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Financing new nuclear

Governments paying the price?

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About this report

This report, commissioned by WISE, describes the results of an investigation into the realised cost, budget overruns, and lead time escalations of six recent nuclear power plant construction projects.

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Summary

WISE Netherlands commissioned this research to provide a clear picture of the current-day construction costs of a nuclear power plant. WISE Netherlands is specifically interested in the government’s share of financing the construction of nuclear power plants, a price to be paid by the taxpayer. The research request follows up on the Dutch government's intention to build two (or even four) new nuclear power plant units in the Netherlands. The current nuclear site at Borssele has been designated as the preferred location for the first two units (Borssele 2-3).

Nuclear power plant construction is not business as usual in a privatised energy market. Governments regularly intervene heavily, either through direct financing, providing loans and guarantees, or via risk-sharing and interference with price measures.

This raises the question of how much a government will have to pay when planning a new nuclear power plant. Based on recent examples, what is the range of cost estimates that can be expected?

To this end, this study aims to provide a detailed analysis of the actual costs and timelines of typical and recent large-scale construction projects of new nuclear power plants. Six nuclear power plants have been selected for this research. They are among the latest to be put into operation globally:

- Olkiluoto 3 (Finland),
- Shin Hanul 1-2 (South Korea),
- Barakah 1-4 (United Arab Emirates),
- Vogtle 3-4 (United States),
- Flamanville 3 (France) and
- Hinkley Point C 1-2 (United Kingdom).

The six power plants use Generation III+ Pressurized Water Reactors. The technologies are from France, the US and South Korea. This matches the technology choices the Dutch government is exploring.

The outcome of the research is compared to the proposals for Borssele 2-3 and Dukovany 5-6. The latter is a Czech project for which the preferred bidder has just recently been chosen: Korea Hydro & Nuclear Power Company (KHNP), the nuclear subsidiary company of Korea Electric Power Corp (KEPCO). This is an interesting example because, on the one hand, KEPCO has shown its ability to realise nuclear construction projects domestically in South Korea, at very cost-competitive prices. On the other hand, its bidding price for the project in Europe lies considerably higher, almost a factor of 4. This may point to additional costs caused by first-of-a-kind characteristics.

The research conducted for WISE calculated factors for both budget overruns and lead time escalations. Both these exceedances are expressed in multiplication factors, to emphasise how many times the initially planned construction cost and construction period have gone over the top.

Based on the data of the six construction projects case studies, the calculated factors are:

Factor	Low	Mean	High
Budget overrun factor	1.6	3.1	6.0
Lead time escalation factor	1.7	2.6	4.6

The identified realised construction costs (in EUR billion) are:

Project	Budgeted cost (EUR bln)	Realised cost (EUR bln)	Budget overrun (EUR bln)	Budget overrun factor
Olkiluoto-3	3.2	11.0	7.8	3.4
Shin Hanul 1-2	4.0	6.4	2.5	1.6
Barakah 1-4	14.1	24.0	9.9	1.7
Vogtle 3-4	9.2	33.9	24.7	3.7
Flamanville 3	3.3	19.9*	16.6*	6.0*
Hinkley Point C 1-2	24.7	46.1*	21.4*	1.9*

Note: * Projected values

The identified realised construction lead times (in years) are:

Project	Scheduled lead time (Years)	Realised lead time (Years)	Lead time escalation (Years)	Lead time escalation factor
Olkiluoto-3	3.9	17.7	13.8	4.6
Shin Hanul 1-2	5.7	11.7	6	2.1
Barakah 1-4	5.9	12.1	6.2	2
Vogtle 3-4	8.5	14.9	6.3	1.7
Flamanville 3	5.1	17.1*	12.0*	3.4*
Hinkley Point C 1-2	6.6	12.1*	5.5*	1.8*

Note: * Projected values

Based on the results from the six case studies, it has been calculated what this would mean for the preparation of Dukovany 5-6 and Borssele 2-3.

According to the Dukovany 5-6’s bid, the project is budgeted at EUR 15.8 billion and a lead time of 12.8 years. The analysis shows that this initially budgeted cost is close to the mean value that is expected based on the case studies. The calculated low expectation is considered unrealistic and ruled out. The mean expectation would be a realised cost of EUR 17.4 billion and a budget overrun factor of 1.1. The high expectation would be a realised cost of EUR 27.3 billion with a budget overrun factor of 1.7.

For Borssele 2-3 a cost estimate is not available yet. The Dutch government intends to make a reserve of EUR 7 billion (for two units), but the financing model has not been chosen, and the proposed budget reserve is awaiting parliamentary approval. Therefore, the analysis took a rough estimate of the available budget (EUR 19 billion) based on the proposed reserve to enable the exploration of the expected cost range. An initial schedule mentions Borssele 2-3 to start operations in July 2035.

The calculated low expectation is considered unrealistic and ruled out. The mean expectation would be a realised cost of EUR 26.1 billion and a budget overrun factor of 1.4. The high expectation would be a realised cost of EUR 41.0 billion with a budget overrun factor of 2.2.

Several financing models have been found. All six cases have a mix of corporate and government financing. Barakah 1-4 and Flamanville 3 have the highest share of government contributions. Olkiluoto 3 and Hinkley Point C 1-2 the lowest. Olkiluoto 3 and Vogtle 3-4 have a cooperative financing model in which the power off-takers participate. In Finland, this is called the Mankala model, and the participants are both corporations and governments. In the US, the participants are also corporations and governments, but also customer cooperatives.
Government price regulation in the form of a Contract for Difference, which guarantees the operator a minimum price, supports the financing of Hinkley Point C 1-2. A price measure is not known for the other five cases. The proposed Dukovany 5-6 project takes three (EU-approved) price measures: direct price support via a power purchasing agreement (PPA), a two-way Contract for Difference, and a partly closed price market (30%) through government auctioning.

The government's participation in the ultimate beneficial ownership of the project companies varies from roughly a quarter to full ownership. On average, the government participation is 64.3%. Remarkable is the large government participation in the projects in Western countries such as France (100%) and the UK (90.8%). Also remarkable is the government participation in the projects in Finland (24.3%) and the US (24.3%), which have only private companies as project sponsors.

For Dukovany and Borssele, the cost per kilowatt (electric) is taken from the case studies and varies from EUR 2,324 (low) to 9,665 (mean) and 15,175 (high expectation). The Dukovany bid translates into EUR 8.778 and the Borssele rough budget estimate into EUR 7,037 per kilowatt (electric).

The International Energy Agency (IEA) uses a value of EUR 6,230 per kWe for nuclear in its scenarios. The 2021 KPMG study identified an average cost per kW installed capacity of EUR 4,973 per kW. The 2022 Witteveen+Bos study identified an average cost of EUR 7,959 per kW but applied a cost of EUR 3,520 per kW in its scenarios. Since the current research identified a mean cost of EUR 9,665 per kWe, it is clear that updating the actual cost of the six projects was necessary. This outcome provides the opportunity to update, reassess, and improve the cost estimates for Borssele 2-3. Higher cost estimates may also lead to changed insights into cost-effectiveness by comparing scenarios of the future energy mix.

The costs per kilowatt (electric) for renewable energy sources range from 1,050 (solar PV) to 1,850 (wind onshore) and 3,620 (wind offshore). This study identified a mean cost per kilowatt (electric) for nuclear power plants of EUR 9,665. This price difference makes solar and wind highly favourable compared to nuclear when considering cost efficiency, lead times and financial risk.

This research identified an average construction lead time of 14.3 years. The expected construction lead times for Dukovany and Borssele are taken from the case studies and are in the range of 11.7 (low) to 17.7 years (high expectation). For Dukovany 5-6 this would result in a commercial operation date between December 2036 and December 2042; and for Borssele 2-3 a commercial operation date between September 2039 and September 2045.

A new nuclear power plant will come too late to result in carbon savings that will contribute to the climate targets for 2040 and earlier. Clearly, a contribution to the 2035 target of carbon-neutral electricity production in the Netherlands is out of sight. Potentially, Borssele 2-3 could contribute to reaching the 2050 climate targets. Whether this may be a significant contribution is a question open to further research.

Samenvatting

WISE Netherlands heeft onderliggend onderzoek laten uitvoeren om een helder beeld te krijgen van de huidige bouwkosten van een kerncentrale. WISE Netherlands is specifiek geïnteresseerd in het aandeel van de overheid in de financiering van de bouw van kerncentrales, een prijs die door de belastingbetaler betaald moet worden. De onderzoeksvraag is een vervolg op het voornemen van de Nederlandse overheid om twee (of zelfs vier) nieuwe kerncentrales in Nederland te bouwen. De huidige kerncentrale in Borssele is aangewezen als voorkeurslocatie voor de eerste twee eenheden (Borssele 2-3).

De bouw van kerncentrales is geen *business as usual* in een geprivatiseerde energiemarkt. Overheden grijpen regelmatig stevig in, hetzij via directe financiering, het verstrekken van leningen en garanties, hetzij via risicodeling en inmenging met prijsmaatregelen.

Dit roept de vraag op hoeveel een overheid moet betalen bij het plannen van een nieuwe kerncentrale. Wat is op basis van recente voorbeelden de bandbreedte van de te verwachten kostenramingen?

Daartoe beoogt deze studie een gedetailleerde analyse te geven van de werkelijke kosten en tijdlijnen van typische en recente grootschalige bouwprojecten van nieuwe kerncentrales. Voor dit onderzoek zijn zes kerncentrales geselecteerd. Ze behoren tot de laatste die wereldwijd in bedrijf zijn genomen of zullen worden genomen:

- Olkiluoto 3 (Finland),
- Shin Hanul 1-2 (Zuid-Korea),
- Barakah 1-4 (Verenigde Arabische Emiraten),
- Vogtle 3-4 (Verenigde Staten),
- Flamanville 3 (Frankrijk) en
- Hinkley Point C 1-2 (Verenigd Koninkrijk).

De zes centrales gebruiken *Generation III+ Pressurized Water Reactors*. De technologieën komen uit Frankrijk, de VS en Zuid-Korea. Dit komt overeen met de technologische keuzes die de Nederlandse overheid verkent.

De uitkomst van het onderzoek wordt vergeleken met de voorstellen voor Borssele 2-3 en Dukovany 5-6. Laatstgenoemde is een Tsjechisch project waarvoor onlangs de voorkeursbieder is gekozen: Korea Hydro & Nuclear Power Company (KHNP), het nucleaire dochterbedrijf van Korea Electric Power Corp (KEPCO). Dit is een interessant voorbeeld omdat KEPCO enerzijds heeft laten zien dat het in staat is om nucleaire bouwprojecten in Zuid-Korea te realiseren tegen zeer concurrerende prijzen. Anderzijds ligt de geboden prijs voor het project in Europa aanzienlijk hoger, bijna een factor 4. Dit kan wijzen op extra kosten die worden veroorzaakt door *first-of-a-kind* kenmerken.

Het onderzoek dat voor WISE is uitgevoerd, berekende factoren voor zowel budgetoverschrijdingen als escalaties van de looptijd van de bouw. Beide overschrijdingen worden uitgedrukt in vermenigvuldigingsfactoren, om te benadrukken hoeveel de oorspronkelijk geplande bouwkosten en bouwperiode zijn overschreden.

Gebaseerd op de gegevens van de zes casestudies van de bouwprojecten, zijn de berekende factoren:

Factor	Laag	Gemiddeld	Hoog
Budget-overschrijdingsfactor	1.6	3.1	6.0
Looptijd-escalatiefactor	1.7	2.6	4.6

De gevonden gerealiseerde bouwkosten (in miljarden euros) zijn:

Project	Begrote kosten (EUR mrd)	Gerealiseerde kosten (EUR mrd)	Budget-overschrijding (EUR mrd)	Budget-overschrijdings-factor
Olkiluoto-3	3.2	11.0	7.8	3.4
Shin Hanul 1-2	4.0	6.4	2.5	1.6
Barakah 1-4	14.1	24.0	9.9	1.7
Vogtle 3-4	9.2	33.9	24.7	3.7
Flamanville 3	3.3	19.9*	16.6*	6.0*
Hinkley Point C 1-2	24.7	46.1*	21.4*	1.9*

Noot: * Geprojecteerde waarden

De gevonden gerealiseerde looptijden (in jaren) zijn:

Project	Geplande looptijd (Years)	Gerealiseerde looptijd (Years)	Looptijd-escalatie (Years)	Looptijd-escalatie-factor
Olkiluoto-3	3.9	17.7	13.8	4.6
Shin Hanul 1-2	5.7	11.7	6	2.1
Barakah 1-4	5.9	12.1	6.2	2
Vogtle 3-4	8.5	14.9	6.3	1.7
Flamanville 3	5.1	17.1*	12.0*	3.4*
Hinkley Point C 1-2	6.6	12.1*	5.5*	1.8*

Noot: * Geprojecteerde waarden

Op basis van de resultaten van de zes casestudies is berekend wat dit zou betekenen voor de voorbereiding van Dukovany 5-6 en Borssele 2-3.

Volgens het *preferred bid* van Dukovany 5-6 is het project begroot op EUR 15,8 miljard en een doorlooptijd van 12,8 jaar. Uit de analyse blijkt dat deze aanvankelijk begrote kosten relatief dicht bij de gemiddelde waarde liggen die op basis van de casestudies wordt verwacht. De berekende lage verwachting wordt als onrealistisch beschouwd en uitgesloten. De gemiddelde verwachting zou te realiseren kosten betekenen van EUR 17,4 miljard en een budgetoverschrijdingsfactor van 1,1. De hoge verwachting zou te realiseren kosten betekenen van EUR 27,3 miljard, met een budgetoverschrijdingsfactor van 1,7.

Voor Borssele 2-3 is nog geen kostenraming beschikbaar. De Nederlandse overheid is van plan een reserve van EUR 7 miljard (voor twee units) te maken, maar het financieringsmodel is nog niet gekozen en de voorgestelde budgetreserve wacht op goedkeuring door het parlement. Daarom is in de analyse een ruwe schatting gemaakt van het beschikbare budget (EUR 19 miljard), op basis van de voorgestelde reserve, om de verwachte kostenrange te kunnen verkennen. Een eerste planning vermeldt dat Borssele 2-3 in juli 2035 operationeel moet zijn.

Ook voor Borssele wordt de berekende lage verwachting als onrealistisch beschouwd en uitgesloten. De gemiddelde verwachting zou te realiseren kosten betekenen van EUR 26,1 miljard en een budgetoverschrijdingsfactor van 1,4. De hoge verwachting zou te realiseren kosten betekenen van EUR 41,0 miljard, met een budgetoverschrijdingsfactor van 2,2.

Er zijn verschillende financieringsmodellen gevonden. Alle zes gevallen hebben een mix van bedrijfs- en overheidsfinanciering. Barakah 1-4 en Flamanville 3 hebben het hoogste aandeel overheidsbijdragen. Olkiluoto 3 en Hinkley Point C 1-2 het laagste. Olkiluoto 3 en Vogtle 3-4 hebben een coöperatief financieringsmodel waaraan de afnemers van elektriciteit deelnemen. In Finland wordt dit het Mankala-model genoemd en de deelnemers zijn zowel bedrijven als overheden. In de VS zijn de deelnemers ook bedrijven en overheden, maar ook klantcoöperaties.

Prijsregulering door de overheid in de vorm van een *Contract for Difference,* dat de operator een minimumprijs garandeert, ondersteunt de financiering van Hinkley Point C 1-2. Voor de andere vijf gevallen is geen prijsmaatregel bekend. Het voorgestelde Dukovany 5-6-project omvat drie (door de EU goedgekeurde) prijsmaatregelen: directe prijsondersteuning via een overeenkomst voor de aankoop van elektriciteit (PPA), een tweezijdig *Contract for Difference* en een gedeeltelijk gesloten markt (30%) voor prijsbepaling via overheidsveilingen.

De overheidsdeelneming in het *ultimate beneficial ownership* van de projecten varieert van ongeveer een kwart tot volledig eigendom. Gemiddeld is de overheidsdeelneming 64,3%. Opvallend is de grote overheidsdeelneming in de projecten in westerse landen als Frankrijk (100%) en het VK (90,8%). Ook opvallend is de overheidsdeelneming in de projecten in Finland (24,3%) en de VS (24,3%), waar alleen particuliere bedrijven als projectsponsors optreden.

Voor Dukovany en Borssele zijn de kosten per kilowatt (elektrisch) afkomstig uit de casestudies en variëren van EUR 2.324 (laag) tot 9.665 (gemiddeld) en 15.175 (hoge verwachting). Het bod van Dukovany vertaalt zich in EUR 8.778. De ruwe begrotingsraming van Borssele vertaalt zich in EUR 7.037 per kilowatt (elektrisch).

Het Internationaal Energieagentschap (IEA) hanteert in zijn scenario's een waarde van EUR 6.230 per kWe voor kernenergie. De KPMG-studie uit 2021 identificeerde een gemiddelde kostprijs per kW geïnstalleerd vermogen van EUR 4.973 per kW. De Witteveen+Bos-studie uit 2022 identificeerde een gemiddelde kostprijs van EUR 7.959 per kW, maar paste in zijn scenario's een kostprijs toe van EUR 3.520 per kW. Aangezien het huidige onderzoek een gemiddelde kostprijs van EUR 9.665 per kWe identificeerde, is het duidelijk dat het actualiseren van de werkelijke kostprijs van de zes projecten noodzakelijk was. Deze uitkomst biedt de mogelijkheid om de kostenramingen voor Borssele 2-3 te actualiseren, opnieuw te beoordelen en te verbeteren. Hogere kostenramingen kunnen ook leiden tot veranderde inzichten in de kosteneffectiviteit bij het vergelijken van scenario's van de toekomstige energiemix.

De kosten per kilowatt (elektrisch) voor hernieuwbare energiebronnen variëren van 1.050 (zon PV) tot 1.850 (wind op land) en 3.620 (wind op zee). Deze studie identificeerde een gemiddelde kostprijs per kilowatt (elektrisch) voor kerncentrales van EUR 9.665. Dit prijsverschil maakt zonne- en windenergie zeer gunstig vergeleken met kernenergie als het gaat om kostenefficiëntie, doorlooptijden en financieel risico.

Dit onderzoek identificeerde een gemiddelde bouwlooptijd van 14,3 jaar. De verwachte bouwlooptijden voor Dukovany en Borssele zijn afkomstig uit de casestudies en liggen in een range van 11,7 (lage) tot 17,7 jaar (hoge verwachting). Voor Dukovany 5-6 zou dit resulteren in een start van de bedrijfsmatige exploitatie tussen december 2036 en december 2042; en voor Borssele 2-3 een start van de bedrijfsmatige exploitatie tussen september 2039 en september 2045.

Een nieuwe kerncentrale komt te laat om te zorgen voor CO_2-besparingen die bijdragen aan de klimaatdoelstellingen voor 2040 en eerder. Het is duidelijk dat een bijdrage aan de doelstelling van een CO_2-neutrale elektriciteitsproductie in Nederland in 2035 buiten beeld is. Borssele 2-3 zou potentieel kunnen bijdragen aan het bereiken van de klimaatdoelstellingen voor 2050. Of dit een significante bijdrage kan zijn, is een vraag die openstaat voor verder onderzoek.

Abbreviations

CGN	China General Nuclear
EDF	Électricité de France
FOAK	First-of-a-kind
GW	Gigawatt
HPC	Hinkley Point C
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
KEXIM	Korea Eximbank or Export-Import Bank of Korea
KEPCO	Korea Electric Power Corporation
KHNP	Korea Hydro & Nuclear Power Company
kWe	Kilowatt (electric)
LCOE	Levelised cost of electricity
MDB	Multilateral Development Bank
NOAK	Nth-of-a-kind
NRC	U.S. Nuclear Regulatory Commission
OCC	Overnight Construction Cost
TOV	Teollisuuden Voima Oyj
UBO	Ultimate beneficial ownership
WEC	Westinghouse Electric Company
WNISR	World Nuclear Industry Status Report
WISE	World Information Service on Energy

Introduction

WISE (World Information Service on Energy) is a grass-roots organisation established in 1978. Its mission is to transition to a world without nuclear and fossil energy.

WISE commissioned this report and the underlying research to provide a clearer picture of the current-day construction costs of a nuclear power plant and, more specifically, to assess the government's share in financing the construction costs. The research request follows up on the Dutch government's intention to build two new nuclear power plant units in Borssele (the Netherlands). The central questions in this study are:

- What are the realised (actual) construction costs and lead times?
- What are the sizes of budget overruns and lead-time escalations?
- How are the costs financed, through investments, loans and other forms of financing?
- Which part of the financing is provided by governments?

The history of nuclear power plant construction shows high budget overruns and major delivery delays. History also shows that governments were not only largely involved in the whole finance setup but also paid the price by covering the losses that occurred.

Nuclear power plant construction is not business as usual in a privatised energy market. Governments regularly intervene heavily, either through direct financing, providing loans and guarantees, or via risk-sharing and interference with price measures.

This raises the question of how much a government will have to pay when planning a new nuclear power plant. Based on recent examples, what is the range of cost estimates that can be expected?

To this end, this study aims to provide a detailed analysis of the actual costs and timelines of typical and recent large-scale construction projects of new nuclear power plants. Six nuclear power plants have been selected for this research. They are among the latest to be put into operation globally. The research covers both budgeted and realised construction costs, enabling the determination of budget overruns. Construction 'lead times' (from construction start to commercial operation start) form a determining factor for overall costs. Therefore, the research pays specific attention to lead time escalation.

Furthermore, the research details the government's share in the ultimately realised cost, through debt financing, equity financing, guarantees, export credit and price regulation. To determine the government's share of the equity investment, the ownership structure of the project sponsors is studied and the ultimate beneficial ownership (UBO) percentage of the participating government(s) is determined.

While the research focuses on the costs of the construction stage, it attempts to shed light on pre-construction costs and the cost of debt financing (capital cost). Outside the scope of the research are the costs and duration of the other stages of a nuclear plant's life cycle: operation, dismantling, temporary and final nuclear waste storage, and other externalised costs.

Chapter 1 reviews the literature on the cost and financing of developing a nuclear power plant. It introduces the topic and provides background to the findings of the underlying research.

Chapter 2 explains the methodology used. It includes a section describing the selection of the six construction projects for this study.

In Chapter 3 the research findings are presented, with a section devoted to each power plant construction project. In Chapter 4, these research findings are applied to the proposed nuclear projects in Borssele (the Netherlands) and Dukovany (the Czech Republic).

Chapter 5 provides overall conclusions, a discussion of the results and recommendations.

A summary of the findings can be found on the first pages of this report.

1

Background: Developing a nuclear power plant

This chapter reviews the existing literature on the topic. The cost of nuclear power is a well-researched and well-discussed topic. Past and new financing models are presented. Past and future construction projects are compared.

1.1 Large-scale construction projects

Large-scale construction projects tend to extend beyond the originally proposed budget and timeline. This 'additional costs' aspect seems to occur almost without exception for various types of construction projects. Nuclear power plant construction projects are no exception to this 'rule'.

A comprehensive study published in 2014 evaluated the construction costs of 401 completed electricity infrastructure projects worldwide (period 1942-2013), representing a total investment value of USD 820 billion (EUR 620 billion) and a total of USD 388 billion (EUR 294 billion) in cost overruns. The mean budget overrun factor was 1.7. The same study gives nuclear projects a mean budget overrun factor of 2.2 and a lead time escalation factor of 1.6. [1] 'Lead time' refers here to the construction period from the start of construction start to the start of commercial operation.

Learning from the past implies that one could expect a proposed budget for a nuclear power plant to become overrun by a factor of 2.2. Seen from both a financing risk point of view and a budget control point of view, this is an alarmingly high factor. Moreover, several researchers emphasise that nuclear power is becoming more expensive over time and speak of a so-called negative learning curve.[2] This phenomenon entails that one could expect a realised budget to be even higher for future projects, even when the initial budget was estimated based on learning from previous experience.

Building on these earlier studies, the underlying research investigates the trend and attempts to update and improve data and indicators for future project cost estimations. Furthermore, it builds on recent reports commissioned by the Dutch government.[3]

1.2 Costs of nuclear power plant development

The following cost types are taken into consideration:

- **Pre-construction cost**

  Costs prior to construction start are rarely considered but can be significant, particularly those related to licensing. Regulator fees are typically USD 60 million (EUR 57 million) per reactor per country, and costs payable by a vendor to support the licensing process are USD 180-240 million (EUR 171-228 million) per design per country.[4]

- **Financing cost**

  Financing costs or (capital costs) are the interest expenses on debt. The total expenses depend on the debt term and the interest rate. Nuclear construction projects have large scheduled construction periods and a high probability of significantly exceeding the schedule (see Section 2.4.5). The longer the construction takes, the further the debt term is extended. An eventual favourable interest rate at the start of construction may develop into an unfavourable interest rate when negotiating the term extension (see further Section 2.4.4).

- **Construction cost**

  The actual construction cost concerns all the costs of the builder and the suppliers during construction.

- **Pre-operational cost**

  Before commercial operation starts, the reactor is tested, and certified by the authorities. This process may take 1-2 years and includes fuel load, grid connection, safety checks and testing of all systems.

The costs that occur following the start of commercial operation are described in Appendix 1.

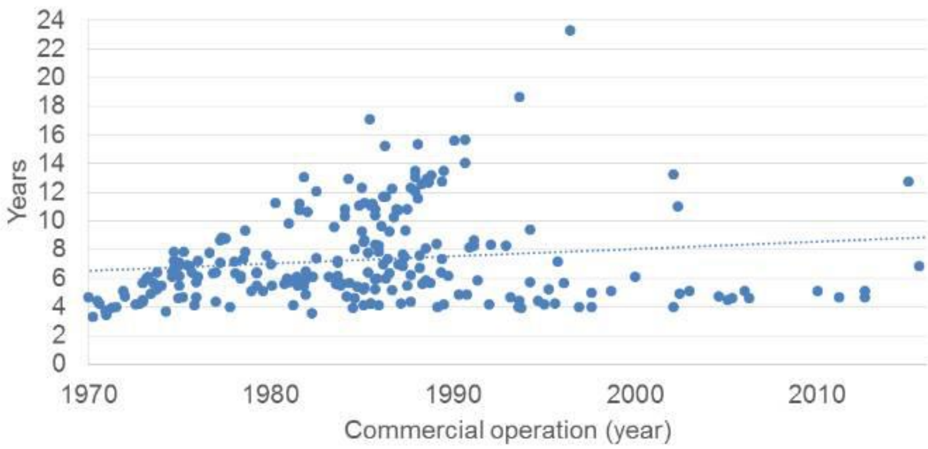
1.3 Lead time escalations

1.3.1 Lead time escalations of nuclear power plants

Literature shows that construction lead time varies highly. A statistical analysis of light water reactors with commercial operation start dates from 1970 to 2016 gives values of 3 - 23 years. The study concludes that the length of construction lead time shows an increasing trend over the reporting period, which suggests a negative learning curve. The negative learning curve is explained by increasing technical complexity, combined with increasing safety measures.[5]

'Negative learning' implies that over time nuclear construction projects tend to need longer periods to construct (Figure 1).

