ENERGY TRANSITION

Conditions and scenarios to meet the future electricity demand in the Netherlands with nuclear energy

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Abstract

In the 21st century, the world faces an enormous challenge of drastically reducing greenhouse gas emissions. Because of this, nuclear power has found its way back on to policy roundtables and into the media. In the Netherlands, non-greenhouse gas emitting electricity sources are necessary, since natural gas is still dominating the electricity generation mix. Because of the need for the transition from fossil fuels towards non-greenhouse gas emitting electricity sources, and difficulties with solar energy and wind energy, nuclear energy might be a useful source in the Netherlands.

The aim of this explorative study is to investigate whether or not nuclear energy is a useful energy source on the long-term in the Netherlands. To add, the aim is to investigate which possible scenarios are available to meet the future electricity demand in the Netherlands. Four conditions are identified which must be met before the implementation of new nuclear power plants is possible. The four conditions are: (1) nuclear energy should have advantages compared to solar energy and wind energy, (2) there should be a potential location to implement a nuclear power plant, (3) there should be public support base, and (4) the role of the Dutch government should be clear.

With both secondary and primary data, these four conditions are investigated and four scenarios are developed with the inspiration of the Dynamic Adaptive Policy Pathways Approach. These scenarios serve as a tool to get an insight how the Netherlands can meet the future electricity demand with or without nuclear energy.

Keywords: *Climate change, Energy transition, Electricity demand, Nuclear energy, Conditions, Future scenarios*

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1. Introduction

1.1 Background & Problem definition

The increased urgency of dealing with mitigation of the looming climate change has sparked renewed interest in the nuclear energy option. After a few decades of rapid growth, investment in nuclear energy has stalled and nuclear energy comprise now only 5% of the global energy production (MIT Energy Initiative, 2018). With climate change being increasingly viewed as one of the most pressing global problems, nuclear power has found its way back on to policy roundtables and into the media (Lenzen, 2008). The need for renewable electricity sources in The Netherlands is important, since currently only 26% of the produced electricity, is sustainable electricity. It has been agreed in the Climate Agreement that this should be 70% by 2030 (Vos, 2021). Furthermore, the Climate Agreement was formed to reduce greenhouse gas emissions with 49% in 2030 compared to 1990 (Rijksoverheid, 2019). Nuclear power might be a good option in the energy transition, because with the generation of nuclear energy, there is no emission of greenhouse gases (Milieucentraal, 2021).

At this moment, there is only one nuclear power plant which generates electricity located in The Netherlands, in Borssele. This nuclear power plant provides about 4% of the electricity used in The Netherlands (Rijksoverheid, 2021b). The Dutch government has plans to keep the current nuclear power plant open for another ten or twenty years (Nuclear Nederland, 2021). However, not all Dutch political parties do support the idea to build two nuclear power plants (Vos, 2021). Even on European level, not all countries agree on each other whether or not nuclear energy is a sustainable energy source. For example, France is highly in favour of nuclear energy, and they also generate a high rate of the total electricity with the use of nuclear energy but Germany is not in favour of nuclear energy at all. Germany decided to quit with nuclear energy production in the country after the nuclear disaster in Fukushima. However, because of the sanctions imposed on Russia due to the current invasion in Ukraine, the delivery of fossil fuels to Germany is in danger. Therefore, Germany has to reconsider the closing of the nuclear power plants (De Ingenieur, 2022). Keeping the German nuclear reactors in operation for a longer time than the end of 2022 would reduce dependence or Russian natural gas. This clearly shows what unexpected circumstances in the world can cause with regard to the energy transition. When there were not political tensions, Germany would not have to reconsider the closing of their nuclear power plants.

In the beginning of this year, the EU decided that nuclear energy can be seen as a ‘green’ energy source, however the German minister of Environment calls it a “mistake”. This minister stated: “A technology that can cause devastating environmental catastrophes and leave behind a large amount of highly radioactive waste cannot be labelled as ‘green’ energy” (De Telegraaf, 2022). This controversy on European level makes it difficult to set out various scenarios for the future, because to meet the goals of the climate agreement, collaboration of countries and the same mindset is of crucial importance. A shared vision is important since this will increase collaboration, because otherwise it might happen that one country decides to close a nuclear power plant and the other decides to build one. This is far from efficient, and therefore the shared vision on European level is needed. Because of this, some agreements within the energy transition are needed. One reasons against nuclear power plants is that nuclear energy produces radioactive waste that remains harmful to the environment and human society for thousands of years (Vos, 2021).

Because of this, various political parties think that it is better to invest in solar electricity production or wind electricity production. But the disadvantage of this is that wind energy and solar energy are not adjustable. For example, when there is no wind and when it is cloudy, it is not possible to

generate electricity with solar panels or wind farms (NOS, 2020). Besides this, solar and wind energy take up a relatively large area. This can be problematic in the Netherlands, since the Netherlands is already densely populated and thus there is not much space left due to various interests and the involvement of many stakeholders with different views and preferences. With this in mind, nuclear energy might be a useful alternative since it is in principle adjustable and always available (NOS, 2020).

1.2 Scientific relevance

The world faces an enormous challenge of drastically reducing greenhouse gas emissions while simultaneously expanding energy access and economic opportunity, as well as the shift from natural gas to electricity, which might lead to an increase in electricity demand (MIT Energy Initiative, 2018). Therefore, countries need to invest and develop sustainable electricity production methods to meet the electricity demand, and to ensure that the emission of greenhouse gases will reduce.

Currently, natural gas is still dominating the electricity generation mix in the Netherlands. In 2019, electricity in the Netherlands was generated with the use of natural gas (60%), other fossil fuel sources (15%), renewable energy such as solar energy and wind energy (21%) and others including nuclear energy (4%) (CBS, 2021a). However, natural gas as a source of energy will come to an end. In the coming years, gas extraction will be reduced to zero (Rijksoverheid, 2021a). This means that other sustainable sources need to be developed to meet the electricity demand in the future. To add to this, electrification from other sectors will result in an even higher electricity demand. Furthermore, using gas for heating and cooking will come to an end and this will be replaced by electricity (Rijksoverheid, 2019).

In 2030, the Netherlands will need 49.000 GWh of electricity per year from offshore wind power and 35.000 GWh of electricity per year coming from solar energy and wind energy from land (Rijksoverheid, 2019). Current production levels for solar and wind from both on- and offshore cannot supply this. Thus, the Climate Agreement suggests that investments in solar and off- and onshore wind are necessary. However, with these electricity sources, reliability becomes an issue as these forms of power are dependable on weather conditions. Due to this reliability problem caused by the intermittency, there is a chance that electricity generated by these sources is high when demand is low and the other way around. Therefore, a reliable electricity source is needed in the Netherlands, and a possible solution might be nuclear energy.

Nuclear energy has contributed to electricity generation worldwide for over 65 years and it still is a well-known electricity source in the world and in Europe. The EU has 103 operating reactors with a total capacity of over 100 GW generating about one quarter of the electricity (WNA, 2022a). The nuclear power plant in Borssele has a capacity of 482 MW, delivering a total of 3.7% of the Dutch electricity supply in 2019 (EPZ, 2020). Moreover, nuclear energy is a land-use efficient way of producing electricity. The average capacity of a nuclear power plant is around 900 MW (WNA, 2022b). According to the U.S. Energy Information Administration (2021), this equals to about 3 million solar PV panels or 431 wind turbines. So, to get the same amount of energy from solar PV panels or wind turbines compared to nuclear energy, the amount of space which is needed is much more than with the implementation of one single nuclear power plant. However, a disadvantage of nuclear power plants is that it takes about 10 to 15 years to get it implemented (ANVS, 2021). An advantage is that nuclear energy is reliable, since it is not dependent on weather conditions. That means that nuclear energy has proven to be a matured and reliable technology in the world today.

