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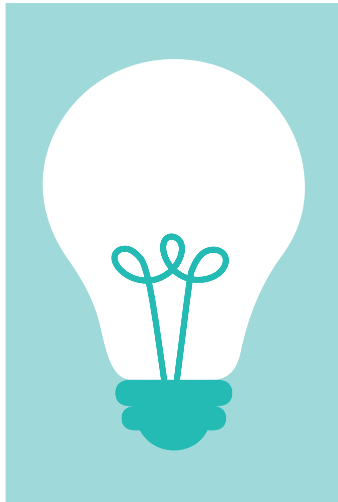
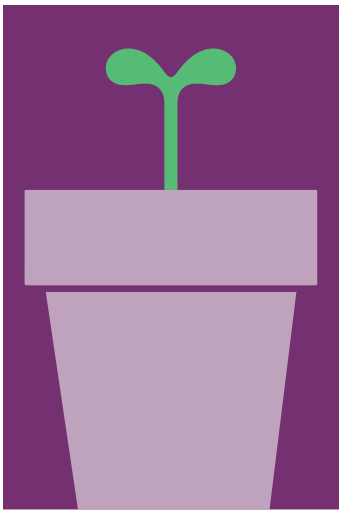
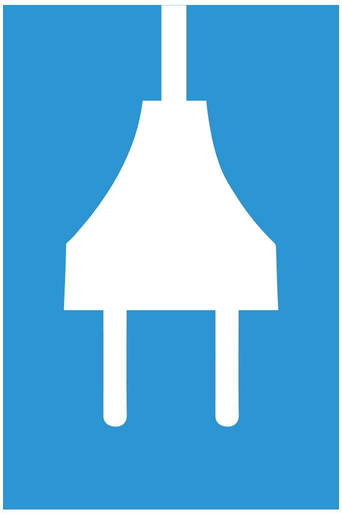
Nuclear Energy and the North

Economics
Technology
Energy systems design
Law
Psychology
Ethics







Economics of Nuclear Energy

Machiel Mulder

State of the Art

To significantly reduce carbon emissions, energy systems must undergo dramatic changes. Consequently, governments are promoting renewable energy sources such as solar PV, wind turbines, hydropower, and biomass. However, even with these policies, the growth in renewable energy is unlikely to be sufficient to meet climate targets. This is partly due to the anticipated increase in electricity demand driven by electrification and hydrogen production. As a result, attention is also turning to another non-carbon energy source: nuclear power.

Challenges and Opportunities

Nuclear power is highly debated due to perceived safety, security, and environmental risks. Additionally, there is uncertainty about how well nuclear power fits within electricity markets characterised by high shares of intermittent generation. These markets require more flexible sources to maintain balance, while nuclear power is generally considered a base-load provider with high fixed costs. Therefore, it may not be economically efficient to rely on such power plants in future electricity markets dominated by renewable energy.

Our Perspective

By exploring the economic value of investing in nuclear power plants under various future electricity market scenarios, we aim to contribute to the societal debate on the potential role of nuclear energy in low-carbon electricity systems. We also seek to enhance understanding of the economic mechanisms behind power plant investments.

The economic value of a nuclear power plant depends on four factors:

- Plant characteristics: This includes construction costs, construction duration, lifetime, operational and maintenance costs, fuel costs, ramping constraints, waste handling and storage costs, and decommissioning costs.
- Degree of utilisation (capacity factor).
- Capture price: The average electricity price the plant receives.
- Contribution to reducing carbon emissions.

While the first factor is exogenous, the others are closely related to the characteristics and functioning of the electricity market. Our analysis excludes the costs of any required network extensions, recognising that these costs may vary significantly across different generation technologies.

The Technology of Nuclear Energy

Nasser Kalantar-Nayestanaki (l) and Myroslav Kavatsyuk

State of the Art

The energy transition dominates ongoing discussions about climate change and how to achieve the goal of zero carbon emissions by 2050. From a technological perspective, all low-carbon sources must be part of the mix to achieve these goals. Various energy-mix models support this, placing the share of nuclear energy at around 10% of total electricity production in the coming decades.

Nuclear power plants are designed and built based on experience gained over the past 70 years. Generation III+ designs have proven to be very safe to operate. Small Modular Reactors (SMRs) are also being designed and built by various companies worldwide. Further, for use in two decades and beyond, research and development on Generation IV reactors is being seriously pursued in various countries. Initial results are promising, showing that these reactors are inherently safe. Alongside reactor research, studies are being conducted to address how to manage nuclear waste, whether produced by Generation III(+) or Generation IV reactors. New technologies seem to partially solve the problem of nuclear waste to a large extent.

Many countries have started or are starting new campaigns for constructing new reactors (Generation III+ and Generation IV). The Dutch government recently decided to construct two new nuclear power plants based on Generation III technology.