Figure 1 Development of construction lead time (1970-2016)

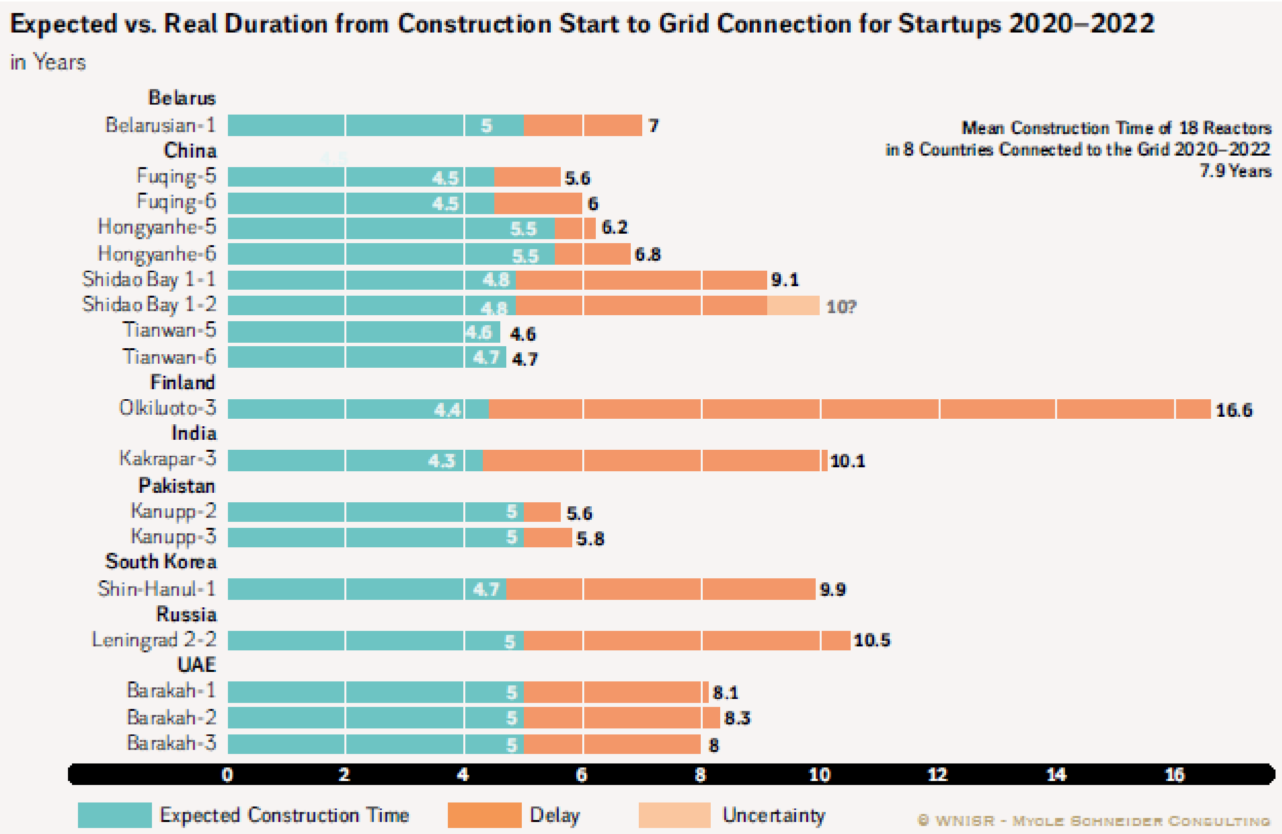


Source: Taken from Portugal-Pereira, J., et al. (2016), *Understanding cost escalation in nuclear reactor construction projects*, Proceedings of the 3rd International Conference on Project Evaluation, ICOPEV 2016, Guimarães, Portugal, online: https://core.ac.uk/outputs/80557209/?source=2, viewed in July 2024.

The comprehensive 2014 study mentioned earlier shows that for 180 nuclear projects, the average lead time escalation was 3.0 years, and the average realised lead time was 7.6 years, a factor of 1.6.[6]

A recent study (2023) shows a mean construction lead time of 9.4 years, as the average for 66 reactors worldwide connected to the grid from 2013 to 2022. Zooming in on grid connection in 2020 to 2022, the mean construction lead time of the 18 reactors involved was 7.9 years.[7] Figure 2 presents the scheduled construction lead times for nuclear power plants connected to the grid in 2020-2022 and clearly illustrates the consequential delays.

Figure 2 Scheduled and realised construction lead times 2020-2022



Source: Schneider M. et al. (2023, December), *The World Nuclear Industry, Status Report 2023*, Paris: A Mycle Schneider Consulting Project. Figure reproduced with permission by the author.

The 2021 KPMG study concludes that the lead time required for a large Western generation III+ nuclear power plant is approximately 11-15 years.[8]

The 2021 RLI study identifies lead times for four recent projects of 9 to 17 years.

The 2022 Witteveen+Bos study concludes that the total development and construction period will be 11 years, with 3 years for preparation and licensing, 2 years to complete the design, and 6 years for construction.[9]

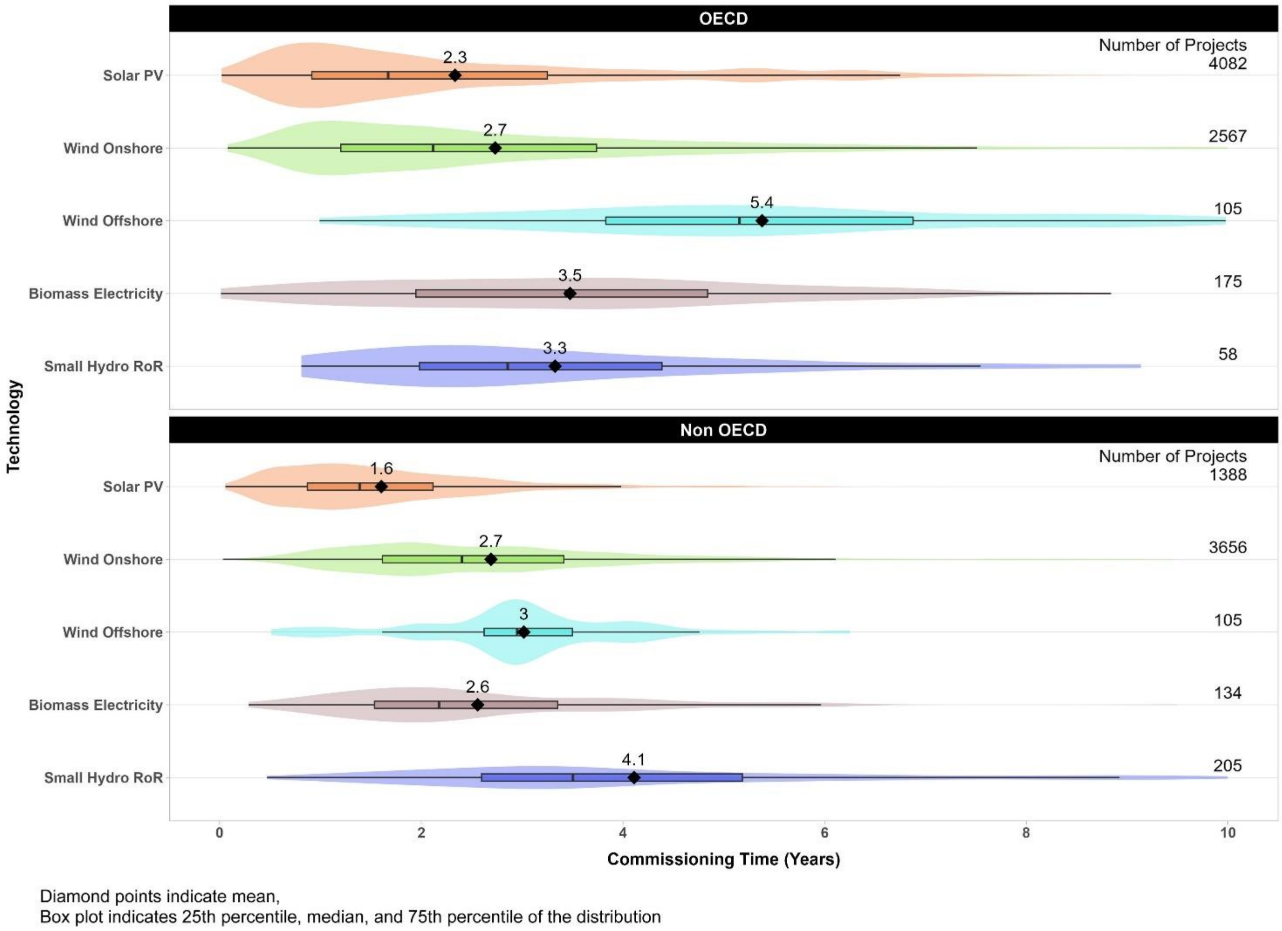
The latest insight into scheduled lead times comes from the recent Dukovany 5-6 agreement. Construction is expected to start in April 2025, and commercial operation of unit 5 will start in 2038.[10]
If this preliminary schedule were to be realised, the first of the two planned units would have a construction lead time of 12.8 years.

1.3.2 Comparison with lead times of renewable power projects

For the discussion of which energy sources contribute to climate mitigation, it is relevant to know how fast alternative sources can be realised to replace fossil fuels. Therefore it is interesting to compare construction lead times of nuclear energy with the construction lead times of renewable energy sources.

Mean commissioning (lead) times of renewable power projects in OECD countries vary from 2.3 (solar PV), 2.7 (wind on-shore) to 5.4 years (wind off-shore), see Figure 3. Solar PV projects experienced lead times of a maximum of seven years, wind onshore projects of eight years, and wind offshore projects of ten years. The coloured shapes in the figure depict the distribution of the lead times of the projects, which gives a further impression of the probability of the lead time.

Figure 3 Distribution of commissioning time for renewable energy (2005-2022)



Source: Gumber A. et al. (2024), *A global analysis of renewable energy project commissioning timelines*, Elsevier: Applied Energy, Volume 358, 15 March 2024, 122563, online: https://www.sciencedirect.com/science/article/pii/S030626192301927X#s0045, viewed in July 2024. The figure is reproduced unchanged, under Creative Commons License CC BY 4.0.
Note: The commissioning time is here defined as the time between permitting and commercial operation start.

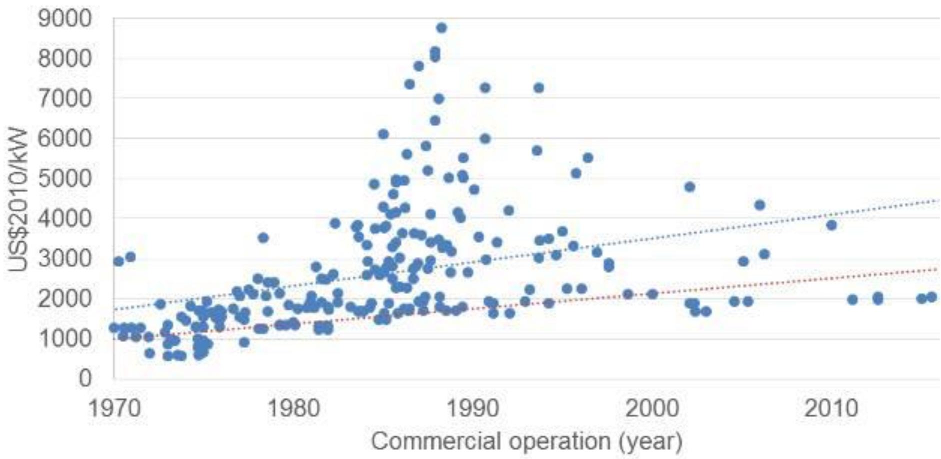
1.4 Cost per kilowatt (electric)

1.4.1 Construction cost of nuclear power plants

Literature shows that construction cost per kW installed capacity varies greatly for nuclear power plants. In one statistical analysis of light water reactors with commercial operation start dates from 1970 to 2016, values of USD 1,000 - 9,000 (EUR 750 - 6,800) per kWe were found. The study concludes that cost per kW shows an increasing trend over the reporting period, which suggests a negative learning curve.[11] This means that over time construction projects tend to get more expensive per MW installed (Figure 4).

This cost rise is amplified by the fact that over the analysed period, the power plants were designed with larger-size reactors (installed capacity increases over time). The cost rise is further explained by the increase in the complexity of nuclear technology, the number of safety measures, and the number of regulatory procedures.

Figure 4 Development cost per kWe (1970-2016)



Source: Taken from Portugal-Pereira, J., et al. (2016), *Understanding cost escalation in nuclear reactor construction projects*, Proceedings of the 3rd International Conference on Project Evaluation, ICOPEV 2016, Guimarães, Portugal, online: https://core.ac.uk/outputs/80557209/?source=2, viewed in July 2024.

Recent studies confirm the high variability of costs and the negative learning curve.

In 2017, a study on emerging trends in financing nuclear power concluded that the estimated construction cost for a nuclear power plant in Western Europe or North America ranged from a minimum of USD 5,000 (EUR 4,700) and a mean of 6,100 (EUR 5,700) to a maximum of 7,300 (EUR 6,800) per kWe.[12]

In 2021, a Polish study on 12 recent nuclear construction projects (24 units) provided a range of (projected) realised construction costs, with a minimum of EUR 5.4 billion, a mean of 12.9 and a maximum of 26.1. The mean (projected) realised cost was determined as USD 5,419 (EUR 4,548) per KWe.[13] Yet, a number of the 12 construction projects were not completed, which implies that the values are a mix of realised and projected construction costs and, therefore, underestimated.

The KPMG study (2021) concludes that the investments required for a large Western generation III+ nuclear power plant are EUR 7 to 13.2 billion. It shows (projected/realised) construction costs for a selection of seven projects in the range of EUR 1,995 to 8,122, with an average of 4,973 per kW.[14]

The 2021 RLI study mentions (projected) realised construction costs of EUR 11 to 30.4 billion based on four nuclear construction projects (Olkiluoto 3, Flamanville 3, Taishan 1-2 and Hinkley Point C 1-2).[15]

The Witteveen + Bos study (2022) mentions (projected) realised construction costs of EUR 8.5 to 25 billion for five of the current research's six case studies.[16] The project costs per kW installed capacity come down to Olkiluoto 3 (5,313), Flamanville 3 (11,875), Hinkley Point C 1-2 (7,813), Vogtle 3-4 (10,743), and Barakah 1-4 (4,052). The average cost of the five projects is 19.7 billion. The average cost per kW installed capacity is EUR 7,959 per kW.

For its two large nuclear reactor scenarios, the Witteveen + Bos study (2022) uses an Overnight Construction Cost (OCC) value of EUR 3,520 per kW from a 2020 IEA/NEA study.[17] This OCC value is outdated since the 2022 OCC value used by IAE is EUR 6,230 per kW (see Section 1.4.2).

The latest insight into cost development comes from the contract signed by the Czech government with Korea Hydro & Nuclear Power (KHNP) to build 2 new units at Dukovany. The winning reactor design is the APR-1000, which is based on the OPR-1000 and APR-1400 designs.[18] Remarkably, this is a First-of a-kind (FOAK) design. KHNP's bid for the Dukovany units 5 and 6 is said to be CZK 400 billion (EUR 15.8 billion).[19] If this amount were to be the realised construction cost, the cost would translate into EUR 8,778 per kWe.

1.4.2 Comparison with construction costs of other energy source projects

The latest outlook of the International Energy Agency (IEA) uses for their modelling the figures presented in Table 1. The table shows Overnight Construction Cost (OCC) and Levelised Cost of Energy (LCOE) scenarios for 2022, 2030 and 2050. The figures apply to the Stated Policies Scenario, which is based on “current policy settings and also considers the implications of industrial policies that support clean energy supply chains as well as measures related to energy and climate.”[20]

Table 1 OCC and LCOE in the IEA Stated Policies Scenarios for EU countries

	OCC (EUR/kW)			LCOE (EUR/MWh)		
	2022	2030	2050	2022	2030	2050
Nuclear	6,230	4,820	4,250	150	120	100
Coal	1,890	1,890	1,890	190	n.a.	n.a.
Gas CCGT	940	940	940	220	250	n.a.
Solar PV	930	590	420	60	40	30
Wind onshore	1,650	1,580	1,520	60	50	50
Wind offshore	3,230	2,150	1,640	70	40	30

Sources: International Energy Agency (2023, October), *World Energy Outlook 2023*, p. 301; International Renewable Energy Agency (2023). *Renewable Power Generation Costs in 2022.*, online: www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022, viewed in July 2024.

For good comparison (introduced in Section 2.4.1), please note that Overnight Construction Cost (OCC) figures do not contain financing costs (or the cost of capital). The Levelised Cost of Energy (LCOE) measures both the construction and operation stages.

To explore the magnitude of the differences in cost, the figures of Table 1 have been set relative to the values of the most expensive renewable energy source (wind-offshore) This creates the following picture (see Table 2).

Table 2 OCC and LCOE in the IEA Stated Policies Scenario for EU countries, relative to Wind offshore.

	OCC (EUR/kW)			LCOE (EUR/MWh)		
	2022	2030	2050	2022	2030	2050
Nuclear	193%	224%	259%	214%	300%	333%
Coal	59%	88%	115%	271%	n.a.	n.a.
Gas CCGT	29%	44%	57%	314%	625%	n.a.
Solar PV	29%	27%	26%	86%	100%	100%
Wind onshore	51%	73%	93%	86%	125%	167%
Wind offshore	100%	100%	100%	100%	100%	100%

Source: See Table 1.

When comparing the cost of nuclear to wind offshore, investing in nuclear would cost around twice the amount in 2022, when comparing both OCC and LCOE. Though both nuclear and wind offshore are predicted to become more cost-efficient in the future, the fall in costs for wind offshore is sharper. IEA predicts the costs of nuclear in 2050 to be around three times as high as wind offshore (OCC 259% and LCOE 333%).

1.5 Budget overruns

The earlier-mentioned 2014 comprehensive study on 401 projects included 180 nuclear power plant construction projects. The 180 projects had a combined construction cost of USD 459 billion (EUR 347 billion) and incurred USD 231 billion (EUR 175 billion) in cost overruns, leading to a mean cost escalation of 117% per project or a factor of 2.2. The overruns afflicted more than 97% of the nuclear projects.[21]

During the course of a project many variables can change: material and components cost, engineering requirements, regulatory approvals, interest charges, construction time, and public support.[22]

An OECD NEA study that examined nuclear plant cost estimates from 2010 to 2020 found that increases in indirect cost are the main driver of nuclear plant cost overruns, with labour cost making up 80% of indirect cost.[23] Another important driver for cost increases is quality assurance/quality control requirements and the advancing insights and regulations in that area. It is estimated that quality control requirements make up 23% of the cost of concrete, and 41% of the cost for structural steel on nuclear plants.[24]

Explanations for budget overruns can be distinguished into technical and political explanations. Technical explanations include the use of new technology (FOAK), technological complexity, new technical standards, unforeseen parts of the project, or miscalculations. Political explanations include additional wishes from the government, the commissioning party, or external stakeholders. A political strategy may be to come up with project amendments during the construction phase. According to some authors, most budget overruns have political causes; according to others, technical causes prevail.[25]

The following sections explain a number of these variables.

1.5.1 Lead time escalation results in higher labour and purchasing costs

In contracts with suppliers of labour and equipment, the tariffs are partly based on the planning schedule. When a reserved (and specialised) workforce input needs to be reallocated to a different time period, additional costs will occur. The same applies to equipment that is kept in stock and needs to be delivered later. This adds to the wage-price and industrial price inflation during the extended construction lead-time, that had not been taken into account during the initial cost estimation.[26]

1.5.2 Lead time escalation results in an escalation of interest during construction

Over a long construction period, during which there are no revenue streams from the project, the interest on funds borrowed can compound into very significant amounts.[27]

A study by DIW Berlin illustrates this by modelling the interest payments for a scheduled lead time of five years, compared to a realised lead time of 15 years. With a five-year construction lead time, the share of interest during construction of the total construction cost is calculated at around 16%. When the construction lead time is 15 years, the share is 41% of the total construction cost, making the interest during construction the main cost driver.[28]

This is further illustrated by a study by the French Nuclear Society (SFEN), which brings comparable figures, but extends the analysis to three different interest rates (Figure 5).

Figure 5 Capital cost as a fraction of total construction cost

	Construction time		
	1 year	5 years	10 years
Capital cost 5%	2%	12%	22%
Capital cost 10%	4%	22%	40%
Capital cost 15%	6%	30%	54%

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

In the two large-scale nuclear scenarios of the Witteveen+Bos study (2022) capital cost is projected as 25% and 45%, respectively.[29]

1.5.3 First-of-a-kind (FOAK) characteristics

From First-of-a-kind (FOAK) to Nth-of-a-kind (NOAK) is a sliding scale, with NOAK at the ultimate endpoint. NOAK is a technology that is so mature that no additional costs arise.

A FOAK brings more or fewer additional costs on a sliding scale, depending on the maturity of a technology. FOAK also depends on the location, the regulatory environment, the local knowledge base, and the availability of experienced designers, engineers, builders, and suppliers.
A FOAK premium is defined as the additional costs that occur due to this phenomenon of a learning curve of a new technology in a new setting (country).[30]

Furthermore, one should not underestimate the efforts needed to bridge knowledge, language and culture when working in close cooperation with reactor suppliers from, for instance, the United States, France, or South Korea. Also, one should not view FOAK only in a European but also in a Dutch context.

Suppose the Netherlands chooses to build a Generation-III+ reactor. For the case of Borssele 2-3, all three reactor technologies in consideration will have substantial FOAK characteristics:

- Tailoring European regulations to new technology;
- Tailoring Dutch regulations to new technology;
- Knowledge of Dutch policymakers and supervisors.

And when Dutch construction companies and suppliers become part of the construction consortium:

- Knowledge of designers, engineers, builders and suppliers of the new technology;
- Integration of designs, logistics and site management (and more) of reactor technology from country X, generator technology from country Y, other equipment supplied by countries A-Z, and construction by Dutch companies.

As the construction of Borssele 1 dates back to 1969, there is a small pool of people in the Dutch engineering world with specialist knowledge of nuclear energy generation in general and an even smaller pool of people with knowledge of modern Generation III+ technology. Regulations and technology in the field of safety measures have made a giant leap forward since 1969.

The Dutch government recognizes the knowledge gap and has, therefore, established a EUR 5 million knowledge and innovation program.[31]

Earlier studies commissioned by the Dutch government concluded that the only technology with a mature enough FOAK character to be built in the Netherlands is the large-scale Generation III+ reactor technology.[32]

However, these studies fail to address the gliding scale of the FOAK characteristics and the forthcoming additional costs. Moreover, the studies fail to mention that the FOAK characteristics concern not just the reactor technology but the entire complex large-scale construction project, including the supply chain.

Australian research by CSIRO calculates a 25% FOAK premium for a new nuclear power plant to be built in Australia. The study warns that First-of-a-kind (FOAK) premiums of 100% have been found.[33] A comment on the CSIRO study by the Australian Energy Council is that the FOAK premiums are underestimated:

- The data need to be properly inflated and converted;
- *"New generation technology electricity costs have 'only a weak transferability' between countries and cost differences can arise from differences in installation, maintenance and fuel costs, or subsidies and different levels of state and private ownership."*[34]

1.6 Overview of financing models

For the financing of nuclear power plants the following financing models (and combinations thereof) are mentioned.[35]

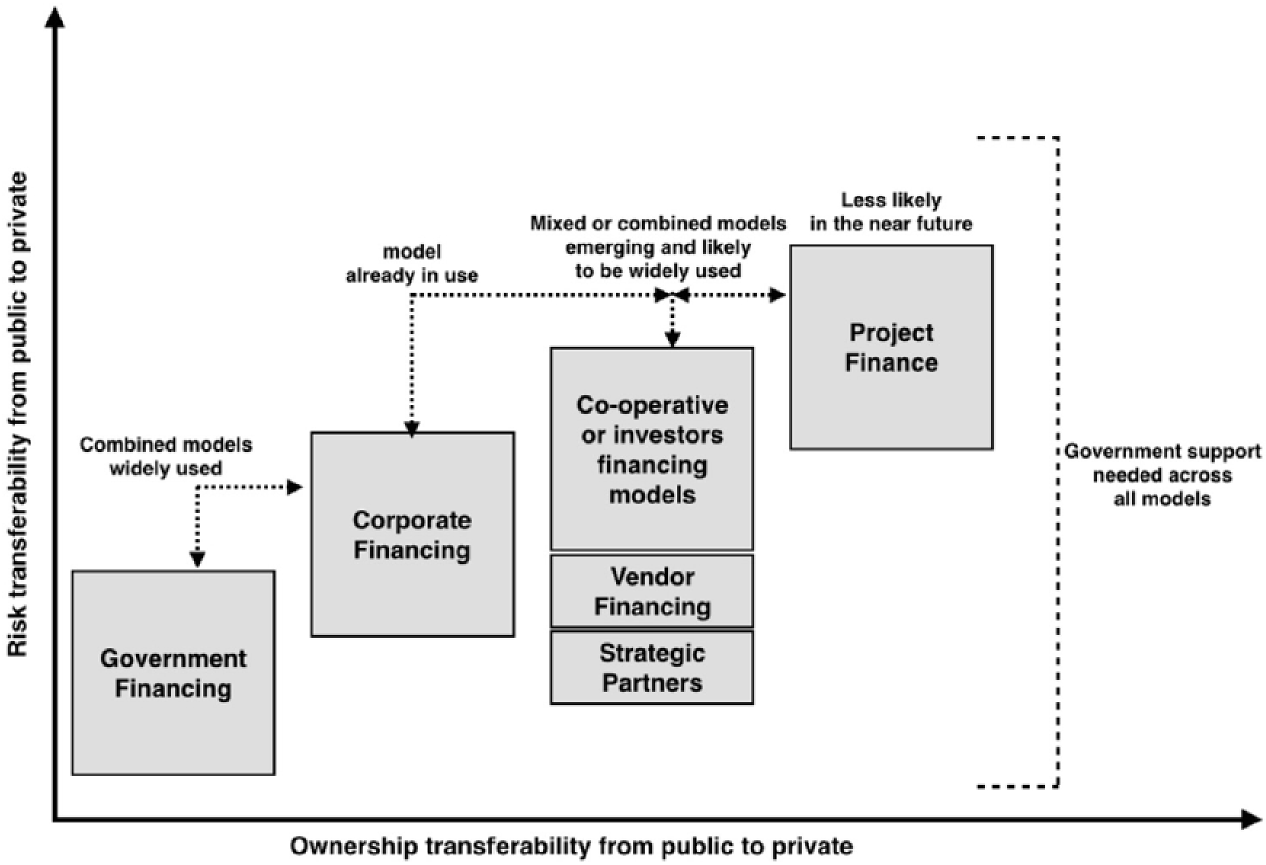
- Government finance (public);
- Corporate finance (private);
- Project finance (public or private);
- Cooperative investment (Mankala model);
- Vendor financing;
- Government-to-government financing;
- Financing by Export Credit Agencies;
- Financing by (Multilateral) Development Banks.