Because of the need for a reliable electricity source, and the difficulties with solar and wind energy, nuclear energy might be a useful in the Netherlands. However, still some questions remain. One of

these questions is whether or not nuclear energy can be seen as a sustainable and 'green' solution to the pressing global climate change problems. As stated before, this is currently an important topic within the EU. A requirement of this label is that it needs to be clear what will be done with the nuclear waste, since that will exist for decades and even centuries (NOS, 2022).

When this debate is made clearer, there are still important questions left. One of these questions is whether or not nuclear energy might be a good solution for the Dutch energy network and the future demand. It might be possible that a scenario will be developed in which the Dutch government will invest in only solar energy or wind energy, with various disadvantages such as intermittency as stated before. It might also be possible that a scenario will be developed in which the Dutch government decides to invest in nuclear energy. But then the question is: What kind of time horizon is needed with the implementation of a new nuclear power plant? Will it operate until for example 2080? Or will there be other developments within the energy transition, so that nuclear energy is not needed anymore? But also, a question about the location is important. Because where do we have to implement a nuclear power plant? It will take some time to establish a zoning plan of potential areas, and it is obligated for municipalities to have zoning plans for their entire territory (Rijkswaterstaat, 2022). The establishment of a zoning plan for a nuclear power plant might take a lot of time due to difficulties and strict regulations (Bestemmingsplan, 2010). This research will provide various scenarios on how to meet the future electricity demand with or without nuclear energy, since it is yet unclear how the world looks like at the end of this century. The scenarios will be developed with inspiration of the Dynamic Adaptive Policy Pathways approach of Haasnoot et al. (2013), the scenario approach, and transition management.

1.3 Societal relevance

The need for sustainable energy is growing. As stated before, only 26% of the electricity in the Netherlands is generated with sustainable sources. That means that there is room for improvement. On the one hand, nuclear energy can be seen as a suitable option, because there is no emission of greenhouse gases. On the other hand, perceptions of people are that nuclear energy is not sustainable, due to the radioactive waste which should be dealt with for centuries. Furthermore, society is often not in favour of nuclear power plants because of the possible dangers. Although the chance of failures is low, the consequences when failures happen are enormous. Therefore, people often do not want to have a nuclear power plant in their surroundings. But if nuclear energy can contribute to sustainable energy production, it might be a suitable option and therefore it is worth looking into it. Especially because of the possible growing electricity demand. The use of natural gas as an energy source will come to an end, as well as the use of other fossil fuels, and therefore other innovations in the energy production are needed in light of the energy transition. The question is whether or not this energy demand can be met with investments in solar energy and wind energy, or that investments in nuclear power plants is the best suitable option.

1.4 Research objective & Research questions

The aim of this explorative study is to investigate whether or not nuclear energy is a useful energy source on the long-term in the Netherlands. To get an insight in the usefulness of nuclear energy in the Netherlands, various conditions must be met which will be explained later on in this research. The long-term in this sense is the energy transition from this moment on, towards the end of the 21th century. If nuclear energy is valuable within the energy transition in the Netherlands, it will take about 10 to 15 years to build a new nuclear power plant and such a nuclear power plant can operate for about 60 years. If the years of implementation and the years of use of a new nuclear power plant are added up, then it will be around the end of the 21th century and therefore this long-term timeframe is used. To add, the aim is to investigate which possible scenarios are available to meet

the future electricity demand in the Netherlands with a combination of non-greenhouse gas emitting energy sources such as wind energy, solar energy, and nuclear energy when it is possible to meet all of the identified conditions which are needed to make nuclear energy useful in the Netherlands.

Main Research question:

Under which conditions can nuclear energy on the long-term play a feasible role within the energy transition in the Netherlands to meet the future electricity demand in combination with reducing greenhouse gas emissions?

Sub-questions:

- What are the advantages and disadvantages of nuclear energy compared to solar energy and wind energy?
- What are potential locations in the Netherlands where a nuclear power plant can be implemented?
- What is the societal perception of the Dutch society towards nuclear energy?
- What is the role of the Dutch government with regard to nuclear energy and possible scenarios to meet the future electricity demand?
- What can the Netherlands learn from the use of nuclear energy in France?
- What are possible scenarios to meet the future electricity demand without greenhouse gas emissions?

1.5 Structure

This thesis starts with explaining several important topics which serves as the basis for this research, to build a particular understanding about climate change, sustainability, energy transition, and the predicted electricity demand. After that, it will be explained what nuclear energy is and why this can be seen as a useful energy source within the current energy transition although it is not renewable. When this is made clear, various conditions will be outlined which will be explained and elaborated on in the continuation of this research. These conditions must be met, otherwise it will be difficult to implement new nuclear power plants in the Netherlands. After that, the concepts used in this research to deal with uncertainty will be explained. Then, the advantages and disadvantages of wind energy, solar energy, and nuclear energy will be explained and a comparison between nuclear energy and solar energy and wind energy sources in terms of costs, reliability, space needed, and amount of energy production will be made. Then, the potential location of a new nuclear power plant in the Netherlands will be discovered with the use of policy documents and media content. When this is done, the societal perception towards nuclear energy will be investigated. This is important, since there needs to be some support base for the implementation of a new nuclear power plant. Furthermore, the role of the Dutch government will be analysed with an historical overview about nuclear energy use in the Netherlands and the Dutch nuclear energy policy. This is necessary because this will give an understanding why the Netherlands have at this moment just one operational nuclear power plant and it will give an insight in the role of the Dutch government regarding the energy transition. To strengthen the research about the usefulness of nuclear energy, this research will look into the current nuclear energy policies of France. This is because France is currently investing a lot in nuclear power plants and this generated electricity is more than 70% of the total generated electricity in that country (Nucleair Forum, 2021). After investigating the possibilities of nuclear energy in The Netherlands, possible future scenarios to meet the future electricity demand will be developed. These scenarios will be developed with inspiration of the Dynamic Adaptive Policy Pathways approach of Haasnoot et al. (2013), the scenario approach, and transition management.

2. Theoretical Framework

2.1 The use of literature

This chapter will firstly identify and elaborate on topics such as climate change, energy transition, sustainability, electricity demand, and nuclear energy to get a particular understanding about the relevance of energy transition and the potential of nuclear energy. This is useful, since it can be seen as the foundation of the topic of nuclear energy within this thesis. Therefore, literature will be used to get an understanding why nuclear energy might be of importance for the Netherlands. For example, when there was no climate change, sustainability would not have been such an important topic today. Without climate change due to the use of fossil fuels, renewable energy sources would not be necessary and energy transition should not be needed. However, reality is different. Climate change is a major concern all around the globe, and therefore sustainability, renewable energy sources, and energy transition is really needed, wanted, and even possible. However, developments and knowledge are needed to make the energy transition from fossil fuels towards sustainable sources possible. Next to this, it is necessary to outline various conditions which should be met before nuclear energy can play an important role within the energy transition. Without meeting these conditions, it is probably impossible to implement new nuclear power plants in the Netherlands. These conditions will be explained at the end of this chapter. With all this knowledge, the potential use of nuclear energy can be researched and it can be made clear whether or not nuclear energy is needed in the Netherlands with regard to the energy transition. Something which has to be taken into account is the uncertainty of the future and the unpredictability. Therefore, this chapter also contains sections about scenario planning, transition management, and the Dynamic Adaptive Policy Pathways Approach.

2.2 Literature review

2.2.1 Climate change

Climate change is one of the biggest challenges the world is faced with at this moment. Already for a few decades, climate change has become a widespread topic. This is a problem that resulted from the emission of greenhouse gases that affect our environment (Kaddo, 2016). Fossil fuels such as coal, oil, and gas became the primary energy sources facilitating rapid industrialization and further fossil-fuel consumption. The burning of fossil fuels over the past 150 years has increased the level of atmospheric carbon dioxide by 33% (Hardy, 2003). This is also visible in figure 1.