Challenges and Opportunities

The main challenges, which also form opportunities for research around nuclear technology, include:

- How safe are the new reactors of Generation III+ and Generation IV?
- What are the main advantages and disadvantages of Generation IV reactors?
- How can SMRs be integrated into the future energy mix?
- How can the development and construction costs of nuclear power plants be reduced?
- How should radioactive waste be managed in the Netherlands?

Our Perspective

We plan to address several questions, leveraging the expertise of our local group. To ensure that new reactors, which must operate for decades (over 60 years), are effective, it is crucial to thoroughly understand the properties of the materials used in the reactor. The reactor designs rely on existing nuclear data models. However, the precision of these data is low for some reaction channels, and for some elements, cross sections for relevant reactions are missing from the database. This often results in overdesigned reactors to meet safety regulations, leading to unnecessarily high costs. For the design of new reactor types, a lack of precise data causes unnecessary iterations in the prototyping phase, resulting in delays in deploying new technologies. To tackle this problem and aim to reduce development and construction costs, a list of candidate materials has been compiled. Samples will be studied using neutron beams at various European facilities. Reaction cross sections for all possible channels will be measured and added to the existing databases.

Although the waste from Generation IV reactors poses much less of a problem, Generation III+ reactors still use the standard fuel cycle, which includes long-lived elements that must be managed in the long term. Various countries are discussing possibilities for long-term repositories at different levels. Studies will be conducted to characterise and offer solutions for the disposal of nuclear waste in the Netherlands.

Nuclear Energy and Energy Systems Design

PV Aravind

State of the Art

Conventional nuclear power plants produce electric power by utilising the heat generated, primarily using steam cycles. These power plants are operational in several countries.

Opportunities and Challenges

Next-generation nuclear reactors are expected to provide heat at high temperatures (around 900°C), creating opportunities for gas turbine applications and process heat utilisation. Fuel production, particularly hydrogen, is also emerging as a promising opportunity. Electrolysers could be used for producing hydrogen or hydrogen-carrying fuels such as ammonia or methanol. Additionally, the development of small to medium reactors offers a wide range of possible temperatures, leading to several innovative applications. However, the applications and process concepts for these reactors are not yet fully developed.

Our Perspective

We propose a focused effort to develop new applications and process concepts. We aim to match technology and applications, particularly in the Netherlands, with a special focus on opportunities in the north. These concepts will be developed through innovative process designs, exergy analysis, and energy cost calculations. Exergy analysis will help create minimal entropy-producing system concepts and operational strategies for emerging technologies. Once optimal process designs are determined, mass and energy balance results and indicative component sizing will inform indicative energy cost calculations.

Initially, the focus will be on the production of nuclear hydrogen and other future fuels. We will develop conceptual process designs based on different technologies, including alkaline electrolysers, PEM electrolysers, solid oxide electrolysers (in various modes), reversible fuel cells/electrolysers, and both conventional and emerging thermochemical cycles. Different system sizes will be considered, and preliminary payback periods will be calculated based on simpler assumptions.

Thermodynamic models for innovative power cycles of varying system sizes will be developed using similar sets of assumptions for common components. Cost calculations, including payback periods, will be carried out. Depending on available resources, we will also evaluate nuclear propulsion opportunities within the Dutch context.

Another focus area will be process heat applications. We will consider large and medium-scale process heat consumers in the Netherlands and develop process models based on different reactor types. Cost calculations will then determine the viability of these concepts under Dutch conditions.

Based on the steps outlined above, we will develop a list of economically appealing nuclear energy technology options, accompanied by indicative cost calculations specific to the Dutch context.

Nuclear Energy and the Law

Lorenzo Squintani

State of the Art

To address its energy needs, the Netherlands has decided to increase nuclear energy production. Nuclear energy is regulated by a complex framework of international, European, and national acts, covering the entire value chain, from raw material extraction to the management of waste products. In the Netherlands, the Nuclear Energy Act forms the foundation of the legal framework for nuclear energy. This act focuses on safety issues throughout the nuclear energy value chain. Among other things, it provides the basis for the licensing procedures for nuclear energy installations and the management of radioactive waste.

This role did not change with the introduction of the Environmental and Planning Act (Omgevingswet) in January 2024. The Environmental and Planning Act primarily brings changes to the regulation of environmental impact assessments and zoning plans, which are also relevant for the construction of new nuclear power plants, but it does not replace the legal regime established by the Nuclear Energy Act. The Nuclear Energy Act is further implemented through various governmental and ministerial decrees and regulations focusing on different elements of the nuclear energy value chain.

Challenges and Opportunities

Examining the development of the regulatory framework for nuclear energy over the years, we observe a continuous tension between ensuring safety and enabling the production and use of nuclear energy, including the management of radioactive waste. A conservative legal approach could hinder and slow down technological developments. This tension becomes increasingly apparent with new technological breakthroughs, such as the deployment of Generation IV power plants or when governments consider extending the lifespan of existing, sometimes decades-old, power plants. From a legal perspective, challenges and opportunities lie in developing the optimal balance between safety and enabling nuclear energy production.

