear power plant until the waste issue is resolved"

Omroep Flevoland, 4 March 2021

Participant: Groningen

Key considerations:

— The Groningen provincial authority is against the building of a nuclear power plant and stated that there is insufficient public support.

— There are various reasons for this, such as plans to use the previously designated area in Eemshaven for other purposes (manufacturing industry, green energy), the issues around nuclear waste, and recent experiences in Groningen with extracting gas and the energy transition.

Participant: Drenthe

Key considerations:

— The provincial authority indicated in writing that it would be both technically and politically impossible, with no available locations and no public support within the province.

Participant: Flevoland

Key considerations:

— The provincial authority indicated in writing that a potential location for a nuclear power plant in Flevoland was investigated in the past. The investigated locations fell through and the Provincial Council therefore took the view that no nuclear power plant would be built in Flevoland.

Participant: Friesland

Key considerations:

— The Friesland provincial authority did not respond to the request to take part in this study, either verbally or in writing.

— Based on this lack of response and recent media statements, it appears that Friesland does not want a nuclear power plant.

The following regions gave a response of 'no' to the question of whether there was interest in the construction of a nuclear power plant (2/2)

"Investigate opportunities for mini nuclear power plants at Maasvlakte II"

AD, 21 February 2020

Participant: Rotterdam City Council

Key considerations:

— In the Rotterdam Climate Agreement, signed in 2019, the main strands were offshore wind, large-scale electrification and green hydrogen. The spatial requirements for these strands are large, and take priority. Nuclear energy is not part of the energy mix in the Rotterdam Climate Agreement.

— The City Council has conducted a study into the spatial impact of the potential construction of a nuclear power plant, given that Rotterdam is an identified location for the generation of nuclear energy. The provisional results show that, in view of the policy commitment to give priority to developments around hydrogen, there is no additional space for a nuclear power plant.

— The Rotterdam City Council will give priority for the use of the scarce space in the port to the creation of a hydrogen hub and the other projects in the Rotterdam Climate Agreement, over facilitating a nuclear power plant.

Appendices

The following market participants took part in the market consultation

List of market participants interviewed

ANVS
APG
Aviva Investors
Bechtel
CEZ
COVRA
Dalmore Capital
Deutsche Bank
Doosan
EDF
EDF Energy UK
EIB
Eneco
Energy Impact Center
Engie (Tractebel)
EON
EPZ
Fennovoima
Fluor
Hitachi GE
Hyundai
KEPCO/KHNP

KEXIM
Macquarie
NRG
NuScale
PGGM
PZEM
Rijkswaterstaat
Rolls-Royce
RWE
Seaborg
Siempelkamp
TenneT
Terrestrial
Thorizon
UK Government, Nuclear Dept.
Urenco
Vattenfall Europe
Westinghouse

Independent industry expert

Most relevant sources

List of most relevant sources

Advances in small modular reactor technology developments, IAEA (2020).

Country profiles, World Nuclear Association (https://www.wodd-nuclear.org/information-library/country-profiles.aspx, last accessed on 28 May 2021).

The role of nuclear energy in the energy transition of North Brabant, TNO (2020).

Removal of energy installations (Part II): Nuclear installations, van Beuge (2016).

Economics and finance of Small Modular Reactors: A systematic review and research agenda, Mignacca & Locatelli (2020).

Economics and finance working group report, Canada's SMR Roadmap (2018).

The energy system of the future: Comprehensive Infrastructure Survey 2030-2050, Netbeheer Nederland (2021).

2019 Annual Report, COVRA (2019).

2020 Annual Report, COVRA (2020).

2020 Climate and Energy Outlook, PBL (2020).

Modern financial models of nuclear power plants, Terlikowski et al. (2019).

Non-baseload operation in nuclear power plants, IAEA (2018).

Nuclear power in the European Union, World Nuclear Association (https://www.wodd-nuclear.org/information-library/country-profiles/others/european-union.aspx, last accessed on 28 May 2021).

Possible role of nuclear in the Dutch energy mix of the future, ENCO (2020).

Power Reactor Information System, IAEA (https://pris.iaea.org/PRIS/home.aspx, last accessed on 1 May 2021).

Projected costs of generating electricity 2020 edition, IEA & OECD-NEA (2020).

Reactor database, World Nuclear Association (https://www.wodd-nuclear.org/Information-Library/Facts-and-Figures/Reactor-Database.aspx, last accessed on 28 May 2021).

Reduction of capital costs of nuclear power plants, OECD-NEA (2000).

Review of Generation IV nuclear energy systems, IRSN (2015).

Small modular reactors: challenges and opportunities, OECD-NEA (2021).

Synthesis on the economics of nuclear energy, William D'haeseleer for the European Commission (2013).

Systemic impact of nuclear power plants, in Climate-neutral energy scenarios in 2050, Kalavasta & Berenschot (2020).