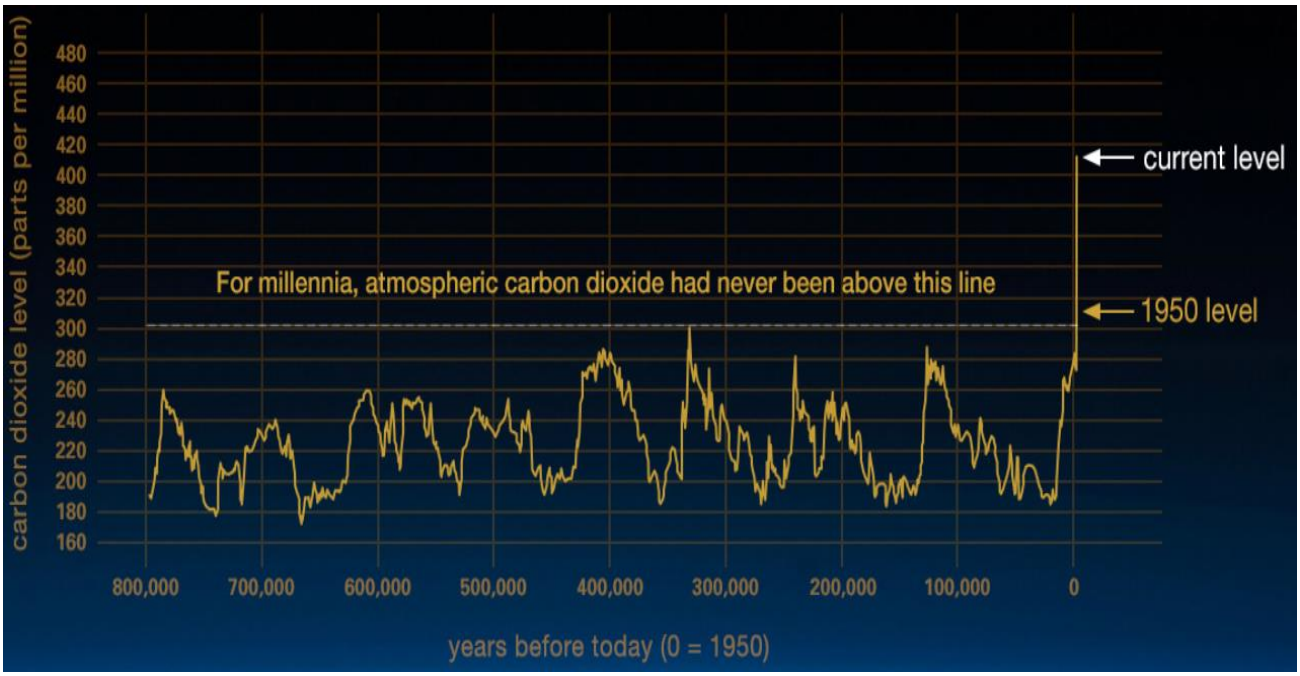

Figure 1: The increase of the level of carbon dioxide over the past 150 years (NASA, 2022c).

The consequence of this is that rapidly global warming is unavoidable when this would not be changed. For human society for example, the consequence is that our health and survival will be challenged, since human society depend on productive agriculture, supplies of water, forest products, and fish (Hardy, 2003). Consequences on Earth in general is that the Earth will become warmer, which will lead to more evaporation and precipitation overall, but some regions will become wetter and others dryer. Besides this, greenhouse effects will warm the ocean and partially melt glaciers and ice sheets, which result in increasing sea levels. Also, more climate extremes such as droughts, floods and extreme temperatures will occur (NASA, 2022a). According to NASA, the Earth average temperature has increased with about 1 degree Celsius during the 20th century. Perhaps this does not sound as a significant increase, however the effects on our environment have proven otherwise (figure 2). The impacts of this small change in the temperature are many, from longer drought seasons and heat waves to more aggressive (Kaddo, 2016).

As already mentioned, greenhouse gases are thought to be the main contributor to climate change. They are very efficient in trapping heat into the atmosphere. Therefore, it results in the greenhouse effect. The solar energy is absorbed by the earth's surface and then reflected back to the atmosphere as heat. Then as the heat goes out to space, greenhouse gases absorb a part of the heat. After that, they radiate the heat back to the earth's surface, to another greenhouse gas molecule, or to space (UCAR, 2022).

To overcome the issue of climate change, a shift from fossil fuel electricity generation towards renewable electricity sources is needed. However, at this moment, the world is too much dependent on fossil fuels for energy, transportation, and manufacturing. This creates a major obstacle to switch to renewable energy (Kaddo, 2016). Because of this, a shift to non-greenhouse gas emitting sources might already be valuable. In this sense, nuclear energy can have a positive impact in the energy transition because although nuclear energy is not renewable, it is a non-greenhouse gas emitting energy source.

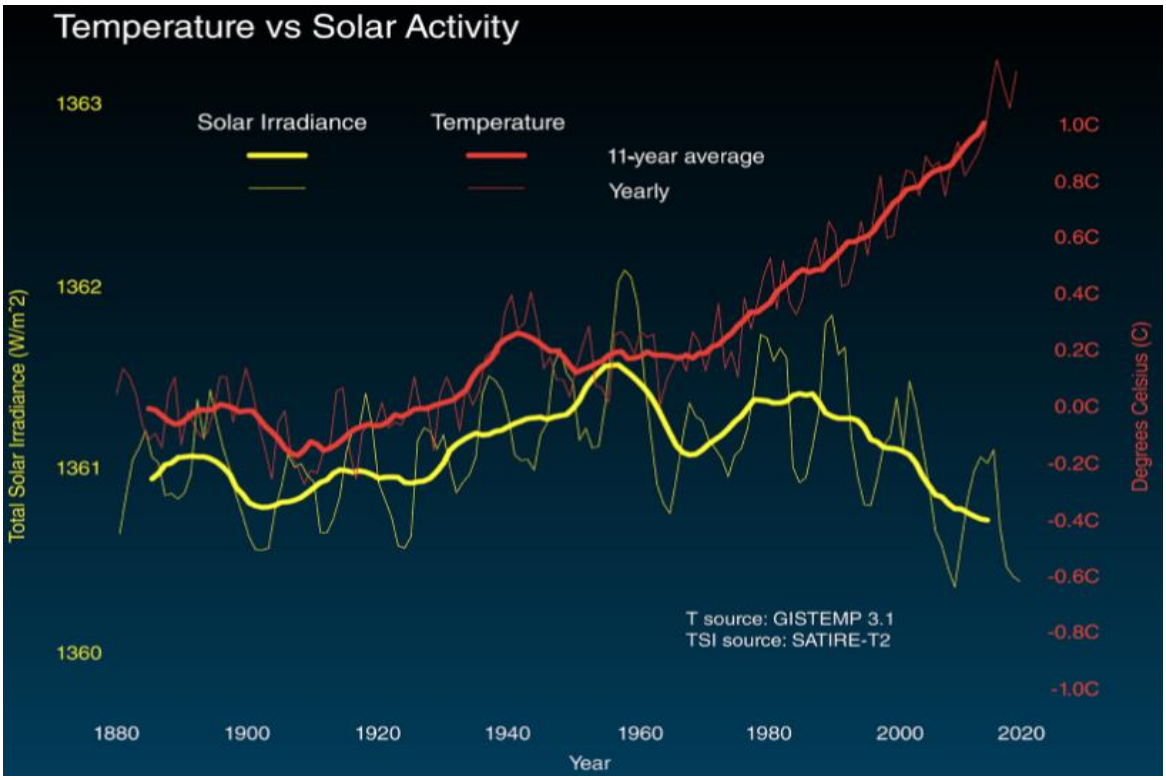

Figure 2: Rising temperature over the last century (NASA, 2022a).