Additionally, challenges and opportunities concern maintaining this balance as our understanding of nuclear technologies and the socio-economic dimensions associated with nuclear energy evolves over time. In other words, we need to develop an adaptive legal framework for the optimal regulation of nuclear energy.

Our Perspective

By developing a model to define the adaptability of legal regimes applied to energy sectors, we can evaluate and compare the level of optimisation in balancing safety and technology development, as well as the adaptability of the chosen balance. This will provide valuable insights into competence allocation, safety standards, and the optimisation of legal tools, making the legal framework for the nuclear energy sector more optimal and adaptive. Accordingly, a roadmap for the development of the legal framework can be created.

The Psychology of Nuclear Energy

Goda Perlaviciute

State of the Art

The energy transition is an enormous societal challenge. Public acceptability is crucial for its successful implementation, as energy projects are more likely to be executed with public support, whereas public opposition can lead to delays or cancellations. The role of social sciences and humanities, particularly environmental psychology, has been increasingly recognised for understanding public perceptions and acceptability of energy projects and policies, and for developing energy initiatives that can gain societal support.

Challenges and Opportunities

How much public support exists for nuclear energy in the Netherlands, and what explains the differences in individual opinions about it? A study on public acceptability of the energy transition in the Province of Groningen found nuclear energy to be the least acceptable of the possible future non-fossil energy sources. International studies similarly indicate that, in general, public acceptability for nuclear energy is higher than for fossil fuels but lower than for renewable energy sources. However, public acceptability is a dynamic concept, necessitating a longitudinal monitor at least at the national level to track changes in public acceptability of nuclear energy over time.

Furthermore, opinions about nuclear energy can vary significantly, with sharp differences between supporters and opponents. Research is needed to better understand the drivers of such individual and group differences, including people's values, perceptions of climate change, perceived costs, risks, and benefits of nuclear energy, and proximity to nuclear energy plants, among other factors. Evidence suggests that people living relatively close to nuclear power plants evaluate nuclear energy more positively than those living farther away.

However, the reasons for such differences are not well understood. Factors could include re-evaluating costs, risks, and benefits (e.g., local employment), getting used to the presence of the plant, or cognitive dissonance (e.g., neglecting possible risks because moving away is not an option). These insights are limited because there has not been systematic research into differences in opinions between local and general public, nor has any study investigated local acceptance of nuclear power plants from before to after their construction.

Our Perspective

We plan to establish a public opinion monitor to track attitudes towards nuclear energy over time. This monitor will include a representative sample of the Dutch population, encompassing different socio-demographic groups. Importantly, it will also include both the general public and local communities living near existing nuclear power plants and locations where new plants are planned (e.g., Borssele). The current Dutch context, with plans to build new nuclear power stations, offers a unique opportunity to better understand local perceptions of nuclear energy. The monitor will study and compare public opinions between the general and local populations, and locally, it will trace opinions from before to during and after the construction of new nuclear power plants, if these plans proceed.

Ethics of Nuclear Energy Use

Simon Friederich

State of the Art

Nuclear energy use has long been one of the most intensely debated issues in the ethics of technology. There used to be a near-consensus that nuclear energy was problematic from an ethical perspective. The risks of nuclear accidents, the responsibility for future generations concerning nuclear waste disposal, and the challenges arising from nuclear proliferation were particularly prominent in arguments for this consensus. However, more recently, this consensus has come under pressure due to several factors: the recognition of climate change as a global catastrophic risk, the environmental advantages of nuclear energy over other energy generation technologies, and the hope that nuclear energy might reduce the overall costs of energy system decarbonisation. Some even argue that increased nuclear energy use is an ethical obligation for political actors in developed countries committed to fast and deep decarbonisation.

Challenges and Opportunities

With the decision to reinvest in nuclear energy in the Netherlands, numerous ethical issues must be thoroughly assessed. These include:

- To what extent does nuclear energy use – and the long-term commitment to it – need to be widely supported by the population, especially in communities hosting reactors, to be ethically viable?
- How should spent fuel reprocessing be judged from an ethical standpoint, given its potential to reduce the challenge of nuclear waste while possibly increasing the complexity of the non-proliferation regime?
- How should the trade-off between protecting against potential or hypothetical radiation harms and enabling nuclear energy to contribute to climate change mitigation be addressed ethically?
- Is it ethically permissible – or even obligatory – to reduce the regulatory burden on nuclear energy use if this facilitates its contribution to climate change mitigation?

Our Perspective

We adopt a pluralistic approach and address these questions from various normative angles. We consider consequentialist/utilitarian perspectives, such as which energy system development strategies have the best prospects for maximising overall benefits and minimising economic, environmental, and climate change-related harms. We also consider deontological perspectives that rely on more categorical "do no harm" imperatives. Considering these different normative perspectives is important because there can be legitimate differences in opinion on whether rapid reductions in national emissions are the more urgent ethical imperative or whether contributing to making zero-emissions technologies globally more accessible and affordable is more critical.