The financing can be further supported with:

- Government loan guarantees;
- Price regulation measures:
  - Power Purchase Agreement (PPA);
  - Contract for Difference (CfD);
  - Regulated Asset Base (RAB);
- Limited liability regulations.

The models differ in the degree to which the risk and the ownership are divided among the public and private spheres. This is illustrated in Figure 6.

Figure 6 Emerging trends of nuclear financing models



Source: Barkatullah, N. and Achmad A. (2017), *Current status and emerging trends in financing nuclear power projects*, Energy Strategy Reviews 18 (2017), pp. 127-140

Project finance is further explained in Section 2.2. For government financing, including by export credit agencies and development banks, see Section 1.7. In the following sections, the other financing models and mechanisms are explained.

1.6.1 Mankala model

The cooperative Mankala model is a cost-price model in which the investment and, depending on guarantees, a significant part of the risks are borne by a large number of private parties. The model is only used in Finland. Within this model, a consortium is formed of several private parties that jointly provide a majority of the share capital for an energy project. Upon delivery, the energy company (the Mankala company) sells the energy directly to the owners of the company, who are usually large power off-takers (usually energy traders, distributors and large industrial companies). Mankala companies are limited liability companies or partnerships that operate as a non-profit cooperative. The purpose of Mankala companies, unlike typical public limited companies, is not to make a profit.

Instead of dividend payments, the owners of a Mankala company receive energy that they are required to purchase through a PPA based on the operating cost price, regardless of whether it is below or above the market price.[36]

In the case of Olkiluoto-3, the project company is owned by five shareholders. Some of these shareholders are, in turn, also Mankala companies. The ultimate beneficial owners include 131 Finnish municipalities.[37]

1.6.2 Vendor financing

In vendor financing, the vendor or project contractor takes part of full responsibility for the construction risks. In a turn-key contract (as in the case of Olkiluoto-3), the project sponsors are not exposed to any risk. The contractor (and its ultimate beneficial owners) takes the financial risk.

1.6.3 Power Purchase Agreement (PPA)

The Power Purchase Agreement (PPA) is an agreement between the future electricity producer and power off-taker to buy in advance a certain volume of electricity at a fixed or indexed price. The PPA provides security for the project developer by arranging a large part of the financing (from revenue) in advance. It reduces uncertainties of consumption volume and electricity price.[38]

1.6.4 Contract for Difference (CfD)

With a Contract for Difference (CfD), the government guarantees a fixed price per MWh, the 'strike price'. In this model, the project developer is responsible for all costs and risks during the construction stage in exchange for the agreed strike price. When the market price is below the strike price during operation, electricity consumers will pay the difference. Or the agreement may stipulate that the government pays the difference. When the market price is above the strike price, consumers will benefit from the lower (strike) price.

The height of the strike price depends on the risks the project developers take and on their share in the total investment. The risk of budget overruns and lead time delays remains with the project developer and its investors. Therefore, the CfD model only offers revenue certainty. It does not cover risks surrounding the permit or other risks associated with the construction.[39]

1.6.5 Regulated Asset Base (RAB)

In the Regulated Asset Base (RAB) model, the risks of the construction project are shared among the project developer and future power off-takers. Already from the start of the construction, the future power off-takers will pay a fee, waiting for services to be delivered following the start of commercial operation.

The fee is determined so that the 'reasonable' costs (including depreciation on the investment, operational costs, and costs in the context of decommissioning up to a certain level) are covered and, in addition, generate a reasonable return on the regulated assets. A regulator (independent third party) determines what 'reasonable costs' are. The model offers the opportunity to third parties to invest and participate in the RAB-assets.

The project developer is responsible when the construction costs exceed the reasonable level set by the regulator. Therefore, the RAB model reduces but does not entirely remove business risks.

Optionally, the government can provide a guarantee ('funding cap'), whereby costs above a certain level are borne by the government.

When the government is the project developer, the role of regulator needs to be transferred to a statutory appointed supervisor.[40]

1.6.6 Dukovany 5-6's EU-approved mixed model

In the case of the financing of Dukovany 5-6 the government fulfils several roles as regulator, purchaser and grantor. This Czech model is approved by the European Commission, under EU State Aid rules. The model is a mix of: [41]

- direct price support during 40 years in the form of a PPA with a State-owned Special Purpose Vehicle (SPV);
- a subsidised state loan;
- a claw-back mechanism;
- a two-way contract for difference;
- a minimum of 70% of power output is to be sold on the open power exchange (and 30% by way of auctions).

1.7 Government financing

There is limited literature available on the government's contribution to nuclear construction projects. Many of the quoted studies emphasize the key role governments have in convincing commercial banks to provide financing. But apart from that, governments often invest significant amounts directly from the government budget. And certainly, in the case of budget overruns, the share of the funding that needs to be provided by the government may increase significantly. However, a quantitative analysis of the average government's share in the total construction cost among a larger set of projects has not been found.

Governments finance projects not only through direct finance (subsidies and loans) but also through direct and indirect equity participation, as several cases in this study will show.

In government-to-government financing, a foreign government finances part of the construction cost. The foreign government supports export opportunities in favour of its national nuclear sector. A more accurate term might be government-supported vendor financing.

This government-supported vendor financing usually takes place through export credit agencies (ECAs) in the form of loan guarantees or loans. But foreign governments may also participate in the equity of a project company (see the case of Hinkley Point C 1-2) or will pay occurring losses (see the case of Olkiluto-3).

Indirect government finance can also take place through a multilateral development bank (MDB). However, financing of nuclear by MDBs is rather rare:

In the period 2013 - 2023, the Development Bank of Latin America (CAF) was the only international development bank to provide a loan to nuclear electricity generation. In 2013, it supported the refurbishment and licence extension of Argentina's Embalse nuclear power plant. The World Bank does not currently allow financing support for nuclear power.[42]

The last time the European Investment Bank (EIB) put investments into nuclear electricity generation was in 1987 when it financed Flamanville units 1 and 2 (EUR 219 million).[43] Since then, the EIB did, however, finance parallel nuclear activities.

From 2000 to 2024, the EIB invested EUR 1 billion in nuclear safety and R&D.[44] Some examples of this policy:

- In January 2009, the EIB provided EUR 400 million to the Areva Uranium Enrichment Facility.[45]
- In December 2023, the EIB provided a EUR 145 million loan to a safety project at the Cernavoda nuclear power plant in Romania.[46]

In the recently leaked EIB 2023-2027 roadmap, the EIB seems to maintain the same restricted policy.[47] Notwithstanding this policy:

- In June 2024, EIB invested in a EUR 3 billion green bond issued by EDF. The EIB participated with a value of EUR 150 million in the third tranche (EUR 1,250 million), earmarked for *"adaptation of the electricity grid to the needs of the energy transition"*.[48]
- The first tranche (EUR 1 billion) of this bond issue was dedicated to the lifetime extension of existing French nuclear reactors. With the French grid mainly distributing electricity from nuclear sources, the question arises to what extent the EIB investment in the third tranche fits into the policy as laid down in the new roadmap.

2

Research and assessment methodology

This chapter describes the research methodology and the selection of construction projects.

The underlying research is based on a review of the general literature on nuclear power construction projects, combined with specific financial research methods. Large utility construction projects are usually financed through project finance.

Section 2.1 explains the selection of construction projects for the purpose of this study. Section 2.2 introduces the concept of project finance. Section 0 describes the research methodology. Section 2.4 defines several indicators that are used to compare construction projects.

2.1 Selection of construction projects

The section describes the selection criteria, the pre-selection and the final selection of construction projects.

2.1.1 Selection criteria

For the purpose of this research, nuclear power plant construction projects are selected based on the following criteria:

- Reactor technology comparable to the technologies selected by the Dutch government: reactor technology originates from the United States, France or South Korea;
- Nuclear power plant construction has been completed and the power plant is in commercial operation;
- Nuclear power plant commercial operation date is as recent as possible;
- Diversity of financing mechanisms among the selected projects;
- Plant location is in a country with comparable government politics and energy market, where possible;
- The degree to which the project company, owners and/or government disclose relevant information.

2.1.2 Pre-selection

Through a literature review, a set of recent construction projects have been pre-selected (Table 3).

For each project, it was determined whether construction had been completed and commercial operation started. The table shows three sections: Plants Atucha 2 to Vogtle 3-4 are in commercial operation; Flamanville 3 to Hinkley Point C 1-2 are under construction; Dukovany 5-8 and Borssele 2-3 are proposed projects. The table is sorted by the (expected) start date of commercial operation.

Table 3 Pre-selection of recent nuclear power plant construction projects

Nuclear power plant construction project	Country	Commercial operation	Reactor type	Reactor origin
Completed, in commercial operation:				
Atucha 2	Argentina	May 2016	PHWR-700	Germany
Kudankulam 1-2	India	October 2016	VVER-1000	Russia
Sanmen 1-2	China	November 2018	AP-1000	United States
Taishan 1-2	China	September 2019	EPR-1750	France
Shidao Bay 1	China	December 2023	HTR-PM	China
Olkiluoto 3	Finland	April 2023	EPR-1600	France
Shin Hanul 1-2	South Korea	December 2023	APR-1400	South Korea
Barakah 1-4	United Arab Emirates	March 2024	APR-1400	South Korea
Vogtle 3-4	United States	April 2024	AP-1000	United States
Under construction:				
Flamanville 3	France	January 2025	EPR-1650	France
Angra 3	Brazil	2026	PWR-1400	Germany
El Dabaa 1-4	Egypt	2026	VVER-1200	Russia
Jaitapur 1-6	India	2026	EPR-1650	France
Oma 1	Japan	2026	ABWR	United States
Akkuyu 1-4	Turkey	2028	VVR-1200	Russia
Hinkley Point C 1-2	United Kingdom	2031	EPR-1750	France
Proposed projects:				
Borssele 2-3	Netherlands	2035	EDF/WEC/KHNP	France/US/South-Korea
Dukovany 5-8	Czechia	2038	APR-1000	South Korea

2.1.3 Selected completed and ongoing construction projects

Out of these pre-selected plants, six nuclear power plant construction projects met the inclusion criteria. They have been selected for the research from the above pre-selection (Table 4).

Three projects have French reactor technology and are located in Europe (Olkiluoto 3, Flamanville 3, and Hinkley Point C 1-2). One project has US reactor technology and is located in the United States (Vogtle 3-4). Two projects have South Korean technology. One is located in South Korea (Shin Hanul 1-2), and the other is in the United Arab Emirates (Barakah 1-4).

The Flamanville 3 and Hinkley Point C 1-2 projects are selected even though commercial operations have not started. Flamanville 3 was expected to start in August 2024, but it was very recently again delayed and is now expected to start in early 2025. Hinkley Point C is expected to start commercial operations in 2031. The reason for including this project is the specific financing model, which is unique to the other pre-selected projects.

The other four selected construction projects have recently gone into commercial operation between April 2023 and April 2024.

Table 4 Selection of nuclear power plant construction projects for this research

Nuclear power plant construction project	Country	Commercial operation	Reactor type	Reactor origin
Olkiluoto 3	Finland	April 2023	EPR-1600	France
Shin Hanul 1-2	South Korea	December 2023	APR-1400	South Korea
Barakah 1-4	United Arab Emirates	March 2024	APR-1400	South Korea
Vogtle 3-4	United States	April 2024	AP-1000	United States
Flamanville 3	France	January 2025	EPR-1650	France
Hinkley Point C 1-2	United Kingdom	2029–2031	EPR-1750	France

All the selected technologies concern Generation III+ pressurised water reactor:

- The AP-1000 (Advanced Passive power reactor) is a Generation III+ pressurised water reactor, designed and produced by Westinghouse Electric Co. It was certified in 2006;[49]
- The EPR (European/Evolutionary Power Reactor) is a Generation III+ pressurised water reactor design. It has been designed and developed mainly by Framatome and Électricité de France (EDF);[50]
- The APR-1400 (Advanced Power Reactor) is a Generation III pressurised water reactor, a technology developed by the South Korean company Korea Hydro & Nuclear Power Company (KHNP). This development followed up on the OPR-1000 (Optimum Power Reactor), also developed in South Korea.[51]

2.1.4 Selected proposed construction projects

The two proposed nuclear power plants, Dukovany 5-8 and Borssele 2-3 (see Table 5), will be used as cases to explore the outcome of the research (See 4). Both projects aim to use the same technology as the above projects (Generation III+ pressurised water reactor).

Table 5 Proposed nuclear power plant construction projects for comparison

Nuclear power plant construction project	Country	Commercial operation	Reactor type	Reactor origin
Borssele 2-3	Netherlands	2035	EDF/WEC/KHNP	France/US/South-Korea
Dukovany 5-6	Czechia	2038	APR-1000	South Korea

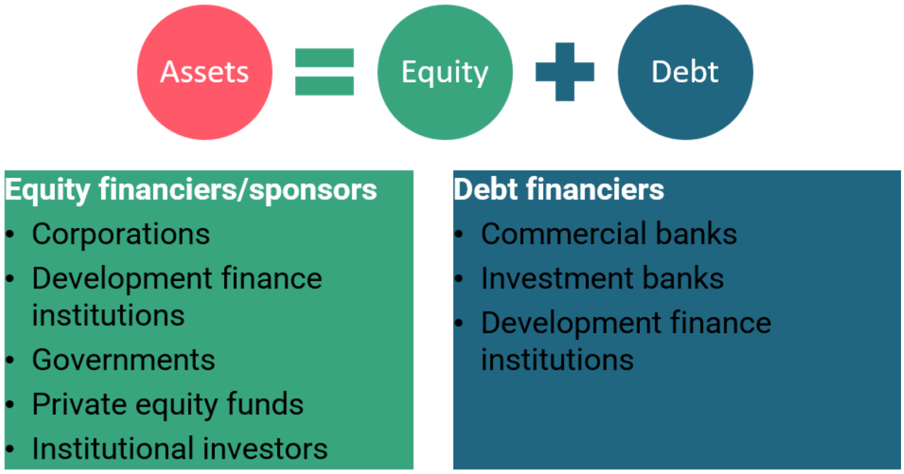
Borssele 2-3 is being prepared by the Dutch government, but no official steps have yet been taken. For Dukovany 5-6, the Czech government recently decided on the preferred bidder. The South Korean APR-1000 provided by KEPCO is the reactor technology of choice.

2.2 Introduction to project finance

Project finance differs from other types of finance in that it involves more risk. Project finance often concerns very large infrastructure or utility projects. A single initiating company may not be able to finance the large sums needed from its own earnings or through commercial lending. Another reason for companies to engage in project financing is to offload risk from their own books.

Therefore, an initiating party will try to establish a consortium of future owners. The first step is to find equity financiers (or sponsors) who will invest in the project. The second step is to arrange licensing and engineering in order to create a viable plan. During the third step, the sponsors attempt to attract debt financing (see Figure 7).

Figure 7 Financing a project



Source: Warmerdam, W. (2021), *Unravelling project finance*, presentation, Amsterdam: Profundo

The total project finance is the sum of equity and debt. At the start of a project, this amount equals the value of the budgeted construction costs. When costs rise during construction, additional financing needs to be attracted in the form of either equity (additional investments by the project sponsors or additional sponsors) or debt (additional loans to the sponsors/project company or additional bonds issued by the sponsors/project company).

This research will determine the debt-equity ratio of the selected projects. When data is missing, a debt-equity ratio of 70/30 is assumed, as consistent with earlier studies on nuclear.[52]

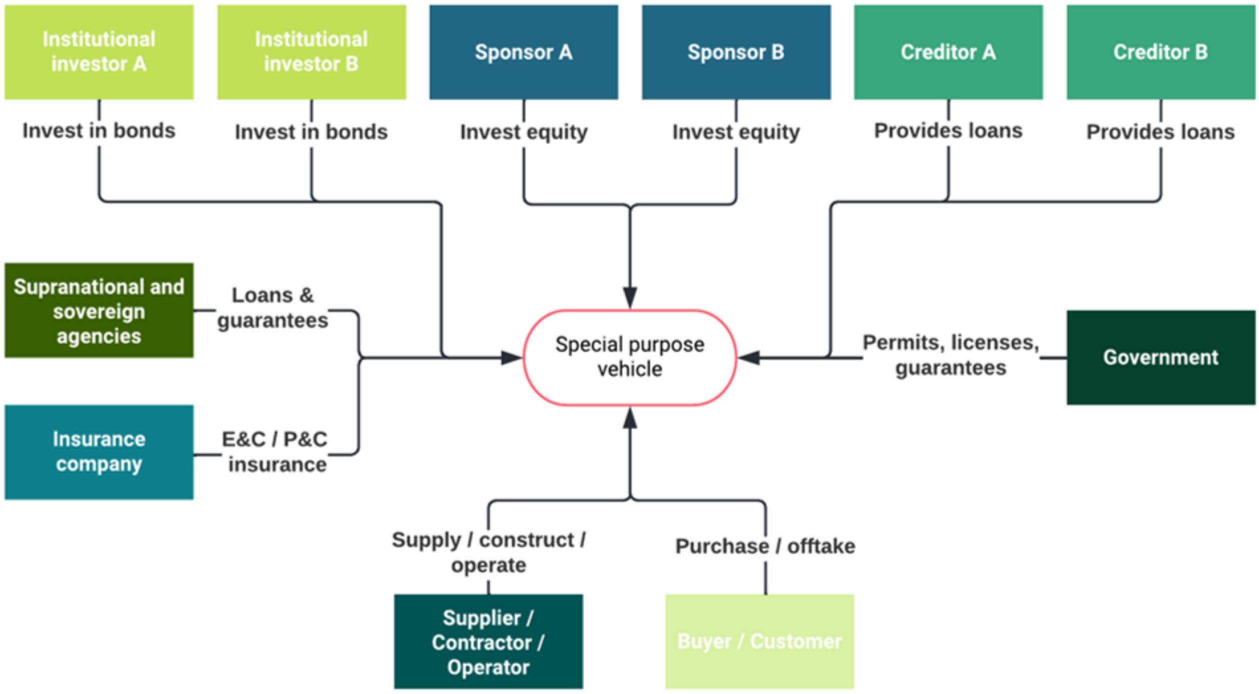
The financing of nuclear power plant construction projects deviates in some aspects from the above. In the case of nuclear power, financing by development finance institutions is rare. On the other hand, governments and export credit agencies frequently provide loans and/or guarantees.

Also, contractors and power off-takers may take a stake in the project. When doing research on project finance, an important activity is the mapping of all relevant actors for the project. These key actors are presented in Figure 8.

The central entity in this figure is the project company or special purpose vehicle. The project company is owned by the sponsors and manages the project assets. It arranges the licensing and contracting. Once construction is completed, the project company may continue as the power plant operator or owner or may be discontinued.

Governments may step into a construction project, and they may do so in virtually any role shown in the figure. The government may take a share in ownership, or a government agency may be the power off-taker. Also, the government may provide a loan or guarantee, or issue bonds. See section 2.4.6 for further explanation.

Figure 8 Key actors in a project



Source: Warmerdam, W. (2021), *Unravelling project finance,* presentation, Amsterdam: Profundo

2.3 Financial research

This research identified equity and debt financing. Equity financing is identified through a literature review, a search for new share issuances and capital injections preceding or during construction, and the determination of the project sponsors' ownership structure.

Debt financing is identified by reviewing specific project finance and corporate finance data sources. Sources used are global financial databases Bloomberg and Refinitiv, project finance database IJGlobal, private equity database Pitchbook, company database Orbis, and annual reports and financial statements published by the project sponsors. Additionally, portfolios of relevant development banks and export credit agencies were examined.

The financial research resulted in a large dataset, which was analysed for the purpose of this report. The dataset contains mostly finance deals earmarked as general corporate financing and, to a lesser degree, deals earmarked as project finance. The description and use of proceeds of the general corporate finance and project finance deals have been reviewed for the financing of a specific construction project.

Although this report presents financing for general corporate purposes, it cannot always be linked to a specific construction project. Financing for general corporate purposes can only be linked to a project when it is provided to a project company whose business activity is restricted to the construction project only. In the accompanying text, it is explained which general corporate financing is dedicated to a specific project.

2.4 Indicators for evaluating power plant construction projects

To compare energy infrastructure construction projects several indicators have been developed. This section explains the different indicators and defines the indicators used for the purpose of this study.

2.4.1 Realised construction cost

In the literature on project evaluation of power plant construction projects the Overnight Construction Cost (OCC) is widely used as an indicator for comparison. OCC is defined as the construction cost as if the project was realised straightforwardly and overnight. Problematically, OCC is *"not sensitive to lead time delays and consequently financial costs, the financial structure of projects, interest rate during the construction period and public subsidies."* [53]

Another indicator often used in comparing power plants is the levelised cost of electricity (LCOE). LCOE measures the cost of electricity generation for a power plant over its lifetime, including operation. However, the present research looks at construction costs, not operational costs, and not costs following the plant's closure.[i]

Since OCC and LCOE are unfit for the purpose of this research, the realised (or actual) construction cost is taken as the primary cost indicator. For this research, the realised construction cost is defined as the total of realised costs incurred before the start of commercial operation. It includes all capital expenditures, development costs, financing costs and other owners' costs.

The costs incurred during construction are exposed to price inflation. Combined with the lengthy lead times, the impact on the realised cost can be considerable. Since most sources used do not mention price levels, the identified costs have been applied in the calculations of this study without indexing. However, in principle, all cost estimates include the expected price inflation. The influence of inflation on the outcome is further limited by using the most recent cost insights (and associated price levels).

Due to deficiencies in the sources, not all types of costs for all construction projects can be identified. Therefore, the realised construction costs, as defined, represent our best estimate of the minimum costs involved in a project.

2.4.2 Reference net capacity

Nuclear power plants use different technologies, with different reactor types and installed capacities. To compare the construction costs among the different makes and models, an indicator commonly used is the cost per kilowatt capacity.

Several measures are used to indicate the capacity of a power plant:

- The nameplate or installed capacity;
- The designed net capacity;
- The reference net capacity.

The net capacity is the installed capacity minus the energy consumed by the power plant for its operations. The reference net capacity is the net capacity measured over a certain period of operation (the reference period).

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[i] Costs for dismantling and waste disposal are, in principle, accounted for in the operational stage in the form of a reservation of funds for these future costs. And should be included in the LCOE measure. However, there is clear evidence of too low reserves for past and running nuclear plants and much debate on the required reserves for future plants. See also Appendix 1.

Furthermore, a power plant produces energy in the form of electricity and heat. The research looks only at the electric output, and therefore, the parameter used is called the reference net capacity (electric).

2.4.3 Cost per kilowatt (electric)

In this study, the cost per kilowatt (electric) is defined as:

- The realised construction cost at the start of the commercial operation, divided by;
- The reference net capacity (electric);
- Resulting in the indicator expressed in euro per kilowatt electric (EUR/kWe).

2.4.4 Budget overruns

Several factors during several project stages cause the originally budgeted costs to be exceeded. The focus of this research will be on the additional costs that occur during the construction stage. Additional costs that have occurred pre-construction during the project preparation stages (policy-making, licensing, contracting, engineering) are not subject to the main analysis, but are mentioned where relevant.

The research will express the additional costs as a (construction) budget overrun. The (construction) budget overrun is defined as the difference between the budgeted construction costs at the start of construction and the realised construction costs at the start of the commercial operation. The budget overrun factor is defined as the ratio between these realised and budgeted costs.

2.4.5 Lead time escalations

Large-scale construction projects tend to extend beyond the originally intended construction period. This 'late delivery' aspect seems to occur almost without exception for various types of construction projects. Nuclear power plant construction projects are no exception to this 'rule'.

Various factors during several project stages cause the commissioned delivery date to be exceeded. The research focuses on the delays that occur during the construction stage. Delays that have occurred pre-construction during the project preparation stages (policy-making, licensing, contracting, engineering, and financing) are not subject to analysis.

For the purpose of this study, the delay is expressed as (construction) lead time escalation. The (construction) lead time is defined as the period between the start date of construction and the start date of the power plant's commercial operation. The lead time escalation is defined as the difference between the realised lead time and the originally scheduled lead time. The lead time escalation factor is defined as the ratio between these realised and scheduled lead times.

2.4.6 Government financing

Apart from being the initiating, licensing and supervising authority, a government may take part in a construction project in several roles:

- Taking a direct stake in the project company (equity financing);
- Attracting loans or issuing bonds (debt financing);
- Providing loans;
- Providing guarantees;
- Providing subsidies;
- Covering the liabilities in case of bankruptcy of a project participant (project company, sponsor, contractor, supplier, purchaser);
- Being the purchaser (power off-taker);

- Intervening (as the regulator) in the energy market by setting a minimum off-take price;
- Covering the liabilities in case of a nuclear accident.

When the government is not participating directly through an equity stake, the government may still be indirectly involved through its (partial) ownership of one or more of the project sponsors. In this study, the government's ultimate beneficial ownership of a power plant construction project is determined through an analysis of the company structure of the project sponsors. Theoretically, the government's ultimate beneficial ownership percentage can be translated into a government share of the initial equity investment by the project sponsors. This theoretical equity amount cannot be regarded as government financing, but it gives an indication of the indirect involvement of a government.

Governments also receive income from a construction project in the form of licensing costs and other fees. These costs may be cost-neutral, covering government agencies' expenses, or generate income.

This research attempts to quantify the government's share in equity and debt financing. Where available, the financial implications of the other mentioned roles are also quantified.

The government financing percentage is the share (%) of the total government financing to the project relative to either the debt financing or the equity financing. Theoretically, in case all debt and equity financing elements are known, the government percentage can be expressed as relative to the realised construction cost. However, due to a lack of source data, the government percentage of realised cost could not be determined. Instead, government participation is in the findings presented as the percentage of ultimate beneficial ownership (UBO).