2.2.2 Sustainability

Sustainability is one of the most widely used buzzwords of the past two decades. Besides this, it is a broad term, since it can be used for almost everything. There are sustainable cities, economies, resource management, businesses, and sustainable development (Scoones, 2007). One of the most widely used definitions is that "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*" (WCED, 1987, p. 43). More broadly spoken, sustainability maintenance of (1) a sustainable scale of the economy relative to its ecological life-support system; (2) a fair distribution of resources and opportunities between present and future generations, as well as between agents in the current generation, and (3) an efficient allocation of resources that adequately account for natural capital (Costanza, 1994). The future generations should also be able to meet their needs, and therefore sustainability is one of the most important topics to overcome the issue of climate change (NASA, 2022b).

As explained before, there is an urgent need to get rid of fossil fuels as primary energy sources to overcome climate change. Therefore, energy production without emitting greenhouse gases is necessary. The importance of energy in achieving sustainable development was recognized when the concept of sustainable energy development was put forward in the UN's World Energy Assessment report. With this report, the sustainable energy development had become an international policy objective reflecting various challenges such as depleting fossil fuels, increasing energy consumption, and climate change (Gunnarsdottir et al., 2020). Because of the importance, sustainable energy development was solidified as an integral part of sustainable development with the introduction of goal seven of the UN's Sustainable Development Goals: "Ensure access to affordable, reliable, sustainable and modern energy for all" (UN, 2015).

Global mitigation efforts can enhance sustainable development in part by reducing the risk of adverse impacts of climate change and also provide co-benefits, such as improved health outcomes (Lundgren & Kjellstrom, 2013). Energy transition is needed to prevent the Earth from global warming, but also to prevent severe consequences due to climate change for the future generations.

2.2.3 Energy transition

To combat climate change and to meet the sustainable development goals, energy transition is needed. To be able to talk about energy transition, it should be clear what a transition exactly is. Transition is a structural change in the way a societal system operates. A transition is a long-term process (25– 50 years) resulting from a co-evolution of cultural, institutional, economical, ecological and technological processes and developments on various scale levels. A transition can therefore be described as a process of the co-evolution of institutions, technologies, policies, individual behaviour and autonomous trends from one relatively stable system state to another (Van der Brugge et al., 2005). The energy sector can be envisaged as a particular type of sociotechnical regime comprising an assemblage of institutions which develop around a particular set of technologies and support the development and use of these technologies (Andrews-Speed, 2016).

At the same time as climate change is developing, so is the science and research developments which are focused on mitigating emissions of greenhouse gasses through a wider reliance on renewable energy sources. Thus, while the planning of a transition towards sustainable energy systems is an ongoing and pertinent step, so is the development of the technologies and approaches that are required for the transition (Østergaard et al., 2021). The most significant feature of renewable energy is its infinite supply, in the sense that renewable sources do not deplete one day. Renewable energy is dependable and copious and will potentially be cheap, once this technology and its present infrastructure are enhanced. The major sources of renewable energy include solar, wind, biomass, geothermal, hydropower and tidal energy (Shahzad, 2012). The most used renewable electricity sources in the Netherlands are solar energy and wind energy (CBS, 2018).

In 2001, the Fourth Dutch National Environmental Policy Plan adopted a transitions approach aiming at 'system innovation' in important societal domains like energy. It proclaimed that persistent environmental problems like climate change cannot be solved by intensifying current policies. Instead, the plan argues, "*Solving the major environmental problems requires system innovation; long drawn-out transformation processes comprising technological, economic, socio-cultural and institutional changes*." (VROM, 2001, p. 30). For the energy system, the policy plan aims at a 40–60% cut in carbon dioxide emissions by 2030 compared with 1990 levels (Kern & Smith, 2008). In the Netherlands, renewable energy requires geographical space and production is mostly decentralized. Some options like solar PV are relatively easy to integrate in an urban environment while other options like wind turbines are mostly realized some distance from urban areas. For this, support of local communities for large numbers of tall wind turbines or biomass cultivation and conversion does not come by itself but has to be organized by creating awareness and developing a public interest. A wider public need to be aware of the required transition and needs to be involved in eventual benefits. Although this is often a difficult process, this is also a chance for improving social coherence (Van Leeuwen et al., 2017). The Dutch transitions approach has created long-term visions and high ambitions by aiming for system innovation in the energy system as well as stakeholder involvement. This way of policy planning encourages long-term thinking in energy policy and the energy sector itself (Kern & Smith, 2008). The energy transition is quite fundamental and involves the following transition areas which are of importance within this research (Van Leeuwen et al., 2017):

1) Transition of energy source: move away from fossil fuels towards renewable sources.
2) Transition of energy consumption: other technology which use other forms of energy. For example, using electricity for heating instead of natural gas.
3) Social transition: increased citizen awareness and involvement.

These transition areas do have an impact on the current electricity use and the future electricity demand. The transition of energy source is straight-forward. Renewable sources are necessary to prevent further climate change, as explained before. The transition of energy consumption might lead to an increase in electricity demand in the future. That means that the Netherlands should be able to deal with this increase in demand, and therefore the generation of electricity with non-greenhouse gas emitting sources should increase. The social transition is of importance since nuclear energy often has societal resistance because of the disadvantages attached to it. When citizens are more involved in decision-making, the societal perception towards nuclear energy should be taken into account.

2.2.4 Electricity & energy demand

Energy is essential for economic development, agriculture, and industry (Cai et al., 2019). Energy plays a significant role in economic prosperity, social welfare, and industry development on global scale (Li et al., 2021). Due to population growth, increasing per capita electricity consumption, and development of industrial sectors, the energy demand increases (Yu & Ghadimi, 2019). Lack of energy in meeting the needs of economic activities leads to stagnation or reduction of economic growth as well as lowering living standards (Liu et al., 2017). The dependence of lifestyle on energy has made it impossible to imagine life without equipment and machinery (Antonopoulos et al., 2020). Also, due to the increase in temperature, the use of cooling devices in the community increases, which in turn requires energy. Along with the increase of population and temperature, with the development of the welfare industry, people in the society also increase. Therefore, the use of cooling tools will be more (Guo et al., 2021).

Forecasts of the future electricity demand in the Netherlands vary. At this moment, the current electricity consumption is approximately 111 billion kWh, but this might very well increase to more than 300 billion kWh in 2050. Even an increase to 500 billion kWh or more is possible (TNO, 2022). To add, according to the PBL (2011), the population will increase from about 16.5 million inhabitants in 2010 to approximately 17-21,5 million in 2050 (CBS, 2022). Besides this, the number of households will increase from 7 million to 9.2 million in 2050 (NIDI, 2020). Due to the assumed growth of the population and economy, activity levels in 2050 will be higher than today. However, due to predicted development of processes of efficiency improvement and the technological developments in the future, electricity use will become much more efficient. In that case, the Dutch electricity consumption in 2050 will be almost 15% higher than the current consumption (PBL, 2011). The predictions are visualized in figure 3.