Technical and economic aspects of load following with nuclear power plants, OECD-NEA (2011).

Technology roadmap update for Generation IV nuclear energy systems, GIF (2014).

The cost of decommissioning nuclear power plants, OECD-NEA (2016).

The future of nuclear energy in a carbon-constrained world: an interdisciplinary MIT study, MIT (2018).

Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020).

Laws and regulations, ANVS (autoriteitnvs.nl/onderwerpen/wet—en-regelgeving, last accessed 10 June 2021).

World nuclear performance report 2020, World Nuclear Association (2020).

Sources used for various recent Generation III+ projects

Sources used to identify information about various recent Generation III+ projects	
Reactor	**Sources[a)]**
General (covering several reactors)	• Unlocking reductions in the construction costs of nuclear: a practical guide for stakeholders, OECD-NEA (2020) • Modern financial models of nuclear power plants, Terlikowski et al. (2019) • https://www.world-nuclear.org/information-library/country-profiles.aspx
Flamanville 3	• https://www.world-nuclear-news.org/Articles/EDF-warns-of-added-costs-of-Flamanville-EPR-weld-r • https://www.edf.fr/en/the-edf-group/dedicated-sections/investors-shareholders/financial-and-extra-financial-performance/financial-results • https://www.edf.fr/en/la-centrale-nucleaire-de-flamanville-3-epr/flamanville-3-nuclear-power-plant-epr • https://www.edf.fr/en/the-edf-group/producing-climate-friendly-energy/nuclear-energy/our-expertise/decommissioning
Hinkley Point C	• Hinkley Point C: Value for Money Assessment, UK government (2016) • https://world-nuclear-news.org/Articles/Hinkley-Point-C-delayed-until-at-least-2026 • https://www.gov.uk/government/collections/hinkley-point-c • https://www.gov.uk/government/organisations/nuclear-decommissioning-authority
Hanhikivi	• Nuclear Legislation in OECD and NEA countries: Finland, OECD-NEA (2019) • https://world-nuclear-news.org/Articles/Hanhikivi-1-design-documents-submitted-to-Finnish • https://world-nuclear-news.org/Articles/Fennovoima-revises-Hanhikivi-1-schedule-and-costs • https://rosatom.ru/en/press-centre/news/rosatom-and-framatome-sign-instrumentation-and-control-design-support-contract-for-hanhikivi-1-npp-f/ • https://www.reutersevents.com/nuclear/finland-pools-resources-streamline-plant-decommissioning • https://www.stuk.fi/web/en/about-us
Olkiluoto 3	• https://www.edf.fr/en/the-edf-group/dedicated-sections/press/all-press-releases/update-on-strategic-partnership-between-edf-and-areva • https://world-nuclear-news.org/Articles/TVO-cleared-for-fuel-loading-at-Finnish-EPR
Vogtle	• https://www.world-nuclear-news.org/Articles/Duo-of-milestones-at-US-AP1000-units • https://www.world-nuclear-news.org/Articles/Progress-at-Vogtle,-but-cost-forecast-rises
Barakah	• Third national report on compliance with the obligations of the joint convention on the safety of spent fuel management and on the safety of radioactive waste management, United Arab Emirates (2017) • https://www.reuters.com/article/us-emirates-nuclearpower-exclusive-idUSKBN1GY1XT • https://www.oecd-nea.org/ndd/workshops/wpne/presentations/docs/4_2_KIM_%20Barakah%20presentation.pdf
Akkuyu	• Global nuclear developments: insights from a former IAEA nuclear inspector, Ikonomou (2020) • https://www.oecd-nea.org/ndd/workshops/wpne/presentations/docs/4_1_Cometto_Akkuyu.pdf • https://rosatom.ru/en/press-centre/news/construction-of-akkuyu-npp-unit-3-turkey-begins/ • https://www.wano.info/news-events/inside-wano/plant-story/akkuyu-nuclear-power-plant-in-turkey
Paks	• https://rosatom.ru/en/press-centre/news/the-full-package-of-documents-for-obtaining-a-license-for-the-construction-of-paks-2-npp-has-been-su/ • https://mvm.hu/mvm-group/mvm-paks-nuclear-power-plant-ltd/?lang=en • https://www.power-technology.com/projects/paks-ii-nuclear-power-plant/

Note: (a) The links (websites) were last accessed on 14 June 2021.

Exchange rates used

Converting amounts to EUR

— All amounts in this report are given in EUR. The exchange rates of the European Central Bank as at 30 April 2021 were used.[1)]

EUR exchange rates as at 30 April 2021	
Currency	**Exchange rate**
USD	0.8277
GBP	1.1512
CAD	0.6741

Source: (1) Euro foreign exchange reference rates, European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/index.en.html, last accessed on 22 May 2021).