3

Results: Six recent construction projects

This chapter describes the costs, financing, and lead times of the six selected construction projects of nuclear power plants in Finland, South Korea, the United Arab Emirates, the United States, France and the United Kingdom. This chapter is divided into a section per construction project. Each section discusses the history of the construction project, the ownership of the project company and the financing of the construction project.

3.1 Olkiluoto 3

This section presents the research findings of the construction project for Olkiluoto unit 3. The nuclear power plant is located in Eurajoki, Satakunta, Finland.

3.1.1 History

Two older units have been operating at the site since 1978 and 1980, respectively. Teollisuuden Voima Oyj (TVO) operates the plant.[54]

Unit 3 is a pressurised water reactor of the model EPR-1600 with a gross capacity of 1,660 MWe and a net reference capacity of 1,600 MWe.[55]

The development of unit 3 started in November 2000, when TVO made an application. In May 2002, the Finnish parliament approved the building of the unit, to be in operation in mid-2009. In October 2003, TVO announced that Areva NP would supply the reactor and Siemens the turbines and generators.[56]

The construction started on 12 August 2005.[57] The commercial operation started on 1 May 2023.[58] Therefore the realised construction lead time is 17.4 years. The lead time escalation is 13.8 years, and the lead time escalation factor is 4.9.

3.1.2 Ownership

Teollisuuden Voima Oyj (TVO) acted as the project agent. Its main business is operating power plants.

The financing was arranged through a typical Finnish model called the Mankala-model. In the Mankala model, a consortium of owners is formed that consists of the future power off-takers of the power plant. TVO is owned by five shareholders, some of which, like TVO, also operate according to the Mankala principle. TVO's shareholders are Finnish industrial and energy companies, whose owners include 131 Finnish municipalities.[59]

TVO is a joint venture owned by five companies: [60]

- Pohjolan Voima Oyj (58.5%);
- Fortum Power and Heat Oy (25.8%);
- Oy Mankala Ab (8.2%);
- EPV Energia Oy (6.6%);
- Kemira Oyj (0.9%).

Most of TVO's shareholders are energy companies. Two of them operate on the Mankala principle (second level of Mankala). This applies to Pohjolan Voima and EPV Energia Oy.[61]

The controlling shareholder of Pohjolan Vojma is UPM-Kymmene Oyj (UPM) with 51.52% of shares.[62] UPM is a wood processing company (pulp and paper, wood and biofuels). It is ultimately owned (54.74%) by Skandinaviska Enskilda Banken (SEB).[63]
SEB Group is publicly listed. Among its largest shareholders are Investor AB (Wallenberg family, Sweden), AMF Pension (Sweden), Alecta Tjänstepension (Sweden) and Swedbank (Sweden).[64]

Fortum Power and Heat Oy is 100% owned by Fortum, a state-controlled entity with 53.05% of the shares owned by the Government of Finland.

Oy Mankala Ab is a hydropower electricity production company. It is 100% owned by Helen Ltd (ownership 100%). Helen Group is a holding company of energy-producing companies (hydro, wind, solar, geothermal, district heating). It is owned by the City of Helsinki.[65]

EPV Energia Oy produces and supplies energy to its shareholders following the Makala principle. EPV Energia's shareholders are 20 energy companies. Largest shareholders are Vaasan Sähkö Oy 42.92%), Seinäjoen Energia Oy (11.89%) and Lahti Energia Oy (8.37%). These tree companies are government-owned (by the cities of Vaasan. Seinäjoen and Lahit, respectively).[66] Therefore, EPV Energia is majority-owned by government bodies in Finland.

Kemira Oyj is a chemical company. The government of Finland is a former shareholder who fully divested in 2024. Largest shareholder is the Paasikivi family (through investment company Oras Invest Oy, 22.6%). Nordea Bank owns 4.73% and Varma Pension 3.89% of the shares.[67]

The ownership structure of TVO is presented in Figure 9.

An analysis of government ownership of all entities in the ownership structure should be made to determine the ultimate government ownership share. Since the number of entities is too large, the minimum government ownership is determined instead. Following the percentages from Figure 9, Olkiluoto 3 is owned by the government with a percentage of at least 28.5%.

Figure 9 Ownership structure of Olkiluoto 3

Sources: See text.

3.1.3 Financing

TVO operates on the Finnish cost-price principle (Mankala principle). This principle states that TVO supplies energy to its shareholders at cost price and delivers the energy it produces to its shareholders in proportion to their ownership.[68]

The project is partly financed through the balance sheet of Teollisuuden Voima Oyj (TVO), with a debt-equity ratio of 75/25.[69] In October 2003, TVO signed a EUR 3.2 billion turnkey contract with the consortium of contractors Areva/Siemens lead by Areva NP.[70] Areva NP was at the time a joint venture owned 66% by Areva and 34% by Siemens.[71]

Since the construction contract is on a turn-key basis, the project sponsors nor the Finnish government are exposed to any risk. The contractor and its ultimate beneficial owners (later: the French government) take the financial risk.[72]

Areva SA suffered large losses from the Oliluoto-3 project. In 2014, the International Atomic Energy Agency (IAEA) stated that Areva made provisions for the write-down of EUR 2.7 billion in its accounts. [73] In June 2016, it was restructured. The main activities were spun off and split into three new companies, with the reactor business continuing as Areva NP and becoming part of EDF. EDF did not take over the activities for Olkiluoto-3, which were continued by Areva SA.[74]
Following the restructuring in 2016, Areva SA's remaining main business activity was the completion of Olkiluoto 3. In January 2017, the French government nationalised Areva. The French government (owning 97% of shares at the time) offered EUR 4.5 per share for the remaining 13%

held by minority investors, including Kuwait's investment fund, EDF and Total (later: TotalEnergies).[75] In July 2017, the French government provided Areva SA with a capital increase of EUR 2 billion "*to meet its cash requirements and ensure the successful completion of the OL3 project*".[76] Before the spin-off parts (called Areva NewCo) were handed over to EDF, the Government of France injected another EUR 2.5 billion of capital into the company.[77]

In March 2018, a settlement was agreed upon in the dispute on cost and schedule overruns. Areva/Siemens claimed EUR 3.52 billion for delayed payments, penalty interest and loss of profit. TVO counterclaimed costs and losses of EUR 2.8 billion. According to the settlement Areva/Siemens had to pay EUR 450 million to TVO.[78]
According to an analyst article on NucNet: *"According to TVO, the original budget for the project was around €3bn. The company said in its Q1 interim report that its "total investment" will be approximately €5.8bn. TVO bought the plant at a fixed price from Areva-Siemens and went to arbitration to settle a dispute over cost overruns. An industry analyst in Finland told NucNet the cost for the suppliers, Areva-Siemens, is likely to bring the total to around €10bn. Bloomberg has put the figure at around €8bn."* [79]Following the settlement, the 2019 WNISR report estimated TOV's total investment to be around EUR 5.5 billion, based on TVO's current capital assumptions and the effect of the settlement agreement. Areva SA's incurred losses were estimated at EUR 5.5 billion, bringing the total estimate to EUR 11 billion.[80]

- **Estimation of realised cost**

Based on the given information, the realised cost is estimated at EUR 11 billion. This figure includes the amounts mentioned in the settlement, taking into account the delayed payments part of the original contract and the EUR 2 billion capital injection. The capital injection in Areva Newco is not accounted for.

If a total realised cost of EUR 11 billion is assumed, the budget overrun amounts to EUR 7.8 billion, which is a budget overrun factor of 3.4.

Areva collapsed in large part due to the Olkiluoto losses.[81] In theory, the nationalisation costs carried by the French government should also be accounted for.

- **Debt financing**

Several loans provided to TVO and several bonds issued by TVO have been identified.

Table 6 shows the deals earmarked as project finance. The export credit by the French export credit agency Coface is a guarantee. In total, the initial project finance has a value of EUR 2,020 million, specifically.

Table 6 Initial debt financing of TVO (2003-2004), earmarked as project finance

Closing/issue date	Type of finance	Description	Use of proceeds	Value (EUR mln)
17 Dec 2003	Loan	Credit facility by BLB, BNP Paribas, JP Morgan, Nordea and Svenska Handelsbanken	Project finance	1,350
25 March 2004	Guarantee	Export credit by Coface	Project finance	570
25 March 2004	Loan	Credit facility by BNP Paribas, BLB, Nordea and Svenska Handelsbanken and HSBC.	Project finance	570
25 March 2004	Loan	Bilateral loan by AB Svensk Exportkredit (SEK)	Project finance	100

Source: IJGlobal (2024), 'Transaction date of selected companies', viewed in July 2024; Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

Table 7 shows the debt financing to TVO for general corporate purposes. In the period 2005-2021, TVO attracted a total value of EUR 14.6 billion.

Table 7 Debt financing to TVO (2005-2021), earmarked for general corporate purposes

Bank	Country	Loans	Underwriting	Total
BNP Paribas	France	2,548	412	2,960
Nordea	Finland	895	625	1,521
Skandinaviska Enskilda Banken	Sweden	737	516	1,253
NatWest	United Kingdom	546	701	1,247
Crédit Agricole	France	546	497	1,043
OP Financial Group	Finland	620	404	1,024
Danske Bank	Denmark	445	510	955
Mitsubishi UFJ Financial	Japan	663	230	893
Mizuho Financial	Japan	546	288	834
Svenska Handelsbanken	Sweden	546	224	770
Swedbank	Sweden	546	216	762
JPMorgan Chase	United States		323	323
BayernLB	Germany	275		275
Barclays	United Kingdom	101	129	230
Deutsche Bank	Germany	101	129	230
Crédit Mutuel	France	101		101
Sampo Group	Finland	101		101
SMBC Group	Japan	101		101
Total		**9,419**	**5,204**	**14,623**

Source: Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

Being earmarked for general corporate purposes, it cannot be said which part of the finance deals was used to finance the construction of Olkiluoto 3. The proceeds may have been used for the operation of Olkiluoto 1-2, the operation of other TVO power plants, or the construction of Olkiluoto 3. Some of the deals involve refinancing.

The loans by the Bayerische Landesbank (BayernLB or BLB) are seen as indirect support of the German Government. [82] BLB is 75% owned by the Government of Bavaria. BLB financed EUR 384 million in project finance and EUR 275 million in corporate finance, for a total of EUR 659 million. For our analysis, 75% of this value is attributed to the Government of Germany (EUR 494 million).

In Table 8 the financing activity in the years around the start of commercial operation (May 2023) is shown. These deals possibly concern the debt refinancing of construction costs.

Table 8 Debt (re-)financing to TVO at project end (2022-2024)

Closing/issue date	Type of finance	Description	Use of proceeds	Value (EUR mln)
24 March 2022	Bond	Teollisuuden Voima Note 2022	Corporate finance	600
15 June 2022	Loan	TVO Refinancing 2022	Corporate finance	1,000
23 May 2023	Bond	Teollisuuden Voima Note 2023 (May)	Corporate finance	600
16 August 2023	Bond	Teollisuuden Voima Note 2023 (August)	Corporate finance	195
15 may 2024	Bond	Teollisuuden Voima Green Bond 2024 (May)	Corporate finance	600

For debt financing of Areva and EDF, see Section 3.5.3.

- **Equity financing**

With the initial budgeted cost of EUR 3.2 billion and the 75/25 debt-equity ratio, the initial equity is EUR 800 million. There are no indications that the additional equity has been raised by the project sponsors during construction.

The distribution of the initial equity provided by the project sponsors is:

- Pohjolan Voima Oyj: EUR 468 million;
- Fortum Power and Heat Oy: EUR 206 million;
- Oy Mankala Ab: EUR 66 million;
- EPV Energia Oy: EUR 53 million;
- Kemira Oyj: EUR 7 million;

- **Government financing**

The Finnish government's role appears to be marginal, as the project company and its (Mankala) sponsors arrange the financing, and builder Areva bears the additional costs.[83]

Looking at ultimate beneficial ownership, the government owns 24.9% or more of the Olkiluoto 3 project. This translates into a theoretical government share of EUR 199 million in the initial sponsor's equity.

On the debt side, the research identified an export guarantee by Coface (French government), an export loan by Svensk Exportkredit (Swedish government), and a commercial loan by BLB (backed by the German government). The French export guarantee led to equivalent commercial loans.

Therefore, the government debt financing consists of the EUR 100 million Swedish loan and part of the BLB's commercial loan (EUR 494 million). Related to total financing, the percentage financed by the Swedish and German governments is 5.4%.

The French government provided a minimum EUR 2 billion capital injection to fulfil Areva's contract obligations. As a result, the French government's contribution can be set at a minimum of 18.1% of total realised cost.

This percentage ignores the losses made by Areva and EDF in their accounts at the expense of their shareholders' value, the French government's capital injection into Areva NewCo, and the French government's nationalisation costs.

Adding up the Swedish, German and French government contributions the final government percentage is a minimum of 23.6% of the realised cost.

Despite the limited role of the national (Finnish) government in direct equity and direct debt financing, also Olkiluoto 3 is an example that nuclear power plant construction projects do not take place without government interference:[84]

- The responsibility for nuclear accidents was strongly limited by the state;
- State-owned power company's (currently Fortum) share in TVO was originally a political prerequisite for the realisation of TVO nuclear plans;
- The export credit guarantee from the French government, the export credit loan from the Swedish government and the BLB loan favoured by the German government assisted in attracting further commercial financing.

- **Financing model**

Usually, Olkiluoto 3's financing model is referred to as the Mankala model. However, when looking at the ultimate beneficial ownership of the participants in the Mankala cooperatives, the Finnish national government and many local governments are involved, bringing in at least 24.9% of the sponsor's equity.

Furthermore, the French, German and Swedish governments supported the debt financing.

In conclusion, the financing model can be described as a mix of corporative financing, (national and local) government financing, foreign government financing and a foreign government guarantee.

3.1.4 Results

The case of the Olkiluoto 3 construction project resulted in the following findings:

- **Known key elements of the financing**
    - Governments of Finland (as ultimate beneficial owner, theoretically 24.9% of sponsor's equity): EUR 199 million
    - Export credit guarantee (French government) EUR 570 million;
    - Export credit loan (Swedish government): EUR 100 million;
    - Project finance by commercial lenders: EUR 1,536 million;
    - Loans from BLB (partly attributed to the German government): EUR 494 million;
    - Part of proceeds of bonds issued by TVO;
    - Losses by Areva SA: EUR 3.5 billion;
    - Losses by EDF;
    - Capital injection by French government in Areva SA: EUR 2 billion;
    - Part of capital injection (EUR 2.5 billion) by French government in Areva NewCo;
    - Part of Areva nationalisation costs by French government;
    - Part of EDF nationalisation costs by French government.

0 gives an overview of the key findings on Olkiluoto 3.

Table 9 Key findings for Olkiluoto 3 construction project

Indicator	Unit	Key data
Financing model	-	Government /Corporate/ Cooperative
Budgeted cost	EUR mln	3,200
Realised cost	EUR mln	11,000
Budget overrun	EUR mln	7,800
Budget overrun factor	**-**	**3.4**
Construction start	-	12-Aug-05
Scheduled commercial operation	-	30-Jun-09
Commercial operation start	-	1-May-23
Planned construction time	Years	3.9
Realised construction time	Years	17.7
Lead time escalation	Years	13.8
Lead time escalation factor	**-**	**4.6**
Reference net capacity	MWe	1,600
Cost per kilowatt (electric)	**EUR/kWe**	**6,875**
Government participation (UBO)	%	28.5%

3.2 Shin Hanul 1-2

Shin Hanul units 1 and 2 are located in Uljin County, North Gyeongsang Province, South Korea.

3.2.1 History

The two power plant units 1 and 2 have been commissioned and are owned and operated by Korea Hydro & Nuclear Power Company. The reference net capacities are 1,414 and 1,340 MWe. [85]

The construction of units 1 and 2 started in July 2012 and June 2013, respectively.[86] The units were scheduled to start commercial operation in April 2017 and April 2018.[87] The commercial operation started in December 2022 and April 2024.[88]

For the two units combined, the realised construction lead time is 11.7 years. The lead time escalation is 6.0 years, a factor of 2.1.

3.2.2 Ownership

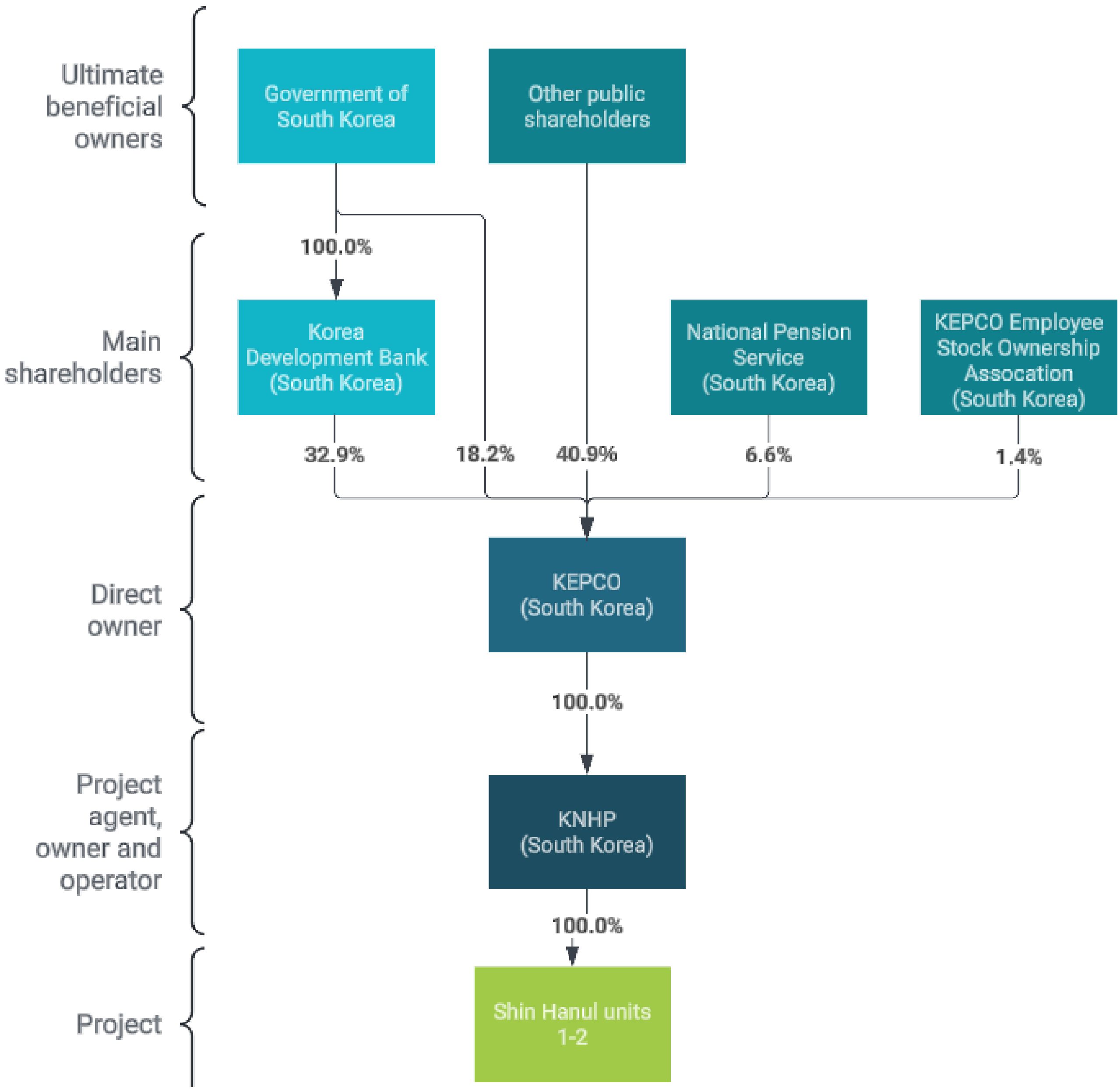
Shin Hanul 1 and 2 are 100% owned and operated by Korea Hydro & Nuclear Power Company (KHNP). KHNP is 100% owned by Korea Electric Power Corp (KEPCO).

KEPCO is a government-owned company with a controlling interest of 51.1% in the hands of the Government of South Korea. This is composed of 18.2% of the shares held directly and 32.9% held indirectly via the Korea Development Bank, which is 100% owned by the Government of South Korea.[89]

Other strategic entities among the shareholders are the National Pension Service of Korea (6.6%) and the KEPCO Employee Stock Ownership Association (1.4%). The remaining shares are traded on the stock exchange market (40.9%). The largest shareholders are Research Affiliates LLC (United States), with 0.13% of the shares, and State Street Global Advisors Ltd, with 0.07% of the shares.[90]

The ownership structure is presented in Figure 10.

Figure 10 Ownership structure of Shin Hanul 1-2



Sources: KEPCO (2023), "Shareholder structure of Korea Electric Power Corp. as of December 31, 2023", online: https://home.kepco.co.kr/kepco/EN/C/htmlView/ENCCHP003.do?menuCd=EN030303, viewed in July 2024; Market Screener (2024), "Shareholders Kepco, as of 22 July 2024", online: https://www.marketscreener.com/quote/*stock/KOREA-ELECTRIC-POWER-CORP-6494969/company/, viewed in July 2024*.

3.2.3 Financing

As of April 2009, the costs were originally budgeted at KRW 7 trillion (USD 6 billion, EUR 3.95 billion).[91]

In October 2017, costs were estimated at KRW 7.98 trillion (USD 7.01 billion or EUR 6.10 billion).[92]

In June 2023, costs were estimated at USD 7.6 billion (EUR 6.4 billion).[93]

Assuming the June 2023 figure was the total realised cost, the budget overrun amounts to EUR 2.45 billion, a factor of 1.6.

- **Debt financing**

The research identified debt financing attracted by KHNP in the form of bonds with a value of EUR 2,188 million. No loan deals were identified. Also, no project finance was identified, see Table 10.

Since KHNP was not only developing Shin Hanul 1-2 but operated many other power plants during the period, the identified corporate finance cannot be attributed specifically to the Shin Hanul 1-2 project.

Table 10 Debt financing of KHNP (2009-2024)

Closing/issue date	Type of finance	Description	Use of proceeds	Value (EUR mln)
22 July 2024	Bond	KHNP Note 2024 / Commercial Bond (USD 500.00m), underwritten by Bank of America, Citigroup, Credit Agricole, JP Morgan, Standard Chartered Bank, UBS	Corporate finance	459
11 July 2023	Bond	Korea Hydro & Nuclear Power Green Note 2023 / Green Bond (USD 500.00m), underwritten by Bank of America, Citigroup, Credit Agricole, Societe Generale, Standard Chartered Bank	Corporate finance	456
21 April 2021	Bond	Korea Hydro & Nuclear Power Bond 2021 / Commercial Bond (USD 500.00m), underwritten by Bank of America, Citigroup, Credit Agricole, HSBC, JP Morgan, UBS	Corporate finance	415
25 July 2018	Bond	Korea Hydro & Nuclear Power Green Note 2018 / Green Bond (USD 600.00m), underwritten by BNP Paribas, Citigroup, HBSC, JP Morgan and Korea Development Bank.	Corporate finance	513
6 July 2011	Bond	KHNP Bond 2011 (July) / Commercial Bond (USD 500.00m), underwritten by Barclays, Golden Sachs, Morgan Stanley, Royal Bank of Scotland.	Corporate finance	345
Total				**2,188**

Source: IJGlobal (2024), 'Transaction date of selected companies', viewed in July 2024; Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

In the period 2009-2024, KHNP's immediate owner KEPCO issued bonds with a total value of USD 21 billion (EUR 18 billion).[94] None of these deals was earmarked for Shin Hanul 1-2. Also, no loan deals were identified for KEPCO. Since Shin Hanul 1-2 is a domestic project, export credit was not applicable. Financing by the Korea Development Bank was not identified.

Based on an assumed 70/30 debt-equity ratio and an identified realised cost of EUR 6.4 billion, the amount of raised debt would be an estimated EUR 4.48 billion.

- **Equity financing**

Based on the assumed 70/30 debt-equity ratio, the initial equity is EUR 1.2 billion, solely borne by KHNP and its immediate parent, KEPCO.

Looking at the ultimate beneficial ownership, the initial equity amount that theoretically can be attributed to the Government of South Korea (51.1%) is EUR 606 million.

- **Financing model**

The financing is provided with corporate equity and commercial debt. However, KHNP is majority-owned by the South Korean government, and therefore state-controlled. For this reason, the model is called a mix of government and corporate financing.

- **Government financing**

The government did not invest direct equity in the project. Debt financing by the government was not identified, but it cannot be ruled out.

- **Finance not directly related to Shin Hanul 1-2**

In 2022, KEPCO filed a record loss of USD 25 billion, with its net debt jumping by 32% to an unprecedented USD 149 billion. KEPCO stock lost 70% of its value over the past seven years.[95] It is not known whether these losses are related to the financing of Shin Hanul 1-2.

- **Additional cost for alternate fuel during lead time escalation**

The delayed construction in the case of Shin Hanul 1-2 led to additional costs for alternate fuel, a type of cost that is usually not accounted for.

The construction was delayed by the former Moon Jae-in administration's nuclear phase-out policy, which forced the country to source electricity from LNG instead. The price difference between electricity generated from LNG and nuclear translates into an additional cost of KRW 9.24 trillion (USD 6.79 billion or EUR 6.47 billion).[96] Taking this loss into account would double the overall costs of Shin Hanul 1-2.

3.2.4 Results

The case of the Shin Hanul 1-2 construction project resulted in the following findings:

- **Known key elements of the financing**
    - Government of South Korea (theoretically as ultimate beneficial owner, 51.1% of sponsor's equity): EUR 606 million;
    - Debt financing: 4.48 billion;
    - Possibly a loss in shareholders' value of KEPCO stock.

0 gives an overview of the key findings on Shin Hanul 1-2.

Table 11 Key findings for Shin Hanul 1-2 construction project

Indicator	Unit	Key data
Financing model	-	Government/ Corporate
Budgeted cost	EUR mln	3,950
Realised cost	EUR mln	6,400
Budget overrun	EUR mln	2,450
Budget overrun factor	**-**	**1.6**
Construction start	-	10-Jul-12
Scheduled commercial operation	-	1-Apr-18
Commercial operation start	-	5-Apr-24
Planned construction time	Years	5.7
Realised construction time	Years	11.7
Lead time escalation	Years	6.0
Lead time escalation factor	**-**	**2.1**
Reference net capacity	MWe	2,754
Cost per kilowatt (electric)	**EUR/kWe**	**2,324**
Government participation (UBO)	%	51.1%

3.3 Barakah 1-4

Barakah units 1 to 4 are located in Ruwais, Abu Dhabi, United Arab Emirates.