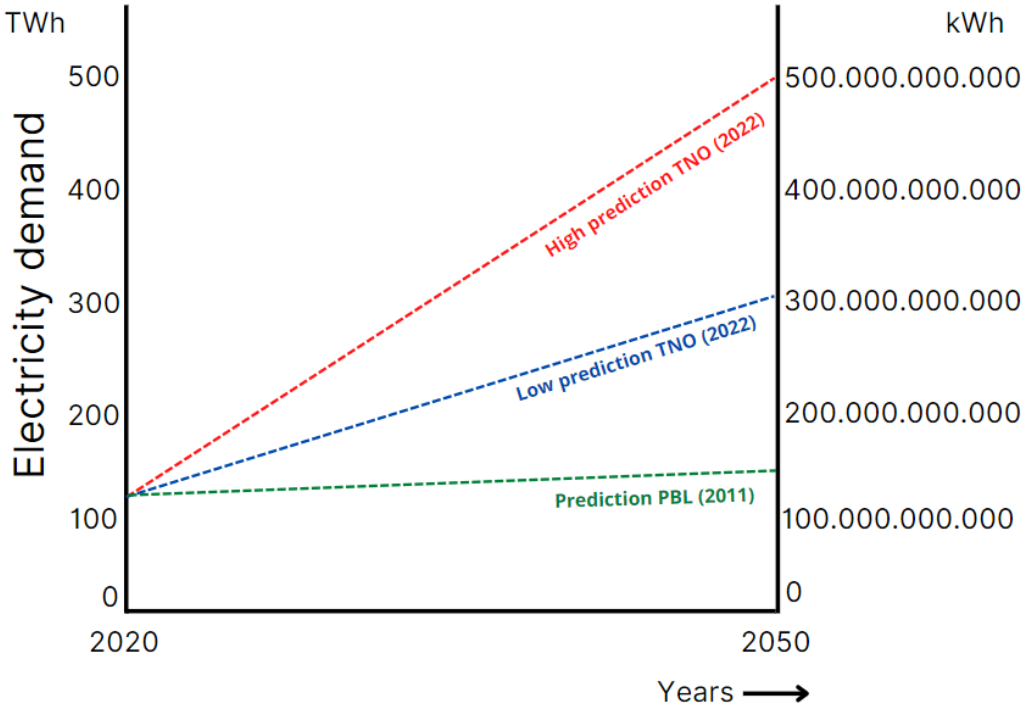

Figure 3: The predicted electricity demand in the Netherlands until 2050 (Author, 2022).

Although the exact prediction of the future energy demand in the Netherlands is uncertain, it can be stated that the electricity consumption will increase. Besides this, to lower the emission of greenhouse gases, transition should be made towards renewable energy sources. That means that in the future of the Dutch energy system, it must be taken into account that much more electricity should be generated with the use of renewable energy sources, because of the increase in electricity demand and the shift from fossil fuels towards renewable energy sources. The challenge for future electricity generation systems worldwide is to avoid harming the environment while delivering high levels of electricity security, reliability, and affordability.

2.2.5 Nuclear energy

This research will examine the potential role of nuclear energy in the Netherlands, since nuclear energy does not emit any greenhouse gases and thus does not contribute to climate change and global warming. However, it is of significant importance to understand that nuclear energy is not renewable energy, and it is also not sustainable energy. The reason for this is that nuclear energy cannot be produced over and over again with the same starting materials. Besides this, with the production of nuclear energy there are left overs which is nuclear waste. This cannot be recycled, so it has to be stored somewhere in the ground. This will exist for many years and therefore nuclear energy cannot be seen as sustainable. Although nuclear energy is not renewable nor sustainable, it might be very useful within the current energy transition since it is one of the few energy sources without the emission of greenhouse gases. So, perhaps nuclear energy is not the ideal energy type in the world, but it has obviously some advantages compared to other energy sources.

The EU has 103 operating reactors with a total capacity of over 100 GW generating about one quarter of the electricity (WNA, 2022a). Electricity generation from nuclear energy worldwide is projected to increase from 2.3 trillion kWh in 2012 to 2.7 trillion kWh in 2020 and 3.7 trillion kWh in 2040. However, concerns about energy security and CO2 emissions are influencing the development of new nuclear generating capacity (MIT Energy Initiative, 2018). These concerns especially rose after several cancellations of nuclear projects which lead to a general stagnation of nuclear energy

development. This trend was initiated by the electricity market deregulation, slower growth of electricity demand, negative public perception (after accidents at Three Mile Islands in 1979 and Chernobyl in 1986), and economic reforms in Russia and Eastern Europe (Omoto, 2005). However, research has concluded that to reach the profound decarbonization necessary to maintain the average increase in worldwide temperatures under 1.5 degree Celsius, mitigating climatic change would be much more difficult without a growing role for nuclear energy (Saidi & Omri, 2020). Nuclear power plants emit a negligible amount of CO2, and nuclear power is one of the technologies with the lowest CO2 emissions when taking into account entire life cycle. Besides this, it can help solve other energy supply problems and has environmental benefits, which are not climate related. The significant increase in the price of fossil fuels observed in recent years, the fear that these prices will remain persistently high in the future and concerns about the reliability of supply in politically unstable regions are fundamental elements of current energy strategies (Saidi & Omri, 2020).

The main advantage of nuclear energy is the capacity to produce large amount of energy, on an uninterrupted basis, from a small number of primary resources. Moreover, this option relies on abundant resources, and consequently represents a stable energy source on the long term, without large price fluctuations as for fossil fuels (Vaillancourt et al., 2008). Finally, considering the future economic growth and energy needs of developing countries, the development of nuclear energy is more and more considered as a valid option in a global strategy of sustainable development (Duffey, 2005). However, nuclear power also consists of a few shortcomings. In particular, the risk of accidents and the generation of radioactive waste are significant shortcomings, contributing to the negative social opinion of nuclear energy. This negative social opinion is often related to emotional responses. Nuclear power evokes a feeling of dread in people (Slovic, 1987), which has been linked to negative affect (Dohle et al., 2010). Nuclear power may threaten people's altruistic and biosphere values because the risks that people associate with it, can be seen as threatening the society at large, future generations, and nature and the environment (Truelove, 2012). On the other hand, nuclear power may be seen as supporting egoistic and hedonic values because it supplies relatively cheap and secure energy, which could evoke positive emotions (Perlaviciute & Steg, 2014).

Another important aspect to take into account is that the development of nuclear energy depends on the geography, the techno-economic potentials, the social-economic situation, the political context in each region. For example, because of the intermittency problem of wind energy in France, a large-scale development of the wind power industry would require additional fossil fuel power to fill the gap and this would lead to more greenhouse gas emissions (Jean-Baptiste & Ducroux, 2003). This can be solved, since nuclear power has the potential and the capacity to fill the gap instead of fossil fuels.

2.3 Literature overview, conditions, and key components

It is now clear that climate change is one of the biggest challenges the world is faced with at this moment. To overcome this issue, a shift from fossil fuel energy generation towards non-greenhouse gas emitting energy sources is needed. This means that it is necessary to get rid of the coal, oil, and gas, and that developments within the energy transition are needed in energy sources with very little or even no greenhouse gas emissions. Furthermore, uncertainties and the unpredictability of the future electricity demand in the Netherlands is something which needs to be taken into account. Although it is almost certain that the total electricity consumption will increase in the future, it is not clear how much this increase will be. There is a need to ensure that there is enough capacity in the future to meet the electricity demand. Both the need to reduce greenhouse gas emissions and the need for sufficient capacity in the future are important within the energy transition and therefore the role of nuclear energy might be valuable to look at. Although nuclear energy is not renewable and perhaps not even sustainable. The reason for this is that nuclear energy cannot be produced over

and over again with the same starting materials. Furthermore, an end product of after nuclear energy production is harmful and unhealthy nuclear waste. This has to be stored for a long period and therefore nuclear energy is not really sustainable. However, there is no emission of greenhouse gases into the environment when producing energy with nuclear materials, and therefore this might be a promising energy source to reduce greenhouse gas emissions and the interrelated problems. At this moment, especially solar energy and wind energy sources are of importance within the energy transition in the Netherlands. However, the main advantage of nuclear energy is the capacity to produce large amount of energy, on an uninterrupted basis, from a small number of primary resources.

But to get an insight whether or not nuclear energy fits within the Dutch energy landscape and whether or not nuclear energy might be a valuable source, various conditions must be met before it is even possible to focus on new nuclear power plants in the Netherlands. When these conditions cannot be met, it is almost impossible to make use of nuclear energy in the Netherlands within the energy transition. Within this research, four conditions will be analysed which are of importance to get an insight in the possible use of nuclear energy. To add, these conditions are also valuable for the development of the different scenarios to meet the future electricity demand in the Netherlands.

The first condition which must be met, is that it should be clear what the advantages and disadvantages of nuclear energy are and how the disadvantages can be solved or at least how to deal with the disadvantages. Besides this, it is important to get an insight in the advantages and disadvantages of wind energy, solar energy, and nuclear energy to see whether or not nuclear energy can be valuable within the Dutch energy landscape.