3.3.1 History

The Barakah nuclear power plant is the first nuclear power plant in the United Arab Emirates.

The reactors are pressurised water reactors of the model APR-1400. The technology is from South Korea, and they are the same reactor type as at Shin Hanul.

Barakah One Company JSC is the project company. It is a joint venture between Emirates Nuclear Energy Corporation (United Arab Emirates) and Korea Electric Power Corp (South Korea).

The operator is Nawah Energy Company (United Arab Emirates).

The contracting consortium partners are Samsung, Hyundai Heavy Industries, Doosan Heavy Industries, Westinghouse and Toshiba.

Construction of unit 1 started on 19 July 2012.[97] Unit 4 was originally scheduled to start commercial operation in July 2018.[98] Unit 4 was connected to the grid in March 2024.[99] The commercial start is expected in September 2024.

Based on these figures, the realised construction time is 12.1 years, with a lead time escalation of 6.2 years, a factor of 2.0.

3.3.2 Ownership

The Barakah power plant project company is called Barakah One Company JSC. It is a joint venture company, owned 82% by Emirates Nuclear Energy Corporation (United Arab Emirates) and 18% by Korea Electric Power Corp (South Korea).[100]

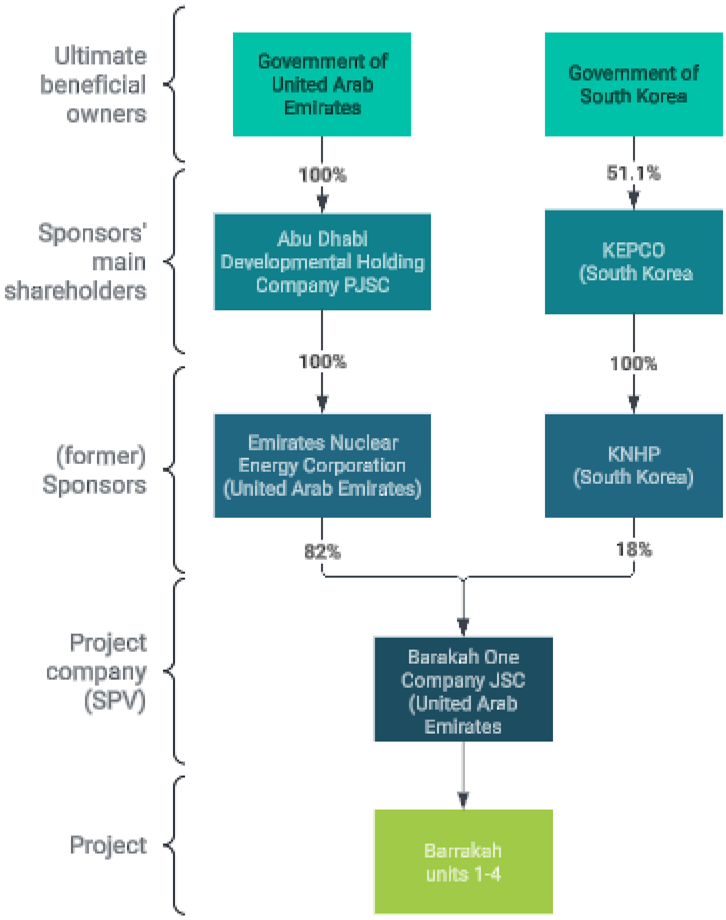
Emirates Nuclear Energy Corporation (ENEC) is owned by Abu Dhabi Developmental Holding Company PJSC (ADQ), which is owned by of Abu Dhabi Developmental Holding Group PJSC. This holding group is an investment holding of the Government of Abu Dhabi. All relations in this ownership structure are 100%.[101]

The government of South Korea owns 51.1% of Korea Electric Power Corp (KEPCO), see further section 3.2.2.

Taking the ultimate beneficial ownership of the two governments together, the government participation is 91.2%.

The ownership structure of Barakah 1-4 is presented in Figure 11.

Figure 11 Ownership structure Barakah unit 1-4



Sources: See text.

3.3.3 Financing

In 2009, the originally budgeted costs announced by ENEC were USD 20 billion (EUR 14.0 billion).[102]

In October 2016, ENEC and KEPCO announced the financial close of the Barakah project. The overall project financing requirements are estimated at USD 24.5 billion (EUR 22.3 billion), financed through:[103]

- A total of USD 21.8 billion (EUR 19.8 billion) in debt financing:
  - USD 19 billion (EUR 17.3 billion) provided as a direct loan from the Government of Abu Dhabi;
  - USD 2.5 billion (EUR 2,3 billion) provided as a direct loan from the Korea EximBank (KEXIM);
  - USD 250 million (EUR 228 million) in loan agreements with commercial banks;
- A total of USD 4.7 billion (EUR 4.3 billion) in equity commitments for the establishment of the Barakah One Project Joint Venture Company in exchange for an equity interest in the company, shared between ENEC and KEPCO.
- Note: The sum of the contributions mentioned by ENEC is USD 26.45 billion (EUR 24.1 billion), higher than the budgeted cost, therefore possibly including financing costs.

In conclusion, the realised cost is EUR 24.1 billion, resulting in a budget overrun of EUR 9.9 billion and a budget overrun factor of 1.7.

- **Debt financing**

Several loans to the project company were identified, but no bond issuances. The total project finance identified is EUR 21.6 billion (excluding the 2024 refinancing of the KEXIM loan), see Table 12.

Table 12 Debt financing of Barakah One Co (2009-2024)

Closing/issue date	Type of finance	Description	Use of proceeds	Value (EUR mln)
20 October 2016	Loan	Barakah Nuclear Power Plant (5600MW) / Government Loan (USD 16,237.00m) 20 Oct 2016 provided by Government of Abu Dhabi	Project finance	14,789
20 October 2016	Loan	Barakah Nuclear Power Plant (5600MW) / Equity Bridge Loan (USD 4,727.00m) 20 Oct 2016 by Government of Abu Dhabi	Project finance	4,305
20 October 2016	Loan	Barakah Nuclear Power Plant (5600MW) / Commercial Loan (USD 250.00m) 20 Oct 2016, provided by First Abu Dhabi Bank, National Bank of Abu Dhabi, Standard Chartered Bank.	Project finance	228
20 October 2016	Loan	Barakah Nuclear Power Plant (5600MW) / Export Credit Facility (USD 2,500.00m) 20 Oct 2016, provided by KEXIM	Project finance	2,277
22 July 2024	Loan	Barakah Nuclear Power Plant (5600MW) Refinancing 2023 / Green Loan (AED 9,200.00m / USD 2,504.78m) 04 Jul 2023, outstanding balance USD 2,420m, provided by Abu Dhabi Commercial Bank, First Abu Dhabi Bank, HSBC, Standard Chartered Bank.	Project finance	2,222

Source: IJGlobal (2024), 'Transaction date of selected companies', viewed in July 2024; Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

No loans and bonds were identified for the project company's immediate parent, ENEC. However, ENEC's immediate parent, ADQ, attracted EUR 11.4 billion in loans and EUR 2.1 billion in bonds from 2009 to 2024. ADQ has a wide range of businesses, so the amounts cannot be linked to Barakah 1-4.

For debt financing attracted by KHNP and KEPCO, see Section 3.2.3.

On 4 July 2023, the outstanding balance (USD 2.42 million or EUR 2.22 million) of the KEXIM loan was refinanced by four banks.[104] This deal became the 'ESG Loan deal of the year':

Barakah One Company wins ESG financing award for groundbreaking green refinancing

"ENEC's Barakah One Company has been selected as winner of the ESG Loan Deal of the Year for the 2024 edition of the prestigious Bonds, Loans & Sukuk Middle East Awards for the $2.42bn refinancing of the Barakah Nuclear Energy Plant project. The Barakah Nuclear Energy Plant refinancing loan, in partnership with First Abu Dhabi Bank (FAB) and Abu Dhabi Commercial Bank (ADCB was the first in the MENA Region and Asia to be independently recognized as a green loan facility. The green refinancing was achieved through participation of prominent UAE banks, supporting the UAE's In-Country Value Program and underscoring the important role of the nuclear energy sector in contributing to the UAE's green economy through clean, carbon-free electricity".

The total identified debt financing is EUR 23.8 billion. However, the 2024 refinancing should be deducted. This brings the total debt financing to EUR 21.6 billion.

- **Debt-equity ratio**

Based on the initial debt and equity at the financial close in 2016, the debt-equity ratio is 82/18.

- **Equity financing**

The initial equity investment at the financial close in 2016 was EUR 4.3 billion. The project company Barakah One Co is an 82/18 joint venture of ENEC and KEPCO. Therefore the initial investment of capital was:

  - ENEC: 3.5 billion;
  - KEPCO: 0.8 billion.

- **Government financing**

The Government of United Arab Emirates financed 3.5 billion in equity (via ENEC) and 19.0 billion in debt (direct loan). This translates into 82% of equity and 88% of debt.

Theoretically, the Government of South Korea financed EUR 396 million in equity (via its 51.1% share in KEPCO). Furthermore, it financed EUR 2.3 billion in debt (via KEXIM). This translates into 9% of equity and 11% of debt.

The two governments' theoretical equity share is EUR 3.9 billion in initial equity (91.2%).

The two governments' share of debt financing is EUR 21.4 billion of the initial lending (98.9%).[ii]

3.3.4 Results

The case of the Barakah 1-4 construction project resulted in the following findings:

- **Known key elements of the financing**
  - Initial equity ENEC: 3.5 billion;
  - Initial equity KEPCO: 0.8 billion;
  - Project finance: EUR 21.6 billion;
  - Government of UAE loan: EUR 19.1 billion;
  - Government of South Korea (KEXIM export credit): EUR 2.3 billion.

0 gives an overview of the key findings on Barakah 1-4.

ii From the 2016 commercial loan (EUR 227 million), First Abu Dhabi Bank financed EUR 72 million. First Abu Dhabi Bank is 33% owned by the Abu Dhabi Investment Council Company, which is state-owned. Attributing the EUR 72 million to the government would not change the mentioned government percentages. In the same way, the 2023 commercial refinancing can be attributed to the Government of Abu Dhabi (for 8.3%).

Table 13 Key findings for Barakah 1-4 construction project

Indicator	Unit	Key data
Financing model	-	Government/ Corporate
Budgeted cost	EUR mln	14,100
Realised cost	EUR mln	24,000
Budget overrun	EUR mln	9,900
Budget overrun factor	**-**	**1.7**
Construction start	-	19-Jul-12
Scheduled commercial operation	-	1-Jul-18
Commercial operation start	-	1-Sep-24
Planned construction time	Years	5.9
Realised construction time	Years	12.1
Lead time escalation	Years	6.2
Lead time escalation factor	**-**	**2.0**
Reference net capacity	MWe	5,321
Cost per kilowatt (electric)	**EUR/kWe**	**4,510**
Government participation (UBO)	%	91.2%

3.4 Vogtle 3-4

Vogtle units 3 and 4 are located in Waynesboro, Georgia, United States.

3.4.1 History

The Alvin W. Vogtle nuclear power plant initially had two units that have been in operation since 1987 and 1989.[105]

Vogtle 3-4 is owned by four sponsors: Georgia Power, Oglethorpe Power Corp, MEAG Power, and Dalton Utilities. The sponsors appointed Southern Nuclear Operating Co Inc (Southern Nuclear) to act as the agent for licensing, engineering, procurement, contract management, construction, and pre-operation services for units 3 and 4.[106]

The development of units 3 and 4 started in August 2006 when Southern Nuclear submitted an Early Site Permit (ESP) application for two additional units at the Vogtle site. In August 2008, the U.S. Nuclear Regulatory Commission (NRC) issued the final Environmental Impact Statement (EIS) for the Vogtle ESP application. The NRC issued the ESP in August 2009.[107] In March 2008, Southern Nuclear filed a Combined Construction and Operating License (COL) application with the NRC. [108]

Construction of units 3 and 4 began on 22 June 2009. In April 2011, the mud mats for units 3 and 4 were poured. In July 2011, the floor section of the AP-1000 reactor was delivered to the side. In February 2012, the NRC issued the COLs for the two units.[109] Construction of the reactor of unit 3 started in March 2013. Eight months later, construction started on the reactor of unit 4 (in November 2013).[110]

The primary contractor was Westinghouse, which filed for bankruptcy in March 2017. However, the construction did not get delayed, with Southern Nuclear taking on the role of project manager and construction firm Bechtel managing the daily construction efforts. In December 2017 Georgia Power, on behalf of the project sponsors, received approval to complete Vogtle 3 and 4. In December 2017 the commercial operation was expected to start in November 2021 (unit 3) and November 2022 (unit 4).[111]

Finally, the commercial operation started in July 2023 (unit 3) and April 2024 (unit 4).[112]

Initially, in 2008, the commercial operation was expected to start in 2016 and 2017.[113]

Therefore, the scheduled construction lead time for the units combined was 8.5 years. The realised construction lead time for the units combined is 14.9 years. The lead time escalation is 6.3 years, which gives a factor of 1.7.

Southern Nuclear, the same company that served as the project agent, operates the power plant (all 4 units).[114]

3.4.2 Ownership

Vogtle 3 and 4 are owned by a consortium of four power-generating companies in the state of Georgia: Georgia Power (45.7%), Oglethorpe Power Corp (30.0%), MEAG Power (22.7% and Dalton Utilities (1.6%).

Georgia Power is 100% owned by Southern Co, a publicly listed company. The largest shareholders are Vanguard (9.2% of shares), Blackrock (7.1%), and State Street (5.3%).

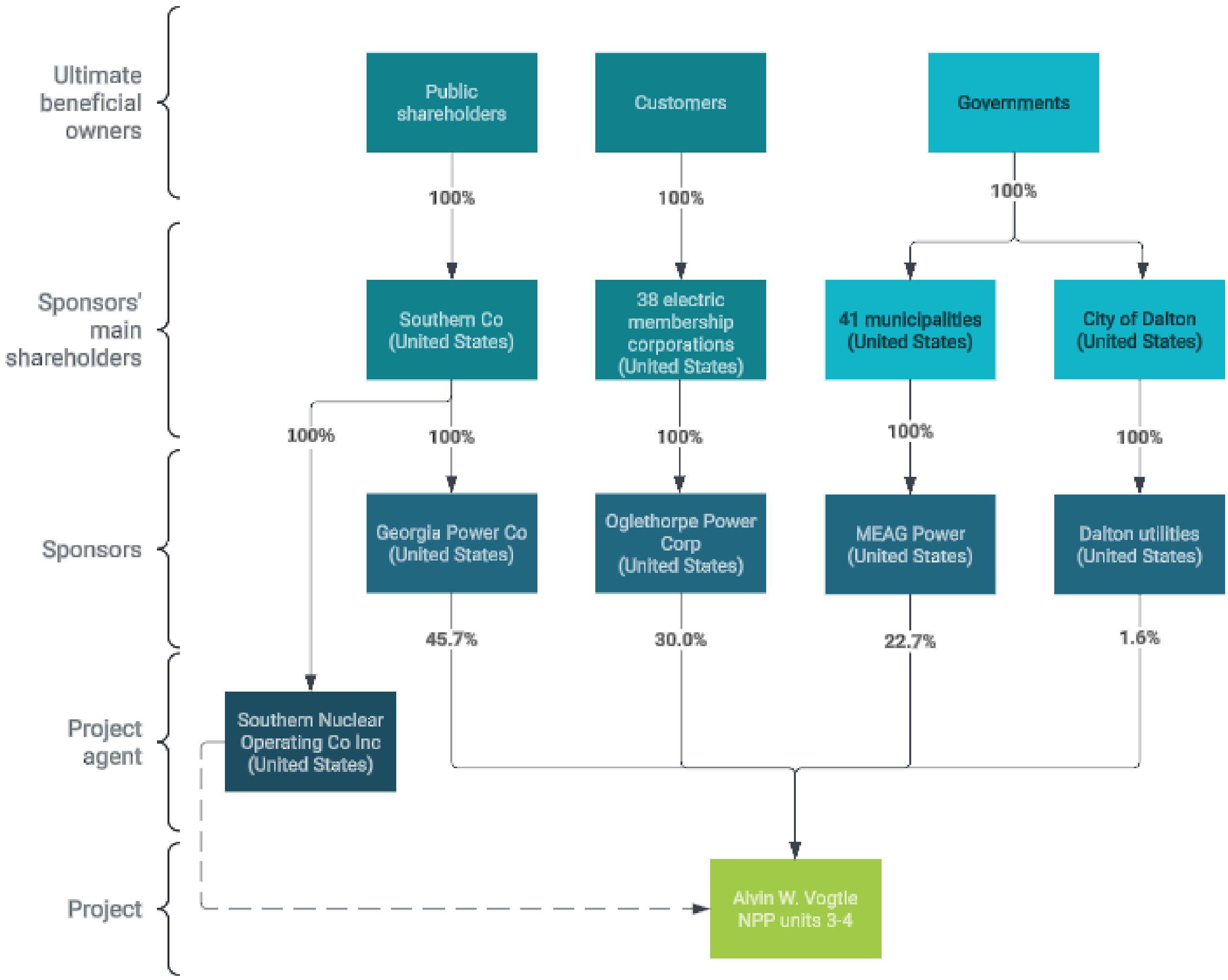
Oglethorpe Power Corp (OPC) is a cooperative owned by its members. The members are 38 retail electric distribution companies in the State of Georgia. All 38 distribution companies are electric membership corporations that are utility cooperatives, which means that they are owned by their customers.[115]

The Municipal Electric Authority of Georgia (MEAG Power) is a non-profit entity owned by 41 municipalities.

The Board of Commissioners of the Water, Light and Sinking Fund, doing business as Dalton Utilities, is the energy company of the city of Dalton, Georgia.[116]

Figure 12 shows the ownership structure. The ultimate beneficial ownership is divided among shareholders (45.7%), customers (30.0%) and government (24.3%).

Figure 12 Ownership structure of Vogtle 3-4



Sources: See text.

3.4.3 Financing

In August 2008, the construction cost was initially budgeted at USD 14.3 billion (EUR 9.2 billion).[117]

In February 2014, the cost estimate had reached USD 15.5 billion (EUR 11.3 billion).[118]

In August 2023, the cost was estimated at over USD 34 billion (EUR 31.2 billion).[119]

In May 2024, a month after the start of commercial operation, the realised construction costs were calculated at USD36.8 billion (EUR 33.9 billion).[120]

Based on these figures the budget overrun amounts to EUR 24.7 billion, a budget overrun factor of 3.7

- **Capping the additional electricity bill for the consumer**

When Vogtle's construction was certified in 2012, Georgia Power estimated that the project would cost customers an extra USD9.60 a month. In 2023, it was estimated that Georgia Power customers had spent an average of USD 100 a year on Vogtle Units 3 and 4 before either reactor generated the first kilowatt. In a settlement with the Georgia Public Service Commission, it was agreed that the maximum amount paid by Georgia Power customers would be capped at USD 7.6 billion (EUR 7.0 billion), which will lead to an additional bill of USD 14 (EUR 13) per month for the average Georgia Power customer.[121]
According to later calculations by the citizens' group Georgia Conservation Voters, the additional bill for the average electricity customer in the State of Georgia will be USD 420 (EUR 387) per year or USD 35 (EUR 32) per month).[122]

- **Debt financing**

Due to the organisation with a project agent, the project finance will have to be attracted by the project sponsors rather than by Southern Nuclear Operating Co. The research identified several deals that are linked to the construction of Vogtle 3-4, see Table 14.

In 2010, the US Department of Energy provided a USD 8.33 billion (EUR 6.1 billion) guarantee to three project sponsors (Georgia Power, MEAG and Oglethorpe Power).[123]

The Development Authority of Burke County reissued a 2008 municipal bond (USD65 million) in 2015. The proceeds were loaned to Georgia Power Company to refinance the construction of air and water pollution control and sewage and waste disposal facilities at the Vogtle plant.[124]

In 2014, MEAG estimated its share of Vogtle reactors 3 and 4 construction costs (22.7%) would come to USD 4.2 billion (EUR 3.1 billion). To finance that amount, MEAG has issued three series of bonds since 2009: Project M bonds, Project J bonds, and Project P bonds earmarked for the construction of units 3 and 4.[125]
MEAG was able to designate its three series of bonds as "Build America Bonds" under the Recovery Act of 2009. As such, MEAG is entitled to receive cash subsidy payments from the US Treasury that will cover 35% of the interest the company will pay to bondholders.[126]
In 2022, the MEAG bond series had the following outstanding values: M series: USD 1,727 million (EUR 1,623 million); J series: USD 2,483 (EUR 2,333 million); P series; USD 1,009 million (EUR 948 million).[127]

On 22 February 2021, Georgia Power issued a USD 750 million (EUR 634 million) bond with the use of proceeds labelled as 'mixed project finance'. According to the bond prospectus, the proceeds may be used for a wide variety of business activities, including nuclear.[128]

Table 14 Debt financing of Vogtle 3-4

Closing/issue date	Type of finance	Description	Use of proceeds	Value (EUR mln)
16 Febr 2010	Guarantee	Loan guarantee (USD 8.33 bln) by US Department of Energy	Project finance	6,123
31 Dec 2008	Bond	Municipal bond (USD 65 mln) issued by the Development Authority of Burke County	Project finance	46
27 May 2015	Bond	Municipal bond (USD 65 mln) re-issued by the Development Authority of Burke County	Project finance	60
2010 - 2023	Bond	Project M bonds issued by MEAG	Project finance	1,623
2010 - 2023	Bond	Project J bonds issued by MEAG	Project finance	2,333

Closing/issue date	Type of finance	Description	Use of proceeds	Value (EUR mln)
2010 - 2023	Bond	Project P bonds issued by MEAG	Project finance	948
22 Febr 2021	Bond	Georgia Power, 3.25% 15mar2051, USD (2021A), US373334KP56	Mixed project finance	634

Source: IJGlobal (2024), 'Transaction date of selected companies', viewed in July 2024; Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

The total identified debt financing to Vogtle 3-4 amounts to EUR 11.7 billion. This includes the amount of the loan guarantee, assuming it resulted in equivalent loans.

EUR 11.7 billion would represent one-third of the total realised cost. Assuming a 70/30 debt-equity ratio, it is clear that roughly half of the debt financing has not been identified.

- **Finance not directly related to Vogtle 3-4**

Many other finance deals, attracted by the project sponsors during the construction period, have been identified, with a combined total of EUR 108 billion (Table 15). It is not known which proceeds from these deals were intended for the development of Vogtle 3-4. The proceeds may also have been used for the operation of Vogtle 1-2, other power plants, or other (general corporate) purposes.

Table 15 Financing identified to the Vogtle 3-4 project sponsors (2008-2024), in EUR million

Group name	**Corporate loan**	Revolving credit facility	Bond issuance	Share issuance	Total
Southern Co	3,522	31,438	43,359	19,823	98,142
Oglethorpe Power Corp	102	4,294	4,445		8,841
MEAG	783				783
Total	**4,407**	**35,732**	**47,804**	**19,823**	**107,766**

Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

Southern Co (including its subsidiary Georgia Power) attracted the most finance. None of these deals was earmarked as project finance and can, therefore, not be linked to Vogtle 3-4.

- **Equity financing**

With a 70/30 debt-equity ratio and a budgeted cost of EUR 9.2 billion, the distribution of initial equity (EUR 2,760 million) was:

- Georgia Power: EUR 1,261 million
- Oglethorpe Power: EUR 828 million
- MEAG Power: EUR 627 million
- Dalton Utilities: EUR 44 million

- **Government financing**

Looking at ultimate beneficial ownership, governments own 24.3% of the Vogtle 3-4 project. Therefore, the theoretical share of the government is 24.3% of the project's initial equity (EUR 617 million).

On the debt side, it is assumed that the government guarantee led to commercial loans. Of the known debt, 58% was corporate/commercial and 42% consisted of municipal bonds.

With a 70/30 debt-equity ratio this translates into EUR 13.7 billion raised by corporate bonds and EUR 10.0 billion raised through municipal bonds.

Not taken into account is the mentioned government subsidies of 35% of interest payments on the MEAG bonds.

- **Financing model**

The financing model combines government, corporate, and cooperative financing. The four project sponsors are all energy companies, but they have very different ownership structures. Georgia Power is owned by Southern Co, which is owned by public shareholders; Oglethorpe Power is cooperatively owned by 38 customer organisations; MEAG Power is cooperatively owned by 41 municipalities; and Dalton Utilities is owned by the City of Dalton. Vogtle 3-4 is the only case study with customers owning and financing a part of the power plant.

3.4.4 Results

The case of the Vogtle 3-4 construction project resulted in the following findings:

- **Known key elements of the financing**
  - Debt financing to Vogtle 3-4 project (project finance): EUR 11.7 billion;
  - Initial equity investment by the four project sponsors (EUR 2.8 billion);
  - Possible materialisation of the government guarantee on loan payments default;
  - Government subsidies of 35% of the interest payments on the MEAG bonds.
  - Part of the losses of the bankruptcy of Westinghouse Electric;
  - Georgia Power customers: EUR 7.0 billion.

Table 16 gives an overview of the key findings on Vogtle 3-4.

Table 16 Key findings for Vogtle 3-4 construction project

Indicator	Unit	Key data
Financing model	-	Government/ Corporate/ Cooperative
Budgeted cost	EUR mln	9,200
Realised cost	EUR mln	33,900
Budget overrun	EUR mln	24,700
Budget overrun factor	**-**	**3.7**
Construction start	-	22-Jun-09
Scheduled commercial operation	-	31-Dec-17
Commercial operation start	-	29-Apr-24
Planned construction time	Years	8.5
Realised construction time	Years	14.9
Lead time escalation	Years	6.3
Lead time escalation factor	**-**	**1.7**
Reference net capacity	MWe	2,234
Cost per kilowatt (electric)	**EUR/kWe**	**15,175**
Government participation (UBO)	%	24.3%

3.5 Flamanville 3

Flamanville unit 3 is located in Flamanville, Normandy, France.

3.5.1 History

Flamanville units 1 and 2 have been operational since 1986 and 1987, respectively. Both reactors are pressurised water reactors of the model P4 REP-1300.

The new unit 3 is also a pressurised water reactor, model EPR-1650. Électricité de France (EDF) is the full owner and operator of all three units.

Construction of unit 3 started on 3 December 2007. The scheduled commercial operation date was set before the end of 2012.[129]

At the start of construction, EDF indicated that it would invest EUR 3.3 billion during the construction stage. Areva would supply the reactor, Bouygues would provide the main civil engineering, and Alstom the turbine generator.[130] Framatome was supplying the nuclear steam supply system.[131]

Regulatory approval to start up was given on 7 May 2024. The next day, the fuel loading started. Commercial operation was expected to start in the summer of 2024.[132]

On 3 September 2024, EDF stated that they started the nuclear divergence process and that grid connection is expected in the fall of 2024.[133] In fact, this means another delay. With the grid connection passing before 30 November, it is likely that the commercial operation will start in early 2025.

The scheduled construction period was 5.1 years. Assuming the commercial operation starts on 1 January 2025, the realised construction period will be 17.1 years, giving a lead time escalation of 12.0 years, a factor of 3.4.

3.5.2 Ownership

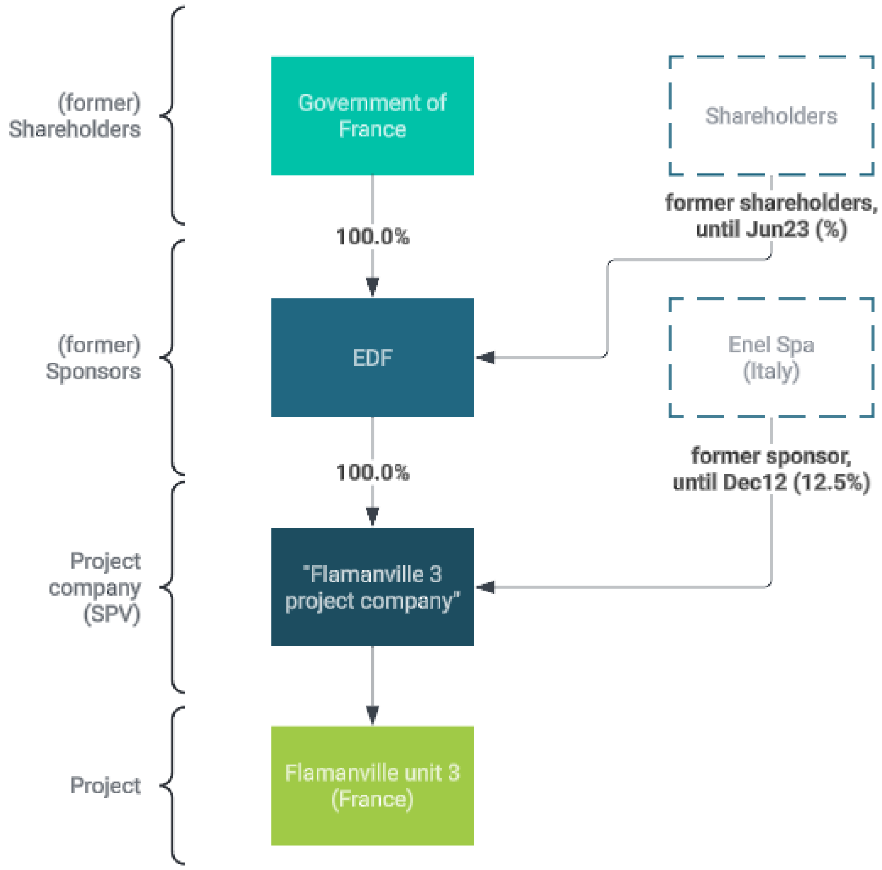
In November 2007, EDF and Italian energy company Enel signed an agreement through which Enel took a 12.5% share in the Flamanville 3 construction project. Following EDF's additional cost statement in December 2012, Enel exited the project and was reimbursed for the prepaid expenses related to its 12.5% stake.[134] The ownership structure is presented in Figure 13.

At the time of the construction start, EDF was a company listed at Euronext, Paris. In 2021 the company suffered a record loss of EUR 18 billion. As a result, the French government started to raise its ownership share in EDF from 84% in early 2022 to 95.82% in May 2023. Following court approval, the French government fully renationalised EDF in June 2023, thereby offering EUR 9.7 billion for the remaining 4.18% of shares.[135]

Supplier Areva NP is 100% owned by EDF. The former Areva SA has been split-up in Technicatome, Framatome and Areva NP.[136]

Supplier Framatome is 80.5% owned by EDF and 19.5% owned by Mitsubishi Heavy Industries.[137]

Figure 13 Ownership structure of Flamanville 3



Sources: See text.

3.5.3 Financing

At the start of construction, EDF indicated that it would finance the project through a EUR 3.3 billion investment during the construction stage.[138] Initially, Enel Spa took a 12.5% share of the project company.[139]

In 2011, EDF reported that the construction cost had almost doubled to EUR 6 billion. On 3 December 2012 EDF reported that the estimated costs had further escalated to EUR 8.5 billion, including inflation.[140]

In September 2015, EDF announced that the estimated costs had escalated to EUR 10.5 billion, and the start-up of the reactor was delayed to the fourth quarter of 2018.[141]

In October 2019, EDF stated that Flamanville 3 incurred an additional EUR 1.5 billion overrun, bringing the cost estimate to EUR 12.4 billion.[142]

In July 2020, the French Court of Audit, published a report calculating additional costs not included by EDF. The report estimates a total of EUR 19.1 billion. The auditors calculated the additional cost of financing due to the construction delay, as well as various expenses incurred before commissioning - spare parts, administrative procedures, tax charges, etc. EDF did not dispute the Court's calculated amount.[143]

In May 2024, according to EDF cost had increased to EUR 13.2 billion (excluding financing costs).[144] This is an extra EUR 0.8 billion compared to the EDFs statement from 2019.

Adding this additional EUR 0.8 billion to the Court of Audit's estimate would result in a realised construction cost of EUR 19.9 billion. This corresponds to a budget overrun of EUR 16.6 billion, with a budget overrun factor of 6.0.

- **Debt financing**

In total, this research identified debt financing to Areva and EDF in the Flamanville 3 project period with a value of EUR 192 billion (Table 17).

Table 17 Debt financing to Areva and EDF (2006-2024), in EUR million

Group name	Borrower Name	Loans	Underwriting	Total
EDF	Electricite De France SA	30,404	99,312	129,716
EDF	Areva SA	7,163	3,919	11,082
EDF	Areva NP SAS		2,357	2,357
Total		**37,567**	**105,588**	**143,155**

Source: IJGlobal (2024), 'Transaction date of selected companies', viewed in July 2024;
Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

This debt amount concerns financing for general corporate purposes and may, therefore, be used for all business activities of Areva and EDF. No specific project finance or any other finance specifically earmarked for Flamanville 3 has been identified.

The Top-15 Financial institutions that provided this debt amount are presented in Table 18.

Table 18 Top-15 Financiers providing debt to Areva and EDF (2006-2024), in EUR million

Bank	Country	Loans	Underwriting	Total
Crédit Agricole	France	4,333	10,368	14,701
Société Générale	France	3,268	9,055	12,323
BNP Paribas	France	3,200	9,032	12,232
HSBC	United Kingdom	2,741	7,541	10,282
Groupe BPCE	France	2,448	5,600	8,048
NatWest	United Kingdom	2,383	5,612	7,994
Barclays	United Kingdom	2,167	5,632	7,799
Mitsubishi UFJ Financial	Japan	2,449	3,421	5,870
Bank of America	United States	1,721	3,953	5,674
Citigroup	United States	853	3,777	4,630
UBS	Switzerland	624	3,314	3,938
Deutsche Bank	Germany	1,035	2,847	3,882
Santander	Spain	951	2,340	3,290
ING Group	Netherlands	809	2,314	3,123
Morgan Stanley	United States		3,099	3,099
Other financiers		8,587	27,684	36,271
Total		**37,567**	**105,588**	**143,155**

Source: IJGlobal (2024), 'Transaction date of selected companies', viewed in July 2024;
Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

- **Equity financing**

Originally, the initial equity investment was EUR 3.3 billion, 100% of the budgeted costs. The initial equity distribution was:

- EDF: EUR 2,887.5 million
- ENEL: EUR 412.5 million

In December 2007 (construction start), the government's share in EDF was 84.8%. Therefore, the government's share in the initial equity can theoretically be set at EUR 2.5 billion.

In December 2012 (ENEL exit), the government's share in EDF was 84.44%. When EDF was nationalised in 2024, Flamanville 3 became fully state-owned. From that point on, the French government became 100% responsible for the additional costs. Whether the French government covered the losses with additional equity is not known.

- **Finance not directly related to Flamanville 3**

Not part of the financing, but worth mentioning, is the bond issuance that followed closely on the operational start of Flamanville 3. In June 2024, EDF issued a bond with three tranches. The first tranche (EUR 1,000 million) is earmarked for the lifetime extension of existing French nuclear reactors; the second tranche (EUR 750 million) for renewable energy and hydropower; and the third tranche (EUR 1,250 million) for adaptation of the electricity grid to the needs of the energy transition.[145]

Whether the proceeds of this bond issue financed losses that occurred with the construction of Flamanville 3 (or Olkiluoto 3 or Hinkley Point C 1-2) will remain unanswered.

- **Government financing**

The government did not directly invest in the project. Theoretically, with a government share in EDF of 84.44% at project start, the initial equity translates theoretically into EUR 2.8 billion in the hands of the French government.

For the debt part, the government financing is not known.

- **Financing model**

The model can be described as a mix of government financing and corporate financing. Initially, EDF was a publicly listed company. Following the losses, restructuring, and nationalisation, what is left is a pure government financing model. However, the shareholders did experience losses through shareholders' value and bear a part of the cost. And EDF did attract loans from commercial lenders.

3.5.4 Results

The case of the Flamanville 3 construction project resulted in the following findings:

- **Known key elements of the financing**
    - Initial equity investment by EDF: EUR 2.9 billion
    - Initial equity investment Enel: EUR 413 million
    - Part of the intitial equity attributed to the French government's ultimate beneficial ownership: EUR 2.8 billion;
    - Reimbursement following the exit of Enel: EUR 613 million;
    - Part or whole of capital injection in Areva NP (NewCo): EUR 2.5 billion;
    - Unknown part of Areva SA's shares buy-out by the French government (nationalisation);
    - Unknown part of EDF's shares buy-out by the French government (nationalisation): EUR 9.7 billion.

Table 19 gives an overview of the key findings on Flamanville 3.

Table 19 Key findings for Flamanville 3 construction project

Indicator	Unit	Key data
Financing model	-	Government/Corporate
Budgeted cost	EUR mln	3,300
Realised cost	EUR mln	19,900*
Budget overrun	EUR mln	16,600*
Budget overrun factor	**-**	**6.0***
Construction start	-	3-Dec-07
Scheduled commercial operation	-	31-Dec-12
Commercial operation start	-	1-Jan-25*
Planned construction time	Years	5.1
Realised construction time	Years	17.1*
Lead time escalation	Years	12.0*
Lead time escalation factor	**-**	**3.3***
Reference net capacity	MWe	1,330
Cost per kilowatt (electric)	**EUR/kWe**	**9,925***
Government participation (UBO)	%	100.0%

Note: * Projected values.

3.6 Hinkley Point C 1-2

Hinkley Point C units 1 and 2 are located at Hinkley Point, Somerset, England.

3.6.1 History

Hinkley Point C 1-2 is constructed at a site adjacent to the four shutdown Hinkley Point A 1-2 and B 1-2 units. The Hinkley Point C units consist of the French EPR-1750 reactor, with a net reference capacity of 1,630 MWe each.[146]

In the original set-up, EDF and British energy company Centrica Plc would form an 80/20 joint venture. However, Centrica pulled out of the project in February 2013. Consequently, EDF indicated that it would start discussions with China General Nuclear Group Company (CGN) about joining the partnership.[147]

In October 2013, EDF, CGN and the UK government agreed on a Contract for Difference.[148] In October 2015, EDF and CGN signed the Strategic Investment Agreement.[149]

The project company for the construction of Hinkley Point C units 1 and 2 has been set up as a joint venture of two partners, nuclear energy companies EDF and CGN, with an originally 65/35 division of shares.

In October 2013, the key suppliers had been agreed:[150]

- Areva SA, later Areva NP (reactor)
- Alstom France (turbines);
- Alstom UK (services during operations);
- Bouygues TP/Laing O'Rourke (main civil works);
- BAM Nuttall/Kier Infrastructure (earthworks).

Construction start dates were in December 2018 and December 2019, respectively.[151] The commercial operation start was scheduled for 2025.[152]

The latest forecast on commercial operation start dates is December 2029 and December 2030.[153] If these start dates are reached, the realised lead time for the units combined would be 12.1 years. That would mean a lead time escalation of 5.5 years, corresponding to a factor of 1.8.

3.6.2 Ownership

The project company is called NNB Generation Co (HPC) Ltd (United Kingdom). It is a joint venture company owned by NNB Top Company HPC (A) Ltd (United Kingdom) and Sagittarius International Ltd (United Kingdom). [154]

EDF created a large number of company entities in the UK. NNB Top Company HPC (A) Ltd has a number of consecutive intermediary holding companies that hold 100% of the shares. The immediate ownership line runs as follows: [155]

- NNB Top Company HPC (B) Ltd (United Kingdom)
- NNB Top Company HPC (C) Ltd (United Kingdom)
- EDF Energy Topco (NNB) Private Ltd (Singapore)
- EDF Energy Holdings Ltd (United Kingdom)
- EDF Energy (UK) Ltd (United Kingdom)
- EDF International SAS (France)
- EDF SA (France)

Furthermore, three entities have been identified that seem related but not part of the company structure:

- NNB Top Company HPC Ltd (United Kingdom);
- EDF Energy NNB Ltd (Hong Kong);

- Nuclear New Build Generation Company (NNB GenCo).

The latter is a subsidiary created by EDF Energy to build and then operate two new nuclear power stations (Hinkley Point C and Sizewell C) in the United Kingdom. For Sizewell C EDF created a comparable intermediary holdings structure in the UK as it did for Hinkley Point C.[156]

The other joint-venture owner CGN also created a number of consecutive intermediary holding companies that hold 100% of the shares:[157]

- Sagittarius International Limited (United Kingdom);
- Libra International Ltd (United Kingdom);
- International Nuclear Investment Ltd (United Kingdom);
- China Wind Power Development Ltd (Hong Kong);
- Definite Arise Ltd (British Virgin Islands).

An entity with the same name (Sagittarius International Ltd) is registered in Bermuda, and may be a related company.

Definite Arise Ltd is directly owned by three parties:

- China Nuclear Power Ltd (Hong Kong), which is a 100% subsidiary of CGNPC International Ltd (Hong Kong), which is a 100% subsidiary of CGN;
- Centire Holdings Co Ltd (British Virgin Islands), with ownership unknown, though assumed to be in Chinese hands;
- Huayuan New Energy Co Ltd (China), which is 100% owned by WinTime Energy Group Co Ltd.

In 2017, CGN set up a new company in the UK, General Nuclear International Ltd (GNI), to make its investments and manage its projects in the UK.[158] However, GNI is not part of Hinkley C 1-2's identified ownership structure.

The most relevant parts of this company structure are presented in Figure 14.

The current ownership can be summarised as follows:

EDF holds 69.5% of the shares. CGN holds 21.3% of the shares. Centire Holdings (British Virgin Islands) holds 6.1% of the shares. WinTime Energy (China) holds 3.1%.

Divided by country of headquarters:

- French entities own 69.5% of the shares
- Chinese entities own 24.1%, and
- the entity in the British Virgin Islands (BVI) owns 6.1%.

If the BVI entity is assumed to be in Chinese hands, the Chinese entities own 30.5% of the shares.

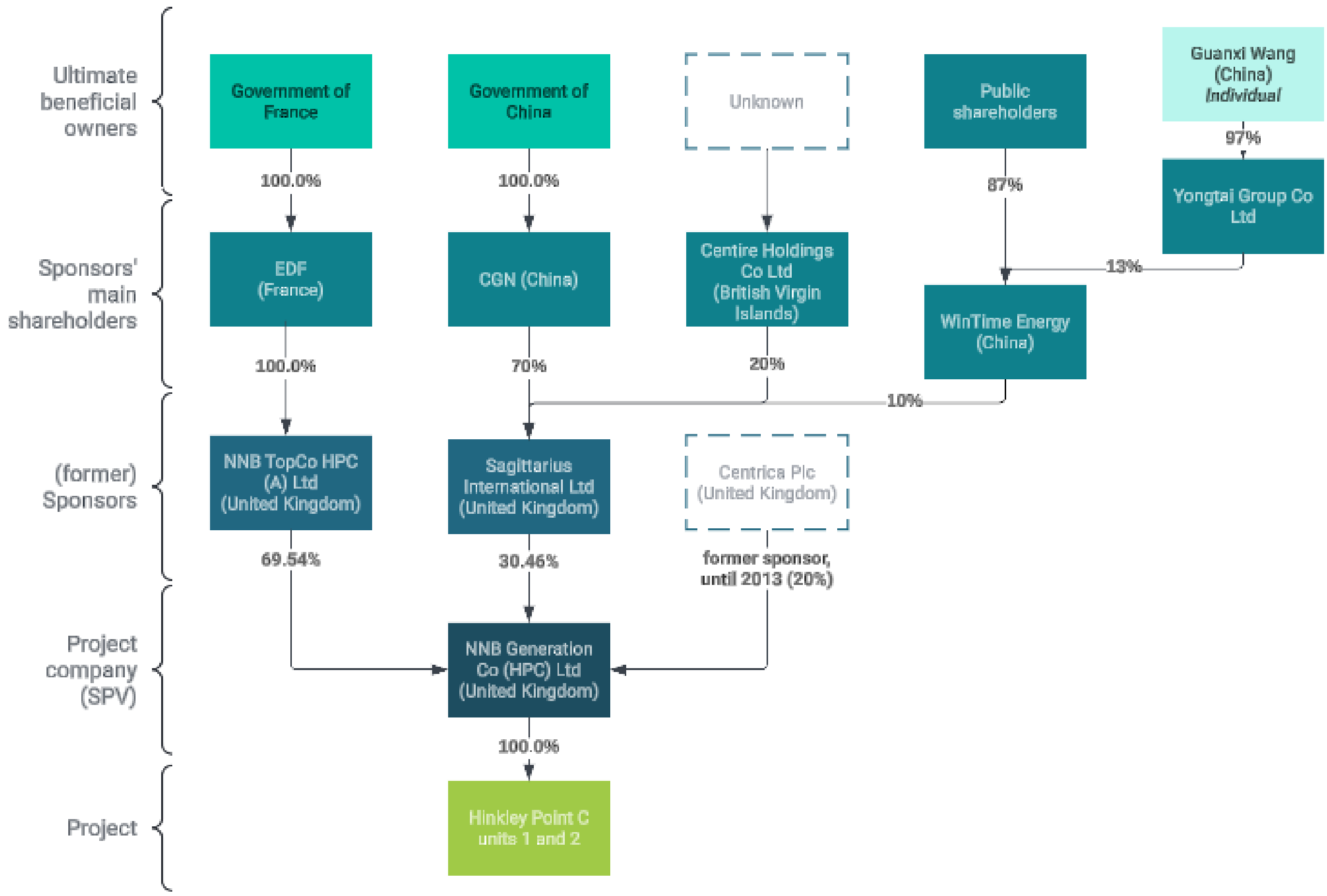
The ultimate beneficial ownership is composed as follows:

- Government of France (69.5%)
- Government of China (21.3%)
- unknown (6.1%)
- public shareholders (2.7%) and
- individuals (0.4%).

Taken together the government ultimate beneficial ownership percentage is 90.8% (or 96.9% if the unknown ownership is attributed to the Government of China).

It is remarkable that the Government of the United Kingdom does not participate and that UK entities do not own any of the plant’s assets.

Figure 14 Ownership structure of Hinkley Point C 1-2



Source: See text.

3.6.3 Financing

The financing model applied to the Hinkley C unit 1 and 2 development is called Contract for Difference. The contract was agreed by EDF, CGN and the UK government in October 2013. It guarantees that the power plant will receive GBP 92.5 (EUR 108.0) per MWh for the first 35 years of operation. The guaranteed price will be inflation-indexed. The guarantee is ratepayer-backed, which implies that the end consumer will pay the price. The project is due to be equity-funded by each partner, at least during the first stage. EDF will fully consolidate the project on its balance sheet.[159]

In September 2015, EDF and CGN committed to provide a contingency margin of GBP 2.7 billion (EUR 3.6 billion). The equity commitment could reach GBP 13.8 billion (EUR 18.7 billion) for EDF and GBP 9.4 billion for CGN. State lender Ofgem (Office of Gas and Electricity Markets) provided a grant of GBP 637 million (EUR 846 million).[160]

In September 2015, the Government of the UK announced the decision to provide a GPB 2 billion (EUR 2.7 billion) infrastructure guarantee to the project.[161]

During the construction process, several forecasts of the total construction costs were provided. The development of the forecasts is presented in Table 20.

Table 20   Forecasts of Hinkley C 1-2 construction costs

Date of forecast	Cost (in GBP bln)	Cost (in EUR bln)	Source
October 2013	18.1	24.7	162
October 2015	18.1	24.7	163
July 2017	19.6	26.6	164
February 2024	34.0	46.1	165

In February 2024, EDF stated that the construction costs would rise, estimating the likely cost at between GBP 31 billion (EUR 42.1 billion) and GBP 34 billion EUR (46.1 billion), with a further GBP 1 billion (EUR 1.4 billion) cost for a third scenario.[166]

Suppose the finally realised costs are EUR 46.1 billion. This would implicate a budget overrun of EUR 21.4 billion and a budget overrun factor of 1.9.

- **Debt financing**

In 2015, EDF stated, *"To fund Hinkley's capital expenditure, EDF hopes to raise EUR 4 billion in 2016. Up to EUR 3 billion of the rights issue will be backstopped by the French government, which owns 85% of the company."* The statement implicates a EUR 3 billion government backstop (guarantee) and the intention to raise EUR 4 billion of debt through bond issues.

In 2017, China Nuclear Power Limited received a loan in pound sterling from the China Development Bank for the construction of Hinkey Point C. The loan value is not disclosed.[167]

CGNPC International Ltd (Hong Kong) issued two bonds in December 2017 and September 2018, with tranches nominated in US dollar and euro. While the proceeds are used for refinancing and general corporate purposes, the Hinkley C agreement is explicitly mentioned. The tranches in EUR (Eurobonds) represent a combined debt value of EUR 1 billion. Since they are not earmarked, they cannot be linked to Hinkley Point C 1-2.[168]

Sagittarius International reported a value of GBP 6.3 billion (EUR 7.1 billion) in outstanding loans to its subsidiary NNB Generation Company (HPC) Ltd. The loans due from HPC have no contractual repayment date and are non-interest-bearing. It also stated that it has committed to provide further funding to HPC for the amount of GBP 814 million (EUR 919 million). The intercompany loans are confirmed by the financial statements of another intermediate parent, International Nuclear Investment.[169] Taken together, this means that the Chinese entities provided and committed to intercompany loans with a total value of EUR 8.0 billion, as of December 2022.

No further earmarked debt finance has been identified for the project company or any of its immediate owners in the UK, or for EDF and CGN subsidiaries based in the UK.

For general debt financing of Areva and EDF, see Section 3.5.3.

General debt financing for immediate and ultimate owners of the Chinese share in the project company is given in Table 21. This concerns financing for general corporate purposes and is not directly linked to Hinkley Point C 1-2.

Table 21 Debt financing to Chinese owners of Hinkley C 1-2 (2013-2024), in EUR million

Group name	Borrower Name	Loans	Underwriting	Total
CGN	China General Nuclear Power Corp	723	14,855	15,579
CGN	CGNPC International Ltd	446	3,661	4,107
WinTime Energy	Wintime Energy Co Ltd	198	5,798	5,997
Total		**1,368**	**24,314**	**25,682**

Source: IJGlobal (2024), 'Transaction date of selected companies', viewed in July 2024;
Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

The Top-15 Financial institutions that provided this debt amount are presented in Table 22.

Table 22 Top-15 Financiers providing debt to Chinese owners of Hinkley C 1-2 (2013-2024), in EUR million

Bank	Country	Loans	Underwriting	Total
Industrial and Commercial Bank of China	China	425	2,805	3,230
China Development Bank	China	29	2,961	2,990
Ping An Insurance Group	China		2,260	2,260
Bank of China	China	72	1,931	2,003
China Merchants Bank	China		1,853	1,853
Agricultural Bank of China	China	13	1,566	1,579
Industrial Bank Company	China		1,227	1,227
China Construction Bank	China	13	934	947
Bank of Beijing	China		725	725
Shanghai Pudong Development Bank	China	29	684	713
China Everbright Group	China		638	638
CITIC	China	1	628	629
Bank of Shanghai	China		624	624
China Eximbank	China	13	606	618
HSBC	United Kingdom	371	90	461
Other financiers		403	4,782	5,185
Total		**1,368**	**24,314**	**25,682**

Source: IJGlobal (2024), 'Transaction date of selected companies', viewed in July 2024;
Refinitiv Eikon (2024), 'Loans and underwriting deals of selected companies', viewed in July 2024.

- **Equity financing**

Calculating with a debt-equity ratio of 70/30 and a budgeted cost of EUR 24.7 billion, the distribution of sponsor's equity investment is (EUR is:

- EDF: EUR 5,510 million;
- CGN: EUR 1578 million;
- Centire Holdings: 452 million;
- WinTime Energy: EUR 230 million.

- **Depreciation of losses**

When Centrica abandoned the project, the company had to depreciate GBP 200 million (EUR 233 million) in losses.[170]

The losses and the restructuring costs of Areva SA, and the nationalisation costs of EDF, may be partly attributed to the Hinkley Point C 1-2 project, but it is not known which part. For more information see Section 3.5.3.

- **Government financing**

Assuming the equity contingencies had to be put forward, the distribution of equity to the state-owned sponsors consisted of:

  - EDF: EUR 13.8 billion;
  - CGN: EUR 9.4 billion;

Combining with the ultimate beneficial ownership of the two respective governments, the equity shares may be imagined as:

  - Government of France: EUR 9.6 billion;
  - Government of China: EUR 2.0 billion.

The governments combined represent an equity value of 11.6 billion, which translates into a theoretical government share of 84% of the initial sponsor's equity.

Furthermore, the UK government provided a EUR 846 million grant, representing 1.8% of the realised cost. This excludes the government guarantee (and backstop) of which it is not known whether they materialised.