The second condition which must be met is that there are possible locations in the Netherlands where new nuclear power plants can be implemented, if nuclear energy has advantages compared to solar energy and wind energy. Not every location has the possibility to implement a nuclear power plant due to safety requirements and zoning plans. Preferably, there is a location available close the sea because nuclear power plants need cooling water when they are producing electricity.

The third condition which must be met is that there is a public support base from the Dutch society with regard to the implementation of new nuclear power plants. It might happen that condition one and condition two can be met, but when there is no public support base for the implementation of new nuclear power plants, it will be difficult to build a new nuclear power plant. Especially if conditions two can be met, it is necessary that local residents close to the potential location are also in favour of new nuclear power plants.

The fourth condition which must be met is that the Dutch government also supports production of electricity with nuclear energy and thus the implementation of new nuclear power plants. It must also be clear which laws and regulations are applicable and how new nuclear power plants can be financed. When the first three conditions are fulfilled, it must be made clear what the role of the Dutch government is regarding new nuclear power plants.

Within the analysis of condition one, there will be a multi-criteria analysis which includes seven components that are of importance when looking at advantages and disadvantages of the three energy sources. After analysing each of the component for every energy source, an overview will be provided with four key components which serves as a comparison between the three energy sources. The four key components are reliability, costs, energy production, and amount of space needed. Reliability has to do with the possible intermittency problems of solar energy and wind energy, as well as the continued energy production of nuclear energy. It will be researched whether or not there are external factors which will influence the energy production of the three energy sources and

with this, an insight can be given about the most reliable energy source and the less reliable energy source. Another component is the costs of implementation. It will be researched which energy source is the most expensive in the sense of implementation, building, and maintenance. With the costs, the electricity production is also an important component because it can be the case that one of the energy sources it much cheaper than the other one, but also much less electricity produces. Therefore, a comparison must be made with the electricity production in relation to the costs. The last component is the amount of space needed. This has to do with the area which needs to be used to make all energy sources operational and useful. For example, wind farms and solar fields take up quite an amount of space in the designated area to make the energy production useful and profitable. The space needed is an important component since the Netherlands is a densely populated country, so there is not much space left to implement solar fields, wind farms, or a nuclear power plant. All these components have to be taken into account when investigating the potential of nuclear energy in the Netherlands, compared to solar energy and wind energy. The three less important components which will not be included in the comparative overview are the avoidance of greenhouse gas emissions, nuisance and ecological impact. Those three are the least important because all three energy sources do not emit greenhouse gases at all, and there might be some nuisance and ecological impact for the energy sources but that would not be a decisive factor to terminate implementation possibilities.

2.4 Inspiration from France

After the analysis of the four conditions, information will be collected about nuclear energy in France. The reason for this is because France is one of the leading countries in the world with regard to nuclear energy. About 70% from the electricity in France is derived from nuclear energy, due to a long-standing policy based on energy security. Furthermore, in February 2022 it was announced that France plans to build six new reactors and they consider building a further eight nuclear power reactors (WNA, 2022c). At this moment, France has 58 nuclear power plants divided on 19 locations. Due to this intensive use of nuclear energy, the French electricity network is efficient and there is a low carbon dioxide emission (Nucleair Forum, 2021). Due to the nuclear energy successes in France, the country will be analysed to get an insight in their energy policies and the potential of these policies in the Netherlands. From the knowledge about nuclear energy in France, lessons can be learned to further develop nuclear energy use in the Netherlands. This analysis is part of the secondary data collection, since there is already much information available about nuclear energy in France on the internet and various scientific articles have been written about this topic. Although France and the Netherlands are not comparable with regard to size of the country, an analysis on France is useful since both France and the Netherlands are located in Europe and are part of the European Union. Besides this, the assumption is that the Netherlands can learn from the French approach regarding nuclear energy and thus it might be that the Netherlands can get inspiration from France.

2.5 Dealing with complexity & uncertainty in long-term planning

Energy transition and sustainable electricity production are challenging society. That is because these topics are often fuzzy and long-term planning is necessary with regard to the energy transition. Because of this, the research about the possibilities of nuclear energy in the Netherlands can be seen as a complex planning situation, since the implementation and use of nuclear energy and nuclear power plants requires the technical rationale side as well as the communicative side of planning (De Roo, 2020). Therefore, dealing with complexity and uncertainty is necessary. This will be done with the concepts '*Scenario Planning*', '*Transition Management*', and '*Dynamic Adaptive Policy Pathways Approach*'. These concepts will be explained in this section and it is visualized in figure 4.

The world is changing fast and with that, the world is becoming more and more complex. This complexity is a result of new knowledge, technologies, and increasing global links and the consequence of it is that the future is becoming more unpredictable and uncertain (Abbott, 2005). Crises such as climate change do also have an enormous impact on humans and the future of the world (Duit & Galaz, 2008). Moreover, not only the uncertainty about environmental issues and climate change is complex, but also the societal perspectives and preferences change over time (Offermans, 2010). For example, since the beginning of 2022, Russia has invaded with Ukraine. This unexpected event led to doubts about the import of Russian gas into the Netherlands. When the Dutch government decides to stop the import of Russian gas, other sources of energy are necessary which might speed up the energy transition in the Netherlands. However, this also means that perceptions about for example nuclear energy can change fast according to events happening in the world. Because of these uncertainties, it is hard for decision-makers to predict what will happen in the future and how the world will develop. Complex societal problems related to sustainability and energy transition are characterized by dissent on goals, values and means. Different people have different perspectives on what is being discussed as 'the problem', they have different values and favour different solutions (Kemp et al., 2007). To get an insight in how the world will develop and to get an insight in what might be necessary with regard to energy transition, various strategies and theories are developed and these will be explained:

Scenario Planning

Scenario planning is a method for imagining possible futures which can be applied to situations of decision making under uncertainty in different fields, including business administration, politics, but also in environmental management and energy planning (Schoemaker, 1995). The objective of Scenario Planning is "*to provide a structured 'conversation' to sensitize decision makers to external and uncontrollable uncertainties and to develop a shared understanding of such uncertainties*" (Stewart & Durbach, 2016, p. 486). Scenario planning is used to develop alternatives for the future to get an insight in what might be possible in the future and to get an insight in what the best possible scenario or future approach is. In energy scenarios, an alternative is usually a combination of technical and organizational options, for example a decentralized energy supply based on distributed renewable resources or a centralized energy supply based on large-scale renewable and conventional power plants (Witt et al., 2020). The power of scenarios is that they do not merely extrapolate the past and present, but present a range of possible futures. That way, scenarios can help to develop a set of measures to be prepared for each future. At the same time, they can indicate what to do to reach a preferred future (Restemeyer et al., 2017).

Transition Management

Transition management is developed for governments to deal with persistent problems that require systemic change. Persistent problems are complex, uncertain, difficult to manage, hard to grasp and operate at different scale levels (Rotmans, 2005). Within transition management, different trajectories are explored and flexibility is maintained. Key elements of the transition management cycle are anticipation, learning and adaptation. The starting point is the structuring of problems. This is followed by the development of long-term visions and goals. Visions of sustainable development for energy supply and other domains are being explored through transition experiments as part of programs for system innovation that are defined in transition arenas, bringing together private and public actors. The use of transition management for the transition to a sustainable energy system illustrates how collective long-term ambitions and a shared agenda can go hand-in-hand with short-term diversity. Transition management is, by definition, about using the energy that arises out of the interaction between long-term consent and short-term dissent through learning-by-doing and doing-

by-learning. By an integrative and outward-looking analysis of societal dynamics, the capacity to anticipate is being improved and alternatives can be developed (Kemp et al., 2007).