- **Finance not directly related to Hinkley Point C 1-2**

In 2019 (August, 19), CGNPC International Ltd (based in Hong Kong and intermediate owner of Hinkley Point C 1-2) received a USD 500 million (EUR 451 million) term loan from the Export-Import Bank of China. The use of proceeds is not specified, and therefore, this loan cannot be linked to the construction of Hinkley Point C 1-2.[171]

- **Financing model**

The financing model of Hinkley C 1-2 is usually referred to as Contract for Difference (CfD). However, given the UK Government loan guarantee and the equity financing by both French and Chinese governments, the financing model must be described as a mix. When the project started, EDF was a publicly listed company, bringing also private finance into the mix. In the end, EDF was nationalised. The private finance remaining is equity financing through the Chinese private company WinTime Energy.

In conclusion, the financing is a mix of foreign government financing, corporate financing, domestic government guarantee, and domestic government price regulation (CfD).

3.6.4 Results

- **Known key elements of the financing**

  - EDF equity: EUR 5.5 billion;
  - CGN equity: EUR 1.6 billion;
  - Intercompany loans of (Chinese-owned and UK-based) intermediate parent Sagittarius International: EUR 8.0 billion;
  - Government of UK grant: EUR 846 million
  - Government of UK guarantee: EUR 2.7 billion;
  - Government of France issuance backstop: EUR 3 billion;
  - Government of China / China Development Bank loan (value not disclosed);

- Possible materialisation of the government guarantee on loan payments default;
- Depreciation of losses by Centrica: EUR 233 million.

Table 23 gives an overview of the key findings on Hinkley Point C 1-2. Since the construction is ongoing the realised cost and lead time concern projected values.

Table 23 Key findings and projections Hinkley Point C 1-2 construction project

Indicator	Unit	Key data
Financing model	-	Contract for Difference
Budgeted cost	EUR mln	24,700
Realised cost	EUR mln	46,100*
Budget overrun	EUR mln	21,400*
Budget overrun factor	**-**	**1.9***
Construction start	-	
Scheduled commercial operation	-	
Commercial operation start	-	
Planned construction time	Years	6.6
Realised construction time	Years	12.1*
Lead time escalation	Years	5.5*
Lead time escalation factor	**-**	**1.8***
Reference net capacity	MWe	3,260
Cost per kilowatt (electric)	**EUR/kWe**	**14,142***
Government participation (UBO)	%	90.8%

Note: * Projected values.

3.7 Overview of the key findings

Table 24 shows the key findings of the project case studies (see next page).

- The realised construction cost varies from EUR 6.4 billion to 46.1 billion.
- The budget overrun factor varies from 1.6 to 6.0 times the originally budgeted construction cost;
- The realised construction lead-time varies from 11.7 to 17.7 years;
- The lead time escalation factor varies from 1.7 to 4.6 times the originally scheduled construction time;
- The realised cost per installed kWe varies from EUR 2,324 to 15,175 per kWe.

Table 24 Key findings for the six selected construction projects (cost in EUR million, lead time in years)

	Olkiluoto-3	**Shin Hanul 1-2**	**Barakah 1-4**	**Vogtle 3-4**	**Flamanville 3**	**Hinkley Point C 1-2**
Location	Finland	South Korea	United Arab Emirates	United States	France	United Kingdom
Reactor type	EPR-1600	APR-1400	APR-1400	AP-1000	EPR-1650	EPR-1650
Reactor supplier	Areva/EDF	KHNP	KHNP	Westinghouse	Areva/EDF	Areva/EDF (France)
Country of supplier	France	South Korea	South Korea	United States	France	France
Financing model	Government/ Corporate/ Cooperative	Government/ Corporate	Government/ Corporate	Government/ Corporate/ Cooperative	Government/ Corporate	Government/ Corporate/ CfD
Budgeted cost	3,200	3,950	14,100	9,200	3,300	24,700
Realised cost	11,000	6,400	24,000	33,900	19,900*	46,100*
Budget overrun	7,800	2,450	9,900	24,700	16,600*	21,400*
Budget overrun factor	**3.4**	**1.6**	**1.7**	**3.7**	**6.0***	**1.9***
Construction start	12-Aug-05	10-Jul-12	19-Jul-12	22-Jun-09	3-Dec-07	11-Dec-18
Scheduled commercial operation	30-Jun-09	1-Apr-18	1-Jul-18	31-Dec-17	31-Dec-12	30-Jun-25
Commercial operation start	1-May-23	5-Apr-24	1-Sep-24	29-Apr-24	1-Jan-25*	31-Dec-30*
Scheduled lead time	3.9	5.7	5.9	8.5	5.1	6.6
Realised lead time	17.7	11.7	12.1	14.9	17.1*	12.1*
Lead time escalation	13.8	6.0	6.2	6.3	12.0*	5.5*
Lead time escalation factor	**4.6**	**2.1**	**2.0**	**1.7**	**3.4***	**1.8***
Reference net capacity (MWe)	1,600	2,754	5,321	2,234	1,330	3,260
Cost in EUR per kWe	**6,875**	**2,324**	**4,510**	**15,175**	**14,962**	**14,141**
Government participation (UBO)	28.5%	51.1%	91.2%	24.3%	100.0%	90.8%

Note: * Projected values.

Table 25 shows the minimum, mean (average) and maximum values among the key findings.

Table 25 Range and average of key findings

Indicator	Min.	Mean	Max.
Budgeted cost	3,200	9,742	24,700
Realised cost	6,400	23,550	46,100
Budget overrun	2,450	13,808	24,700
Budget overrun factor	**1.6**	**3.1**	**6.0**
Scheduled lead time	3.9	6.0	8.5
Realised lead time	11.7	14.3	17.7
Lead time escalation	5.5	8.3	13.8
Lead time escalation factor	**1.7**	**2.6**	**4.6**
Reference net capacity (MWe)	1,330	2,750	5,321
Cost in EUR per kWe	**2,324**	**9,665**	**15,175**
Government participation (UBO)	24.3%	64.3%	100.0%

Note: The minimum, mean and maximum values must be interpreted per indicator. Do not consider the indicators in conjunction.

The mean budget overrun factor is 3.1, and the mean lead time escalation factor is 2.6. Based on this average of the six most recent construction projects, one could propose a rule of thumb of multiplying both the original construction budget and schedule by a factor of at least two-and-a-half.

The research identified commercial debt financing of the project's sponsors, earmarked for 'general corporate purposes', that cannot be directly attributed to financing the specific construction projects. In total, EUR 97 billion of debt has been identified that was provided to the sponsors of the six selected projects. To give an idea of financial institutions that were financing the sponsors in the construction periods (2003 – 2024) of the six plants, the Top-50 debt providers are presented in Appendix 1.

The realised cost per installed kWe varies from EUR 2,324 to 15,175 per kWe.

The government's participation in the ultimate beneficial ownership of the project companies varies from roughly a quarter (24.3% of Vogtle 3-4) to full ownership (100% of Flamanville 3). Remarkable is the large government participation in the projects in France and the UK. Also remarkable is the government participation in the projects in Finland and the US. This is much higher than expected at first sight since all project sponsors are private companies. Only by mapping the full ownership structure does the government's ultimate beneficial ownership come to light.

On average, government participation (UBO) is 64.3%. This is higher than expected but in line with previous studies that emphasize the need for large government participation in nuclear energy projects to reduce risks and attract capital.

4

Key findings applied to Dukovany and Borssele

This chapter explores the cost and lead time of two proposed nuclear construction projects in the EU. Based on the findings on budget overrun and lead time escalation factors of six nuclear power projects in the previous chapter, an analysis has been made of what this would mean for the proposed construction of Dukovany units 5 and 6 and Borssele units 2 and 3.

4.1 Dukovany 5-6

For Dukovany 5-6, a reference net capacity is assumed of 1,800 MWe, based on a 2 x 1,050 MW nameplate capacity. The analysis is based on the minimum, mean and maximum cost per kWe of the six projects in the research (from Table 25). Also, the realised lead times of the six projects are used to calculate the lead time escalation. The outcome of the analysis is presented in Table 26.

Table 26 Exploration of cost and lead time for Dukovany 5-6

	Proposal	Low expectation	Mean expectation	High expectation
Budgeted cost	15,800	15,800	15,800	15,800
Realised cost	15,800	4,183	17,396	27,314
Budget overrun	0	-11,617	1,596	11,514
Budget overrun factor	**1.0**	**0.3**	**1.1**	**1.7**
Construction start date	1-Apr-25	1-Apr-25	1-Apr-25	1-Apr-25
Scheduled commercial operation date	1-Jan-38	1-Jan-38	1-Jan-38	1-Jan-38
Commercial operation date	1-Jan-38	26-Dec-36	5-Jul-39	19-Dec-42
Scheduled lead time	12.8	12.8	12.8	12.8
Realised lead time	12.8	11.7	14.3	17.7
Lead time escalation	0	-1.0	1.5	5.0
Lead time escalation factor	**1.0**	**0.9**	**1.1**	**1.4**
Reference net capacity (MWe)	1,800	1,800	1,800	1,800
Cost in EUR per kWe	**8,778**	**2,324**	**9,665**	**15,175**

Sources: See text.

This analysis shows that at the low end of the range, the proposed budget is a factor of three too high. This outcome would mean the project to be realised under budget, which is unlikely and viewed as unrealistic.

Looking at the mean expectation, the proposed cost and the projected realised cost are comparable in size, with a factor of only 1.1 in budget overrun. This is an indication that the Czech government and the South Korean supplier held a seemingly realistic perspective on the cost calculations. Therefore, this outcome is viewed as realistic.

At the high end of the range, the budget overrun would be EUR 11.5 billion, leading to an expected realised cost of EUR 27 billion. Therefore, the high expectation would implicate a budget overrun factor of 1.7, which seems a very reasonable factor compared to the findings in this study (a mean factor of 3.1) and evidence from the literature (1.6 for energy infrastructure projects). This outcome can be viewed as realistic, too.

When construction starts according to plan in April 2025, the commercial operation would start in December 2036 (low), July 2039 (mean) or December 2042 (high).

When comparing the scheduled lead time of 12.8 years to the projected realised lead times from the analysis, it is remarkable that both the low (factor 0.9) and mean (factor 1.1) expectations are in line with the proposed schedule. Also, the high expectation (factor 1.4) is still close.

From the literature, known mean realised lead time values are 7.6 to 9.4 years, and a mean lead time escalation factor of 1.6 (see Section 1.3). With this factor from the literature, the expected realised lead time for Dukovany 5-6 would be 20.4 years. With the mean lead time escalation factor of 2.6 from this research (six power plants), the expected realised lead time would be 33.2 years. The expected 33.2 years seems unrealistic. Although the expected 20.4 years is higher than the lead times realised by the six projects in the case studies, it is not far apart from the highest value (Olkiluoto 3 with 17.7 years). Therefore, it can be viewed as realistic.

The Czech government has chosen a smaller reactor type (2 x 1,050 MW nameplate capacity) than the Dutch government (2 x 1,650 MW) intends to take. Apparently, the Czech choice is based on minimising the risk of exceedances caused by FOAK characteristics. However, the choice for lower risk comes with a higher cost per kilowatt (electric), compared to the Borssele set-up.

4.2 Borssele 2-3

The Dutch government is exploring the options to build two new units at Borssele.[172]

The final decision on the location is expected at the end of 2024. The government has earmarked EUR 4.5 billion to finance the two new units (from the EUR 35 billion reserved for the energy transition until 2030) in the 2024 State Budget. In the general agreement for the new Dutch cabinet, it is stated that the State Budget will be raised with an additional EUR 9.5 billion and that the resulting EUR 14 billion available is for the construction of four units.[173] However, this intended reservation awaits parliamentary approval in the upcoming State Budget 2025 round.

Presumably, half of the reservation is destined for Borssele 2-3, which is EUR 7 billion for two units. However, the financing model has not been decided on, so the use of the government reservation and the participation of corporate equity partners and commercial lenders are unknown. The government reservation may be used for equity investment (full or part ownership), debt financing (a state loan), subsidies, guarantees and price measures. An estimate of the construction cost has not been made available.

The construction of Borssele 2-3 is expected to start in 2028, and according to initial plans, it will be ready around 2035. Each unit will have a capacity of between 1,000 and 1,650 MW.[174]

4.2.1 Expected costs and lead times for Borssele 2-3

Since the proposed budget is not known, the analysis is based on a rough estimate of a EUR 19 billion available budget (see section 4.2.2).

Furthermore, the analysis is based on a 2 x 1,650 MW nameplate capacity, assuming the Dutch government will pursue this choice. This is equivalent to a reference net capacity of approximately 2,700 MWe.

Equally to the exploration for Dukovany, the analysis is further based on the minimum, mean and maximum cost per kWe of the six projects in the research (from Table 25). Also, the realised lead times of the six projects are used to calculate the lead time escalation. The outcome of the analysis is presented in Table 27.

Table 27 Exploration of cost and lead time for Borssele 2-3

	Proposal	Low expectation	Mean expectation	High expectation
Budgeted cost (rough estimate)	19,000	19,000	19,000	19,000
Realised cost	19,000	6,275	26,094	40,971
Budget overrun	0	-12,725	7,094	21,971
Budget overrun factor	**1.0**	**0.3**	**1.4**	**2.2**
Construction start date	1-Jan-28	1-Jan-28	1-Jan-28	1-Jan-28
Scheduled commercial operation date	1-Jul-35	1-Jul-35	1-Jul-35	1-Jul-35
Commercial operation date	1-Jul-35	27-Sep-39	5-Apr-42	19-Sep-45
Scheduled lead time	7.5	7.5	7.5	7.5
Realised lead time	7.5	11.7	14.3	17.7
Lead time escalation	0	4.2	6.8	10.2
Lead time escalation factor	**1.0**	**1.6**	**1.9**	**2.4**
Reference net capacity (MWe)	2,700	2,700	2,700	2,700
Cost in EUR per kWe	**7,037**	**2,324**	**9,665**	**15,175**

Sources: See text.

The analysis shows that, on the low end, the expected realised cost would be EUR 6.3 billion. Based on the realised cost for Shin Hanul 1-2, this outcome is considered too low and unrealistic (the same explanation as for Dukovany).

The mean expectation would give an expected realised cost of EUR 26.1 billion and a budget overrun of EUR 7.1 billion.

The high expectation shows a realised cost of EUR 41.0 billion and a budget overrun of 22.0 billion. These values may seem extreme, but are based on the evidence not unrealistic. To bring this to mind, the cases of Flamanville, Vogtle and Hinkley Point show (projected) realised costs in the range of EUR 20 to 46 billion and budget overruns in the range of EUR 17 to 25 billion.[iii]

Looking at the intended start of commercial operation in 2035, the analysis shows that on the low end, the start date may be September 2039. The mean expectation is a start in April 2042, and the high expectation is a start in September 2045.

iii Flamanville 3 and Hinkley Point C 1-2 have not started commercial operation, yet. Therefore, their realised cost may be higher than the current cost estimates.

This corresponds to the expected realised lead times of 11.7, 14.3 and 17.7 years and lead time escalation factors of 1.6, 1.9 and 2.4, respectively. The low-end factor matches the value of 1.6 given by the literature. The high-end factor is close to the mean escalation factor (2.6) as determined for the six cases, which would result in an expected lead time of 19.5 years (June 2047). As already discussed for Dukovany, this is still a realistic perspective.

The case of Olkiluoto 3 experienced a lead time escalation of factor 4.6, which would result in an expected lead time of 34.5 years (June 2062). This is considered unrealistic, under the premise that the lead time escalation, as realised for Olkiluoto 3, is too extreme and could be prevented in future.

The outcomes show the high range of uncertainty in:

- Projected realised costs (EUR 6 to 41 billion);
- Projected budget overruns (EUR 7 to 22 billion);
- Projected realised lead times (11.7 to 17.7 years);
- Projected lead time escalations (4.2 to 10.2 years).

These uncertainties and forthcoming financial risks need to be addressed properly in the cost calculations and planning of Borssele 2-3. Also, the planning needs to be reviewed and reassessed against the Dutch government's targets of carbon-neutral electricity production in 2035.

As input for these calculations and discussions, this chapter concludes with some notes on sufficient coverage, the magnitude of the expected realised cost and the timelines of climate targets.

4.2.2 Rough estimate of sufficient coverage in the budget

To make an estimate of the coverage, it is assumed that, first, from the Dutch government's proposed budget, EUR 7 billion is allocated to Borssele 2-3. Second, it is assumed that EUR 5 billion is used for equity investment by the Dutch government and EUR 2 billion for other expenses ((preparation, bidding process, knowledge programme, guarantees, etc). Third, it is assumed that this amount is used in full as equity participation by the Dutch government in the venture. Combined with a 70/30 debt-equity ratio, these assumptions lead to a debt part of EUR 12 billion.

Taking together these rough estimates of EUR 5 billion in equity and EUR 12 billion in debt, the estimated budget would be EUR 19 billion available for the financing of Borssele 2-3.

Therefore, the EUR 7 billion Dutch government's proposed budget reserve would be sufficient to attract the financing needed to cover the EUR 16 billion cost of the low expectation. However, it would not be sufficient to attract the financing needed to cover the cost of EUR 26 billion, the mean expectation. Naturally, it would also not be sufficient to cover the cost of EUR 41 billion, the high expectation. In this theoretical exercise, the expected budget overrun would be EUR 7 billion (mean expectation) or EUR 22 billion (high expectation).

4.2.3 Magnitude of expected cost

The mean and high cost expectations for Borssele 2-3 are EUR 26.1 and 41.0 billion. This represents a significant amount for the government and society. To illustrate the magnitude of this amount, the expected costs are compared in Table 28 and Table 29.

Furthermore, the expected cost is compared to the Dutch state budget 2024[175], the budget of the Ministry of Economic Affairs and Climate (EZK)[176], the Dutch Gross Domestic Product (GDP) 2023[177], and the Energy transition budget until 2030.[178]

Table 28 Comparison of the expected cost (mean expectation)

Compared to	EUR billion	Relative size
Expected cost (mean expectation)	26.1	100.0%
State budget 2024	503.1	5.2%
Budget EZK 2024	12.2	213.2%
GDP 2023	1,033.0	2.5%
Budget energy transition 2030	35.0	74.6%

Sources: see text; Note: The expected cost is compared to a single-year budget to get a sense of its magnitude. In practice, the reserve will be built up over several years and presented in the government's multi-year budget.

The expected cost (mean expectation) represents about 5% of the total annual state budget and is more than double the EZK ministry's annual budget (213%). Furthermore, it represents 2.5% of the GDP and 75% of the multiple-year energy transition budget.

Table 29 Comparison of the expected cost (high expectation)

Compared to	EUR billion	Relative size
Expected cost (high expectation)	41.0	100.0%
State budget 2024	503.1	8.1%
Budget EZK 2024	12.2	334.8%
GDP 2023	1,033.0	4.0%
Budget energy transition 2030	35.0	117.1%

Sources: See text. Note: The expected cost is compared to a single-year budget to get a sense of its magnitude. In practice, the reserve will be built up over several years and presented in the government's multi-year budget.

The expected cost (high expectation) represents about 8% of the total annual state budget and is more than triple the EZK ministry's annual budget (335%). Furthermore, it represents 4% of the GDP and exceeds the multiple-year energy transition budget (117%).

4.2.4 International and Dutch climate targets' timelines

The expected lead times for Borssele 2-3 are 11.7 (low), 14.3 (mean) and 17.7 years (high expectation), resulting in commercial operation starting in September 2039, April 2042, or September 2045, respectively.

In Table 30, these lead time expectations are compared to the timelines of set climate targets. This provides insight into whether a newly built nuclear power plant could potentially contribute to carbon savings.

Table 30 Potential number of years contributing to climate targets

Source	Reduction target	Year	Years to target	Potential number of years contributing to climate targets*		
				Expected start of commercial operation		
				2039	2042	2045
COP 21 Paris 2015 [179] NL Climate Policy 2023 [180]	45% 60%	2030	6.3	-8.8	-11.3	-14.8
NL Carbon-neutral electricity production NL Climate Law 2023 [181] NL Climate Policy 2023	100% 55% 70%	2035	11.3	-3.7	-6.3	-9.7
EU Climate Law 2021 [182] NL Climate Policy 2023	90% 80%	2040	16.3	1.3	-1.3	-4.7
COP 21 Paris 2015 EU Climate Law 2021 NL Climate Law 2023	100%	2050	26.3	11.3	8.7	5.3

Sources: See table. Notes: Red < 0 years; Orange < 5 years; Green > 5 years.
* Not taking into account the compensation of pre-operation carbon emissions

Whether the carbon savings actually will occur also depends on the carbon intensity of the stages prior to commercial operation. It will take some time to compensate for the CO_2 emissions during construction and in the supply chain. This is further explained in the section 5.3.2.

The table shows that a new nuclear power plant in the Netherlands can potentially only contribute to the climate targets set for 2050. It will come too late to contribute to the climate targets of 2040 and earlier. Clearly, a contribution to the 2035 target of carbon-neutral electricity production is out of reach.

The potential remaining carbon-saving years to contribute to the 2050 targets amounts from 5.3 to 11.3 years. With the unknown time period to compensate for the pre-operation carbon emissions, it cannot be confirmed that Borssele 2-3 will lead to an actual contribution to reaching the climate targets. Potentially, Borssele 2-3 will contribute, but whether this will be a significant and cost-effective contribution remains a question to be answered.

5

Conclusions, discussion and recommendations

This concluding chapter starts with the conclusions. The results are further discussed in Section 5.2. Section 5.3 gives recommendations for further research.

5.1 Conclusions

For the six selected construction projects, this research determined a range of values for budgeted and realised construction costs and for scheduled and realised construction lead times.

Expressed in EUR billion, the identified budget overruns are minimum 2.5, mean 13.8 and max 24.7. The identified realised construction costs are:

- Shin Hanul 1-2: EUR 6.4 billion;
- Olkiluoto 3: EUR 11.0 billion;
- Flamanville 3: EUR 19.9 billion;
- Barakah 1-4: EUR 24 billion;
- Vogtle 3-4: EUR 33.9 billion;
- Hinkley Point C: EUR 21.4 billion.

Compared to the initially budgeted costs, the realised costs and budget overruns (in EUR billion) are:

Project	Budgeted cost (EUR bln)	Realised cost (EUR bln)	Budget overrun (EUR bln)	Budget overrun factor
Olkiluoto-3	3.2	11.0	7.8	3.4
Shin Hanul 1-2	4.0	6.4	2.5	1.6
Barakah 1-4	14.1	24.0	9.9	1.7
Vogtle 3-4	9.2	33.9	24.7	3.7
Flamanville 3	3.3	19.9*	16.6*	6.0*
Hinkley Point C 1-2	24.7	46.1*	21.4*	1.9*

Note: * Projected values

The identified realised cost figures are, almost without exception, higher than the figures reported by earlier studies. This is mainly due to updating the figures to the latest standings. Several construction projects were not finished during the latest cost estimates and are, therefore, incomplete. It is also good news for the Dutch preparations, while the advancing insights provide the opportunity to reassess and improve the cost estimates.

The identified realised construction lead times (in years) are:

Project	Scheduled lead time (Years)	Realised lead time (Years)	Lead time escalation (Years)	Lead time escalation factor
Olkiluoto-3	3.9	17.7	13.8	4.6
Shin Hanul 1-2	5.7	11.7	6	2.1
Barakah 1-4	5.9	12.1	6.2	2
Vogtle 3-4	8.5	14.9	6.3	1.7
Flamanville 3	5.1	17.1*	12.0*	3.4*
Hinkley Point C 1-2	6.6	12.1*	5.5*	1.8*

Note: * Projected values

When looking at the budget overrun and lead time escalation factors, the research identified the following ranges, based on the six selected cases:

Factor	Minimum	Mean	Maximum
Budget overrun factor	1.6	3.1	6.0
Lead time escalation factor	1.7	2.6	4.6

Following Dukovany 5-6's proposals, the project is budgeted at EUR 15.8 billion and a lead time of 12.8 years. The analysis shows that this initially budgeted cost is close to the mean value that is expected based on the case studies. The calculated low expectation is considered unrealistic and ruled out. The mean expectation would be a realised cost of EUR 17.4 billion and a budget overrun factor of 1.1. The high expectation would be a realised cost of EUR 27.3 billion with a budget overrun factor of 1.7.
Dukovany 5-6's lead times are taken from the case studies and range between 11.7 (low), 14.3 (mean), and 17.7 years (high expectation), resulting in a commercial operation date between December 2036 and December 2042.

Looking at Borssele 2-3, a cost estimate is not available yet. The Dutch government intends to make a budget reserve of EUR 7 billion (for two units), but the financing model has not been chosen, and the proposed budget reserve is awaiting parliamentary approval. Therefore, the analysis took a rough estimate of the available budget (EUR 19 billion) based on the proposed reserve to enable the exploration of the expected cost range. An initial schedule mentions Borssele 2-3 to start operations in July 2035.
The calculated low expectation is considered unrealistic and ruled out. The mean expectation would be a realised cost of EUR 26.1 billion and a budget overrun factor of 1.4. The high expectation would be a realised cost of EUR 41.0 billion with a budget overrun factor of 2.2.
Borssele 2-3's lead times are, like Dukovany, taken from the case studies and range between 11.7 (low), 14.3 (mean) and 17.7 years (high expectation). This would result in a commercial operation date between September 2039 and September 2045.

For Dukovany and Borssele, the cost per kilowatt (electric) is taken from the case studies and varies from EUR 2,324 (low) to 9,665 (mean) and 15,175 (high expectation). The Dukovany bid translates into EUR 8.778 and the Borssele rough budget estimate into EUR 7,037 per kilowatt (electric).

The IEA uses a value of EUR 6,230 per kWe for nuclear in its scenarios. The 2021 KPMG study identified an average cost per kW installed capacity of EUR 4,973 per kW. The 2022 Witteveen+Bos study identified an average cost per kW installed capacity of EUR 7,959 per kW but applied a cost of EUR 3,520 per kW in its scenarios.

Since the current research identified a mean cost of EUR 9,665 per kWe, it is clear that updating the actual cost of the six projects was necessary. This outcome provides the opportunity to update, reassess, and improve the cost estimates for Borssele 2-3. Higher cost estimates may also lead to different insights into cost-effectiveness for comparing scenarios of the future energy mix.

- **Government financing**

The study analysed the government contribution to the financing of the six selected construction projects. This has led to some remarkable observations:

- In the Olkiluoto and Hinkley Point cases, the financial contribution of the domestic governments (Finland and the UK, respectively) was limited, while the contribution of foreign governments was significant. In literature, this is sometimes called government-to-government financing, but a more accurate term is government-supported vendor financing. In the mentioned cases, the governments support the export opportunities in favour of their national nuclear sector.
- Remarkably, this has come at a considerable price, especially for the French government, which had to restructure and nationalise Areva and EDF.
- Furthermore, especially in the cases of Olkiluoto, Hinkley Point and Vogtle, the domestic government turned out to be more involved in the financing than it was thought. This is caused by governments owning significant company shares through their ultimate beneficial ownership of the project sponsors, which is not visible at first sight.
- Due to EDF's nationalisation and its presence in three of the case studies, these projects started with a larger corporate share of equity and ended up with a larger government share of equity.
- The financing of Barakah 1-4 may be described as nearly pure government financing. The government financing of Shin Hanul 1-2 is set at 51%, following the government share in KEPCO. However, as the Government of South Korea is the majority owner, KEPCO is state-controlled and, therefore, the financing decisions of Shin Hanul 1-2 are in the hands of the government.
- The financing of Flamanville 3 may be described as a mix of government and corporate financing, with the government share getting larger in time, due to the covering of losses, shareholders buy-out and nationalisation. Part of the losses were also borne by the shareholders in the form of missing out on dividend payments and the loss of shareholder value. Although fully government-owned, EDF is a corporation, and part of the losses have been covered by internal accounting at the expense of returns of operations of other business activities. Also, a part of the financing has been provided by commercial lenders.
- The realised construction cost per installed kWe varies from EUR 2,324 to 15,175 per kWe. There is no clear relationship between government participation and lower costs.
- The government's participation in the ultimate beneficial ownership of the project companies varies from roughly a quarter (24.3% of Vogtle 3-4) to full ownership (100% of Flamanville 3). Remarkable is the large government participation in the projects in France and the UK. Also remarkable is the government participation in the projects in Finland (24.3%) and the US (24.3%), which have only private companies as project sponsors. On average, government participation (UBO) is 64.3%.

- **Comparison to renewable energy sources**

The costs per kilowatt (electric) for renewable energy sources range from 1,050 (solar PV) to 1,850 (wind onshore) and 3,620 (wind offshore).

With the mean cost per kilowatt (electric) for nuclear identified in this study of EUR 9,665, solar and wind are highly favourable compared to nuclear when considering cost efficiency, lead times and financial risk.

The outcome also confirms the IEA's 2022 scenarios' choice of the OCC value for nuclear (EUR 6,230 per kWe) and the rising trend it predicts.

- **Construction completed in time to deliver meaningful CO2 savings?**

This research identified an average realised construction lead time of 14.3 years. Construction is preceded by a political, planning, and preparation phase of three years at a minimum. When starting development in 2025, the construction of a nuclear power plant would start in 2028, which would lead to the start of commercial operation in 2039 (low), 2042 (mean), or 2045 (high expectation).

A new nuclear power plant will come too late to result in carbon savings that will contribute to the climate targets for 2040 and earlier. Clearly, a contribution to the 2035 target of carbon-neutral electricity production in the Netherlands is out of sight. Potentially, Borssele 2-3 could contribute to reaching the 2050 climate targets. Whether this may be a significant contribution is a question open to further research.

- **Financing models**

Several financing models have been found. All six cases have a mix of corporate and government financing. Barakah 1-4 and Flamanville have the highest share of government contributions. Olkiluoto 3 and Hinkley Point C 1-2 the lowest.

Olkiluoto 3 and Vogtle 3-4 have a cooperative financing model in which the power off-takers participate. In Finland this is called the Mankala model and the participants are both corporates and governments. In the US, the participants are also corporations and governments, but also customer cooperatives.

Government price regulation in the form of a Contract for Difference, which guarantees the operator a minimum price, supports the financing of Hinkley Point C 1-2. A price measure is not known for the other five cases.

The proposed Dukovany 5-6 project takes three (EU-approved) price measures: direct price support via a power purchasing agreement (PPA), a two-way Contract for Difference, and a partly closed price market (30%) through government auctioning.

5.2 Discussion

5.2.1 Magnitude of numbers

The analysis delivers a range of budget overruns from EUR 2.5 to 24.7 billion, with budget overrun factors of 1.6 to 6.0. At first glance, these numbers seem implausible. Yet, they are actual numbers representing realised projects.

When we apply these numbers to the cases of Borssele 2-3 and Dukovany 5-6, the numbers may seem implausible, again. Yet, do they?

The analysis in this research explores the magnitude of the numbers. These are theoretical exercises, but they do give us valuable information about the magnitude of the numbers, the range of possible scenarios, the uncertainties of the cost calculations and the financial risk involved.

Based on the research findings it can be concluded that:

- All projects experienced exceedances of budget and time;
- The minimum identified budget overrun was a factor 1.6 (relative to the initial cost estimate);
- Taking the average budgeted cost of the six projects (EUR 10 billion), these minimum values lead to a budget overrun of EUR 6 billion and a projected realised cost of EUR 16 billion.

One could argue that these projections overestimate the costs. Because a current cost estimation would already include lessons from the past and take the historical budget overruns into account. That is a valid point.

However, it is worth noting that the same argument also applies to the original budgeted costs of the six case studies. These were also based on the latest insights at the time of their initial cost estimation.

The history of budget overruns teaches us that we should not be too confident when - prior to a project – judging the quality of an initial budget calculation. After all, the history lesson is that, at any given time in history, the actual costs of large-scale infrastructure projects are structurally underestimated by large. Literature gives an average budget overrun factor of 1.6 for large-scale energy infrastructure projects. Nuclear power plant construction projects show, in general, larger budget overrun factors.

The history of the six nuclear power plant construction projects shows a great degree of variability and unpredictability in realised construction costs and timelines. Cost estimators cannot be asked to accurately predict the future developments that will determine the actual cost and timeline. However, since the occurrence of budget and lead-time exceedances is certain, cost estimators can be asked to broadly explore the whole cost range and produce the lowest and highest conceivable cost estimates.

The literature and this research suggest that initiators' and contractors' underestimations may be systemic. Since the budgets and risks involved are expressed in billions, policy-makers and members of parliament must be on the lookout for extreme cost scenarios.

Furthermore, the costs form a considerable part of the Dutch national budget for 2024 and beyond. The high costs entail the obligation to weigh the cost-effectiveness of alternative energy sources in the final decision-making.

5.2.2 Cost per kilowatt (electric)

This research identified a mean cost per kilowatt (electric) of EUR 9,665, with a minimum of 2,324 (Shin Hanul 1-2) and a maximum of 15,175 (Vogtle 3-4).

- **Exceptional setbacks or confirming the negative learning curve?**

The IEA uses a value of EUR 6,230 per kWe for nuclear in its scenarios. The KPMG study identified an average cost per kW installed capacity of EUR 4,973 per kW. The Witteveen+Bos study identified an average cost per kW installed capacity of EUR 7,959 per kW, but applied in its scenarios a EUR 3,520 per kW cost figure.

This research identified a mean cost of EUR 9,665 per kWe. The preliminary budget for the proposed Dukovany 5-6 comes down to EUR 8,778 per kWe. The rough estimated budget for Borssele 2-3 translates into EUR 7,073 per kWe.

Our research included a number of construction projects that experienced large setbacks (Vogtle, Flamanville, and Hinkley Point), with resulting costs per kilowatt (electric) at EUR 10,000 and above. But the research also included Olkiluoto 3, Shin Hanul 1-2 and Barakah 1-4, with costs per kilowatt (electric) below EUR 7,000.

The mean values identified during this research are higher than those given by earlier research. This may be explained by the fact that the six most recently completed construction projects have been analysed in this research. Or did Vogtle, Flamanville, and Hinkley Point experience exceptional setbacks? Or are the observed rising construction costs due to the increasing complexity of technology and safety measures, a phenomenon that is described by some authors as ‘the negative learning curve of nuclear’?

Leaning on the Dukovany cost estimate, we argue that the higher figures are explained by taking the six most recent projects and that our research findings fit into this ‘negative learning curve’ theory. In this assumption, it is acknowledged that Vogtle, Flamanville, and Hinkley Point experienced exceptionally large overruns, which are primarily explained by exceptionally low initial cost estimates. It seems EDF severely underestimated the construction costs of the new EPR-1600/1650/1750 technology.

Shin Hanul 1-2, on the other hand, showed positive learning (see paragraph below). The fact that in the Dukovany bid, the cost estimate (EUR 8,778 per kWe) is 3.7 times as high as the Shin Hanul 1-2’s realised cost (EUR 2,234 per kWe) has to be considered a result of learning. At the same time, the height of the Dukovany cost estimate can be viewed as a confirmation of the ‘negative learning’ theory.

- **Shin Hanul 1-2 an outlier in the dataset?**

The minimum value of EUR 2,324 per kWe originates from the Shin Haul 1-2 case. As argued, the value was deemed too low to be of use for the cost exploration of Dukovany and Borssele.

The low value, compared to the Barakah and Dukovany cases, raises the question of whether the value is indeed the true realised cost. Comparing this figure to Barakah and Dukovany where the same technology is/will be applied:

- The Barakah 1-4 case has a realised value of EUR 4,510 per kWe;
- The Dukovany 5-6 case has a proposed value of EUR 8,778 per kWe.

Based on this comparison, one may wonder what causes the almost factor 2 cost difference between the realisation of an APR-1400 in South Korea and the United Arab Emirates and the more than factor 3 cost difference between the realisation of an APR-1400 in South Korea and an APR-1000 in the Czech Republic.

Part of the explanation must lie in the additional cost caused by FOAK characteristics, and part lies in the cost inflation of raw material prices. Also, the wage-price levels differ (Czech Republic EUR 19,905; South Korea EUR 33,797; Netherlands EUR 51,522).[183]

Several authors have explored this question. The general consensus is that the South Korean government and industry made the choice to build two series of nuclear power plant units in sufficient numbers to create economies of scale. The well-developed supply chain and maintaining a specialised workforce and knowledge base led to considerable cost efficiencies. This shows that learning in nuclear power may require significant operational experience in addition to complete construction experience, before benefits are accrued in the form of new rationalised designs and lower construction costs.[184]

This means that in the South Korean case, the Nth-of-a-kind (NOAK) aspect is a major contributor to overall cost reduction. For the Netherlands and the Czech Republic, it is expected that First-of-a-kind characteristics will considerably influence the cost and timeline.

5.2.3 Budget overruns

The six case studies' realised costs range from EUR 6.4 to 46.1 billion, with an average of EUR 23.6 billion.

The KPMG study (2021) concludes that the investments required are EUR 7 to 13.2 billion.

The RLI study (2021) mentions (projected) realised construction costs of EUR 11 to 30.4 billion based on four nuclear construction projects (Olkiluoto 3, Flamanville 3, Taishan 1-2 and Hinkley Point C 1-2). [185]

In our findings, the information is updated recently (September 2024). Both Flamanville 3 and Hinkley Point C 1-2 have recently adjusted their projected commercial start dates.

When looking at the budget overrun factor, the highest factor found is 6.0 for Flamanville 3. If we apply this factor to the Dukovany and Borssele cases, it produces too high figures for the realised cost, with a high expectation of EUR 100 billion. This leads to the conclusion that applying a budget overrun factor of 6.0 is unrealistic. Therefore, we did not use it.

The underlying cause is that while the Flamanville 3's realised cost is not extremely high, the budgeted cost is extremely low. The originally budgeted cost was EUR 3.3 billion, which is about the same as the budgeted cost for Olkiluoto-3 (EUR 3.2 billion) with the same reactor technology. Apparently, EDF seriously underestimated the building cost of their new EPR-1650 at that time severely.

5.2.4 Lead time escalations

The 2021 RLI study mentions (projected) realised lead times of 9 to 17 years based on four nuclear construction projects (Olkiluoto 3, Flamanville 3, Taishan 1-2 and Hinkley Point C 1-2). The RLI expects the earliest start of commercial operation of a new Dutch nuclear power plant in the years 2035-2040.[186]

In our findings, the information is updated since Flamanville 3 is close to commercial operation in the meantime, and Hinkley Point C 1-2 has a new projected commercial start date.

5.3 Recommendations

As a follow-up to this study, a number of research topics are proposed. The recommendations are put in two categories: the financing (Section 5.3.1) and the potential to contribute to the climate goals (Section 5.3.2).

5.3.1 The financing of new nuclear

The following topics for further research into the financing of new nuclear are envisioned;

- **Cost scenarios including capital costs due to interest during construction**

Interest during construction forms a significant part of the realised cost of a construction project. Since the total amount of due interest depends highly on the construction lead time, and lead times are variable and unpredictable, it is recommended to explore cost development for several lead-time length scenarios. For the case of Borssele 2-3, this would provide information on the height and the range of expected due interest payments.

- **Financial research into the potential financiers of Dukovany units 5 and 6**

Being the most recent power plant in development and situated in an EU country, Dukovany 5-6 is believed to be a leading example for the preparation stages of Borssele 2-3. Therefore, more detailed insight into potential financiers, the financing construction, and the proposed construction costs and lead time may provide information that will improve the quality of the arguments for the decision-making in the Netherlands.

- **Comparison to budget overruns of other large-scale projects in the Netherlands**

This study aims to illustrate that while budget overruns and lead time escalations are normal for large-scale construction projects, the exceedance factors of nuclear construction projects are on a different scale. To this end, the budget overruns and lead time escalations of a number of large-scale construction projects in the Netherlands will be studied.

For instance, the construction of the Amsterdam Noord-Zuid metro line, for which the exceedances were deemed quite extraordinary at the time, had a budget overrun of factor 2.1 and a lead time escalation of only factor 1.9. These factors are much lower than the factors found in this research for nuclear power plants (on average 3.1 and 2.6, respectively). The hypothesis for this research is that the budget overruns of nuclear projects are higher than the highest budget overruns in Dutch construction history. The outcome of the study would inform policy-makers to be extra careful with cost calculations for nuclear power plants.

- **Green financing**

During the research several bond issues have been encountered that received the ESG status ‘Green bond’. The argument is that nuclear does contribute to climate targets. However, as has been postulated, the contribution of ‘new nuclear’ to reach the Paris climate targets may be doubted.

It is recommended that the ESG criteria that enabled the green labelling of nuclear energy financing be studied. The study may result in recommendations to refine the ESG criteria so that they actually contribute to the climate targets.

- **Investment policies of International Finance Institutions**

For decades, international finance institutions (IFIs) have refrained from financing nuclear energy. Recently, EIB broke this pattern by participating in a green bond issue by EDF. A study into the investment and exclusions policies of IFIs can identify the different arguments IFIs take to decide upon investments in nuclear energy.

- **Investment policies of global pension funds**

Pension funds are among the largest investors worldwide. A study into the investment and exclusions policies of pension funds could reveal the different arguments pension funds take to decide upon investments in nuclear energy. This would provide information for engagement with pension funds to strengthen their exclusion policies or to initiate divestments.

- **Financial research into ‘Who benefits from financing new nuclear’**

This is research that Profundo has done before and can be updated. It concerns research to identify all lenders providing credit to nuclear power plants (both under construction and in operation). And to identify all investors in shares and bonds issued by nuclear power plants. By doing so, Profundo analyses the largest creditors and investors worldwide. Results can be presented as rankings of the Top-50 global banks, the Top-50 global pension funds, the Top-50 global investment managers, etc. In general, the outcome of such research may be used to engage with financial institutions on their nuclear investment policies and to encourage financial institutions to divest from nuclear power.

5.3.2 The potential of new nuclear in contributing to the climate targets

This research identified an average realised construction lead time of 14.3 years. The construction is preceded by a political, planning and preparation phase of three years at a minimum. When starting development in 2025, the construction of a nuclear power plant would start in 2028, which would imply the start of commercial operation in 2042.

The hypothesis formed during the research is that a new nuclear power project will come too late to result in meaningful CO2 savings that will contribute to the set and agreed-upon 2040 and 2050 climate targets. The construction lead times identified during this research support this insight.

- **Scenarios for potential Borssele 2-3 commercial operation start dates**

In light of the realised construction lead times presented in this study, it is recommended to do further modelling with scenarios to explore the range of feasible commercial operation start dates of Borssele 2-3. In this proposed research, the lead times of pre-construction stages should be taken into account (policy-making, political decision-making, bidding process (2 years), contracting (1 year), environmental impact assessment, licensing and financing).

- **The potential to contribute to climate targets 2035, 2040 and 2050**

Based on timeframes identified through the above scenarios, it is recommended to further study the potential contribution of Borssele 2-3 to carbon savings related to the Dutch national emission targets as has been set and agreed upon in the national and international context. Relevant climate targets are summarized in Table 30.

The research would explore lead time scenarios to compare with the timeline of the climate targets. It would also include the pay-back period needed to compensate for CO_2 emissions that occurred pre-operation (see next and further bullet points).

The outcome of the proposed research is expected to conclude that Borssele 2-3's positive climate impact would come too late to play a significant role in combating climate change in the period up to 2050.

- **Break-even point climate emissions of construction**

Adding to the previous discussion, eventual carbon savings by a new nuclear power plant will occur from the start of commercial operation *but following an average 14-year construction period in which carbon is emitted*. Put differently, the CO_2 savings are preceded by 'CO_2 investments'. Net CO_2 savings will occur only following a CO_2 investment pay-back time.

Mining and manufacturing construction materials like concrete and steel are highly carbon-intensive. Transport and construction-side equipment use fossil fuels, which also contribute significantly to carbon emissions.

It is recommended to study the magnitude of the carbon footprint of supplied materials and construction work. Based on that it would be possible to determine the duration of the pay-back time to make break-even with the 'CO_2-investments'. Put in a formula:

> *Year of start* CO_2 *savings =*
>
> *projected pre-construction lead time + scheduled construction lead time +*
>
> *estimated lead time escalation + calculated '*CO_2 *investment' pay-back time*

- **Carbon emissions of uranium fuel supply chain**

Another source of carbon emissions attributed to nuclear energy is the nuclear fuel supply chain. It is postulated that following the depletion of the richest uranium ores, the mining and refining of lower-grade ores will become so energy-intensive that the carbon savings will be annulled.[187]

It is unclear whether this factor will be important in the near future. Based on sector reports, high-grade ores (and corresponding low-cost prices) may be available for a long time:

- The World Nuclear Association states that "the world's present measured resources of uranium (5.7 Mt) in the cost category above present spot prices and used only in conventional reactors, are enough to last about 90 years."; [188]
- The so-called NEA 'Red Book' concludes: "*Considering current yearly uranium requirements of about 60,000 tU, identified recoverable resources, including reasonably assured resources and inferred resources, are sufficient for over 130 years. Exploitation of the entire conventional resource base would increase this to around 250 years*".[189]

It would be interesting to see future research that either confirms or refutes the impact of the carbon contribution of the refining of decreasing uranium ore grades.

- **Full life-cycle analysis**

In a time when solutions are urgently needed, it seems remarkable that researchers do not agree on nuclear power's climate impact. Estimates vary widely, from 4 to 150 g CO_2/kWh.[190]

It is recommended to study nuclear energy's carbon footprint from a full life-cycle perspective. This includes the uranium refining mentioned and all other pre-construction emissions. It would also include the carbon emissions of the dismantling (including transport, recycling, and final disposal of demolition waste) and the temporary and 'final' storage of nuclear waste.

A final remark about 'final storage': storing high-radioactive waste in a controlled environment will require energy input. Considering the virtually endless storage time of hundreds of thousands of years, the total required energy input over the complete storage period may be high, even when the energy input per year may be low. This aspect should turn up in a full life-cycle analysis as well.

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Appendix 1 Post-construction cost

This appendix explains some of the costs that will occur post-construction. These costs are not considered in this study. For the decision-making, when the full life-cycle costs of nuclear are considered, the costs that occur post-construction (and post-operation) are also relevant. For the sake of completeness, they are mentioned here, but not described in detail.

- **Operational cost**

  The costs in this stage are all operation and maintenance costs, including fuel supply, reprocessing of spent fuel, insurance for nuclear incidents, and reservations for waste disposal and dismantling.

  The debt of the construction financing is refinanced, and loan repayments and interest payments will continue during the operational stage, as will the return of capital to the equity investors (dividend payments). Interest during construction can amount to 20%, and the return of capital to 47% of the levelised cost of electricity (LCOE).[iv]

- **Dismantling costs**

  The dismantling of a nuclear power plant is a complex and lengthy process. Dutch law requires the dismantling to start directly following the operational stage. The financing of the dismantling costs must be arranged before the commercial operation starts. Dismantling (including demolition and site restoration) may take approximately 20 years.[v]

  Known cost estimates are:

  - In 2018, the dismantling costs of Belgian nuclear power plants were estimated at EUR 15.1 billion, for seven facilities with a combined installed capacity of 6,000 MW. Cost per kWe are assessed at EUR 2,500 per kWe;
  - In 2021, the dismantling costs of Hinkley Point C 1-2 (3,200 MW combined) were estimated at GBP 7.3 billion (EUR 8.7 billion) or GBP 2,300 (EUR 2,739) per kWe.[vi]

- **Liability costs**

  As stated in the law (Dutch Nuclear Incident Liability Act), the Dutch government and the operator of the Borssele unit(s) share the liability in case of an accident at Borssele. Liability or insurance covers costs of up to EUR 3.2 billion.[vii] Nuclear incidents at Chernobyl and Fukushima have demonstrated that damage costs may amount to hundreds of billions.

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iv RLI (2022, September), *Splijtstof, Besluiten over kernenergie vanuit waarden*, p. 90, online: https://www.rli.nl/publicaties/2022/advies/splijtstofviewed in August 2024.

v RLI (2022, September), *Splijtstof, Besluiten over kernenergie vanuit waarden*, p. 93, online: https://www.rli.nl/publicaties/2022/advies/splijtstofviewed in August 2024.

vi RLI (2022, September), *Splijtstof, Besluiten over kernenergie vanuit waarden*, p. 93, online: https://www.rli.nl/publicaties/2022/advies/splijtstofviewed in August 2024.

vii Overheid.nl (2022, 1 January), “Wet aansprakelijkheid kernongevallen“, online: https://wetten.overheid.nl/BWBR0003234/2022-01-01, viewed in July 2024.

The EUR 3.2 billion liability is divided into four tranches: [viii]

1. Operator EUR 1,200 million (Borssele operator via insurance);
2. Dutch territory EUR 500 million (Dutch government);
3. Cross-border EUR 300 million (Member states of the Brussels Convention);
4. Additional EUR 1,200 million (Dutch government).

The Dutch government's contribution to tranche 3 is EUR 6 million per incident, which will rise to EUR 9 million when Borssele 2-3 is built.[ix]

The Dutch government's total liability is EUR 1,706 million, which corresponds to 53%. Other Brussel Convention members are liable for 9%, bringing the total government liability to 62%.

When the operator is (partially) owned by the government, the government's liability share will be higher and cover partially or fully the operator's liability (38%), too.

- **Temporary waste disposal**

  The current Dutch policy for temporary waste disposal is to store it in the COVRA facility adjacent to the Borssele 1 nuclear power plant until the year 2100. The tariffs for high-level radioactive waste are not disclosed. [x]

- **Final waste disposal**

  In the year 2100, the waste disposal facility for permanent storage is planned to commence operations. The facility is currently thought to be a deep geological repository, that is, a storage facility deep underground in a geological formation that has been stable for millions of years.

  The total amount required for the final storage was determined by research by COVRA in 2017. The required amount is estimated at EUR 2.8 billion (2020 price level) to cover the expenses in the period 2100 - 2186. The required amount is collected into a provision, with allocations in the form of a waste allowance, complemented with returns on investments. The expected real return on the investment strategy is 3.5% (5.5% nominal). The waste allowance is a fixed rate surcharge on the temporary waste disposal fees as applied by COVRA.[xi]

viii Overheid.nl (2022, 1 January), "Wet aansprakelijkheid kernongevallen", online: https://wetten.overheid.nl/BWBR0003234/2022-01-01, viewed in July 2024; CE Delft (2011, July), Nuclear energy: The difference between costs and prices.

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Appendix 2 Top-50 Providers of debt to project sponsors

Table 31 Top-50 Debt providers to the direct sponsors of the six selected nuclear power plants (2003-2024, in EUR million)

Bank	Country	Loans	Underwriting	Total
Bank of America	United States	4,789	3,910	8,699
Citigroup	United States	3,959	3,889	7,848
Truist Financial	United States	3,788	3,418	7,206
Wells Fargo	United States	3,781	3,351	7,132
JPMorgan Chase	United States	2,451	4,315	6,765
Barclays	United Kingdom	2,762	3,239	6,001
Mizuho Financial	Japan	2,685	2,847	5,531
Mitsubishi UFJ Financial	Japan	2,297	3,019	5,316
Goldman Sachs	United States	1,753	3,301	5,055
Morgan Stanley	United States	1,713	2,833	4,545
Scotiabank	Canada	1,781	2,281	4,061
US Bancorp	United States	1,688	1,367	3,055
UBS	Switzerland	852	1,701	2,553
PNC Financial Services	United	1,198	926	2,124
Royal Bank of Canada	Canada	637	1,273	1,910
Toronto-Dominion Bank	Canada	1,066	489	1,555
BNP Paribas	France	848	629	1,477
Farm Credit Services Commercial Finance Group	United States	1,320	27	1,347
Commerzbank	Germany	516	476	993
Santander	Spain	453	528	980
Fifth Third Bancorp	United States	485	458	943
CIBC	Canada	311	528	839
Intesa Sanpaolo	Italy	322	490	812
NatWest	United Kingdom	255	458	713
National Rural Utilities Cooperative Finance Corporation	United States	687		687
Northern Trust	United States	650		650
Banco Bilbao Vizcaya Argentaria (BBVA)	Spain	140	456	596
BMO Financial Group	Canada	253	326	579
Deutsche Bank	Germany	151	359	510
Jones Financial Companies	United States		492	492
Regions Financial	United States	227	252	479
Loop Capital	United States		444	444
Synovus Financial	United States	349	73	421

Bank	Country	Loans	Underwriting	Total
Shank Williams Cisneros & Co	United States		363	363
KeyCorp	United States	127	179	305
CastleOak Securities	United States		245	245
Bank of New York Mellon	United States	192	41	233
SAR Holdings	United States		218	218
SMBC Group	Japan	62	140	202
BayernLB	Germany	193		193
Crédit Agricole	France	52	118	170
Williams Capital Group	United States		158	158
Blaylock Beal Van	United States		142	142
CL King & Associates	United States		139	139
Bank One	United States	133		133
ABN Amro	Netherlands	113	18	131
Huntington Bancshares	United States		121	121
Cabrera Capital	United States		116	116
R. Seelaus & Co	United States		115	115
ING Group	Netherlands	113		113
Other financiers		152	1,115	1,267
Total		45,300	51,382	96,681

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