Dynamic Adaptive Policy Pathways Approach

To deal with uncertainty in long-term decision making, the Dynamic Adaptive Policy Pathways approach is developed with the use of two underlying approaches. The first is the Adaptation Pathways approach (Haasnoot et al., 2013). Central to adaptation pathways are adaption tipping points, which are the conditions under which an action is no longer able to meet the objectives (Kwadijk et al., 2010). A nuclear disaster is an example of such a tipping point with regard to the implementation of nuclear power plants. When such a disaster happens, the condition of public support base cannot be met since people will have fear and therefore plans about nuclear energy implementation have to be terminated. The Adaptation Pathways approach presents a sequence of possible actions after a tipping point (Haasnoot et al., 2013). The second underlying approach is the Adaptive Policymaking. Adaptive Policymaking is a theoretical approach describing a planning process with different types of actions and signposts to monitor to see if adaptation is needed (Haasnoot et al., 2013).

Both approaches aim at supporting decisionmakers in handling uncertainty in long-term decision-making and emphasize the need for adaptivity in plans in order to cope with deep uncertainty. The Dynamic Adaptive Policy Pathways approach resulted from using the strength of both earlier developed approaches. The key principles of the Dynamic Adaptive Policy Pathways approach which are of relevance within this research are (Haasnoot et al., 2013):

1. The use of transient scenarios representing a variety of relevant uncertainties and their development over time;
2. Anticipating and corrective actions to handle vulnerabilities and opportunities;
3. Several Adaptation Pathways describing sequences of promising actions;

This new approach can be useful for this research since this approach deals with uncertainty in the long-term future, and therefore this approach will be used as an inspiration to develop various scenarios for future electricity generation and delivery, possibly with the use of nuclear energy. This approach is useful with regard to energy because energy policymaking is a complex process. As such, decisionmakers can find themselves confused or incapable of making proper decisions, often due to insufficient information about the uncertainties they need to consider (Michas et al., 2020). With the use of this approach, various possible scenarios will be developed for the energy transition in the Netherlands to meet the future electricity demand in a sustainable way. With this approach, it will be made clear whether or not nuclear energy is necessary or whether or not the future electricity demand can be met with other sustainable sources such as wind- or solar power. The scenarios will be developed with knowledge about the future electricity demand, the capacities of sustainable energy sources, and the developments within the current Dutch energy transition.

2.6 Conceptual model

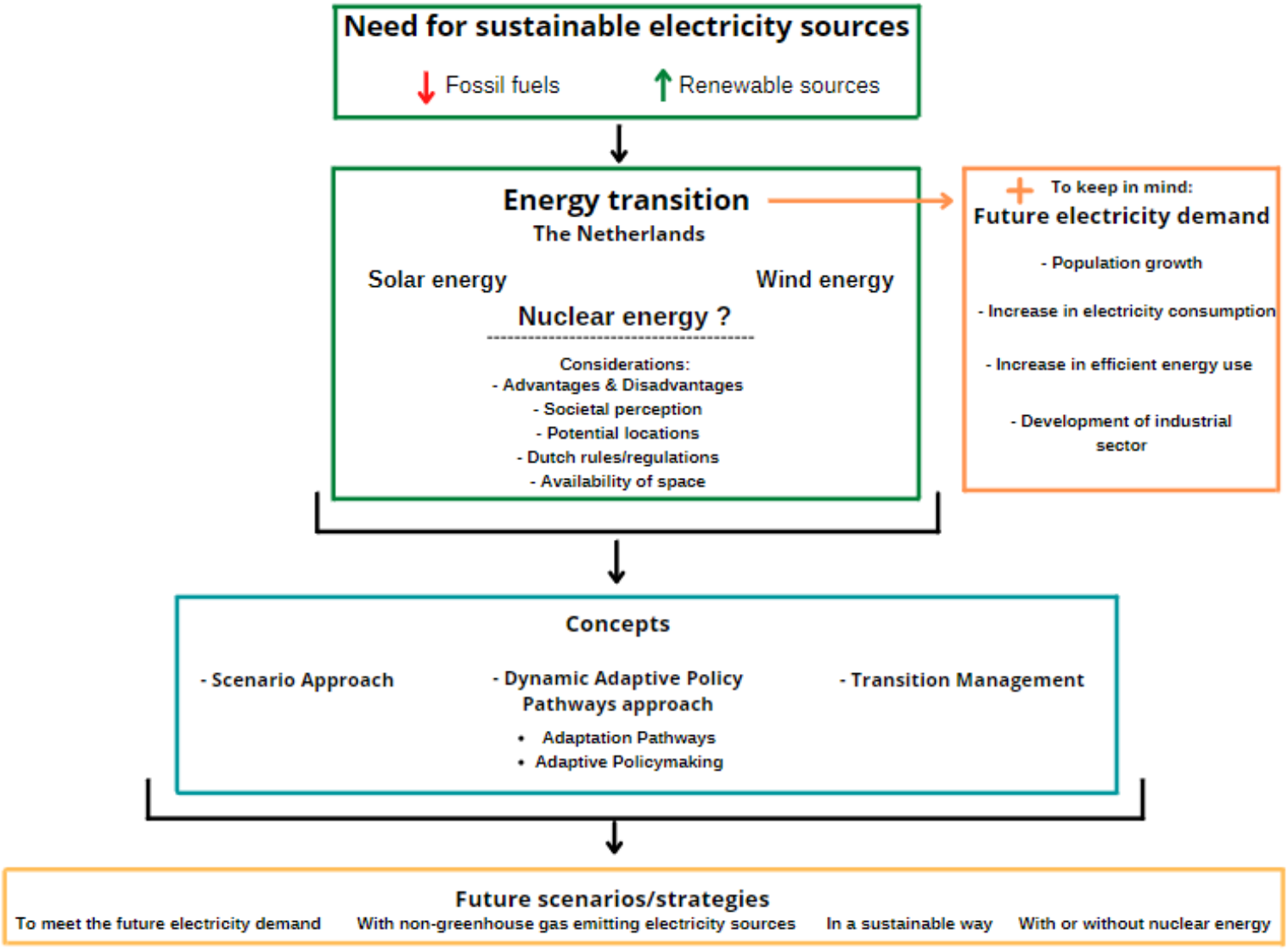

Figure 4: Conceptual model (Author, 2022).

3. Methodology

3.1 Academic literature, policy documents, and media content

This research is primarily based on academic literature, policy documents, and media content. Especially media content is necessary to write about the academic and societal relevance of this research as well as the background information. Various media sources have been analysed by reading the content of a particular media source, and then evaluating whether or not the content is useful, reliable, and valuable for this research. Useful information in this sense depends on whether or not the content is informative and have an added value within this research, and reliability is investigated with a comparison of various media contents to see if the content matches with each other and when that is the case, it can be assumed that this content is reliable. Background information about climate change, sustainability, energy transition, electricity demand & energy demand, and nuclear energy is collected with the use of academic articles which have been peer-reviewed and therefore can be seen as reliable information sources. Furthermore, knowledge from various prominent institutes and organizations such as NASA and the World Nuclear Association is used within this research, also to get an insight in the background information which is necessary to understand before writing in depth about nuclear energy in the Netherlands.

To gain knowledge about the energy transition in the Netherlands, as well as the potential for nuclear energy in the Netherlands, policy documents are used. These documents are written by well-known research centres such as the TNO and governmental organizations. To add, policy documents from the website of the Dutch government about the energy transition and nuclear energy are used within this research. Policy documents and media content will also give information about the debate and implementation possibilities of new nuclear power plants. Especially in the media, the perception towards nuclear energy is provided as well as the advantages and disadvantages of nuclear energy. In policy documents, in-depth information about the possible locations and implementation possibilities is provided. Knowledge about complexity and uncertainty will be gained with the collection of information about the concepts used within this research, these concepts are scenario planning, transition management, and Dynamic Adaptive Policy Pathways Approach. Information about these concepts will be gained with the use of academic articles.

Information about the four conditions, mentioned earlier in this research, will be gained with the use of academic literature, policy documents and media content. The advantages and disadvantages of nuclear energy will be written with media content since already useful comparisons between solar energy, wind energy, and nuclear energy are made. The strategy is to get an insight in a number of important components which need to be compared. To see which components are necessary to compare, various media contents and academic sources about advantages and disadvantages of various energy sources will be compared. When various components are mentioned in various articles and media contents, it can be assumed that these components are important and therefore these will be used in this research. With these components, a multi criteria analysis will be made about wind energy, solar energy, and nuclear energy. Each of the energy source will be ‘graded’ on every component. The lowest and worst value is one, which means very negative. So, for example when the reliability has a score of one, it means that the source is not reliable at all. If the costs have a score of one, it means that the source is expensive to implement. The highest score is 5, which means very positive. So, when the amount of electricity component scores a 5, it means that there is much electricity generated with the use of a particular energy source. Also, one of the components is the avoidance of greenhouse gas emissions. If all energy sources score a 5 on that, it means that all energy sources do not emit any greenhouse gases while generating electricity, which is very positive.

The results will be compared, to get an insight whether or not nuclear energy can have an added value within the energy transition. Information about the spatial component of nuclear energy, the possible locations, and the role of the Dutch government will be collected with especially policy documents, but also with academic literature. There are already policy documents about nuclear energy in the Netherlands, as well as the potential locations and therefore it can be assumed that these policy documents contain knowledge and information which might be of importance within this research. Information about nuclear energy in France, as well as information about their nuclear energy policies, will be collected with the use of information from the World Nuclear Association. As mentioned before, the WNA is a prominent organization, especially with regard to nuclear energy. Therefore, it can be assumed that this organization provides useful information about nuclear energy in France. Academic sources, media content, and policy documents from governments and organizations will maximize the reliability of this thesis and therefore statements in this thesis with a reference to academic articles can be seen as 'true' statements.

3.2 Use of survey results

Besides using academic literature, policy documents and media content, this research will also make use of primary data. Primary data in this sense is the collection of survey results about the perception of Dutch society towards nuclear energy. This primary data is collected by I&O research, a prominent research organization in the Netherlands. They have done research about nuclear energy in the Netherlands and this research is publicly available and therefore valuable and useful within this research. The data which will be collected is about the public perception towards nuclear energy and it also contains information about the public support base towards nuclear energy. This will help to get an insight in whether or not inhabitants of the Netherlands are in favour of nuclear energy because the research contains survey questions about whether or not people in the Netherlands want more nuclear power plants, or that they prefer other sustainable energy sources and this will give an answer on the sub-question about the societal perception towards nuclear energy.

Furthermore, this data will provide knowledge on which energy sources are the most popular among the Dutch society. This data is representative for the Dutch society and therefore it can help to give an insight in the public opinion about nuclear energy. Surveys are useful within this research since it offers a lot of information about thoughts and opinions of people (Clifford et al., 2010). Often, the assumption is that people are not in favour of nuclear energy because of the possible failures with severe consequences and thus the risks related to nuclear energy. However, to get an insight in whether or not people are against nuclear energy, a survey is the best method to gain knowledge on this since relatively many people are asked about their opinion. One disadvantage of the survey is that it only is a snapshot at one specific moment. It can be that perceptions about nuclear energy change within a few months, but within the timeframe of this research it is not possible to conduct surveys once in a while to see how the results change within a specific timeframe. The reason why a survey will be used instead of interviews, is that a survey is more useful since this method of data collection is more time-efficient with in general a higher response rate than interviews. To clarify, with a survey it is possible to gain knowledge on the general perception towards nuclear energy in the Netherlands in a relatively small timeframe with a high number of responses, whereas with an interview it is not doable to get the preferred number of responses in a short timeframe. The questions will be formulated in such a way that it is immediately clear what is asked, and therefore these questions are relatively easy to answer. Furthermore, surveys deliver the most direct measure of the thoughts and intentions of people, and that makes it one of the most valuable sources of data (Martin et al., 2014). Because of these reasons, a survey is much more preferable than interviews.

The strategy within this research is that academic literature, policy documents, and media content will provide information about the background information. This will eventually lead to four conditions which must be met before the implementation of new nuclear power plants in the Netherlands is possible. So, it starts with providing knowledge about the advantages and disadvantages of nuclear energy. After that, the sources provide information about the spatial component and where a new nuclear power plant can be implemented and what is needed for that. Then, the role of the Dutch government and information about financing new nuclear power plants will be provided with the use of academic articles and policy documents. Lastly, information about nuclear energy use in France will be provided with media content and knowledge from prominent organizations. This is visualized in table 1 and 2.

The information and knowledge from this secondary data will answer sub-questions 1, 2, 3 and 5. The collection of primary data will provide information and knowledge on the public perception towards nuclear energy, which is also one of the conditions, and therefore this data will answer sub-question 4. So, when all sub-questions are answered with the use of secondary data and primary data, it is possible to conclude whether or not the necessary conditions can be met. If the conditions can be met, it is possible to implement new nuclear power plants in the Netherlands. If the conditions cannot be met, it will become close to impossible to implement new nuclear power plants in the Netherlands However, due to uncertainty and complexity, the future cannot be predicted. Therefore, scenarios must be developed about the implementation of new nuclear power plants in the Netherlands and this will be done with inspiration from the Dynamic Adaptive Policy Pathways Approach concept. These scenarios do only add value to this research when it is possible to implement new nuclear power plants in the Netherlands, so when all conditions can be met. If the conditions cannot be met, it is not needed to develop future scenarios for the energy transition in the Netherlands with the use of nuclear energy.

3.3 Data collection techniques

Research questions	Information	Method of analysis	Documentation
Main RQ: **"Under which conditions can nuclear energy on the long-term play a feasible role within the energy transition in the Netherlands to meet the future electricity demand in combination with reducing greenhouse gas emissions?"**	Comparison with other sources of energy and where a potential nuclear power plant can be located. Knowledge on the implementation of nuclear power plants and the use of nuclear energy. Long term energy strategy of the Netherlands. Possible ways to go in the future. Reduction of greenhouse gas emissions.	Academic literature analysis, media content analysis, policy documents analysis, MCA analysis, knowledge from primary data, inspiration from concepts.	Microsoft Word
Sub-Q1: **"What are the advantages and disadvantages of nuclear energy compared to solar energy and wind energy?"**	Advantages and disadvantages of nuclear energy, solar energy, and wind energy. Comparison between these energy sources.	Comparison of the advantages & disadvantages of the energy sources with the use of an MCA.	Microsoft Word
Sub-Q2: **"What are potential locations in the Netherlands where a nuclear power plant can be implemented?"**	The potential/possible locations in the Netherlands to implement a nuclear power plant.	Analysis with the use of policy documents.	Microsoft Word
Sub-Q3: **"What is the societal perception of the Dutch society towards nuclear energy?"**	Knowledge on the public's opinion about nuclear energy. Knowledge on popular and unpopular energy sources.	Primary data analysis from I&O research.	Microsoft Word
Sub-Q4: **"What is the role of the Dutch government with regard to nuclear energy and possible scenarios to meet the future electricity demand?"**	The role of the national government in the Dutch energy transition. The role of the government with the possibilities of nuclear energy. The role of the national government regarding financing possible nuclear power plants. Knowledge on the public's opinion about nuclear energy.	Analysis with academic literature and policy documents.	Microsoft Word
Sub-Q4: **"What can the Netherlands learn from the use of nuclear energy in France?"**	Knowledge on how to implement nuclear power plants. Knowledge on investments in nuclear energy. Knowledge on policies behind the use of nuclear energy as well as safety standards.	Use of literature from the WNA, a prominent organization with regard to nuclear energy.	Microsoft Word

Sub-Q5: **"What are possible scenarios to meet the future electricity demand without greenhouse gas emissions?"**	Various scenarios with regard to meeting the future electricity demand in the Netherlands. With or without nuclear energy, and whether or not nuclear energy can be used as a back-up source or if it should work on full capacity.	Scenarios will be developed with inspiration from the Dynamic Adaptive Policy Pathways Approach.	Microsoft Word

Table 1: Data collection techniques and research questions.

3.4 Research framework

Literature/Online sources review	Online sources such as websites and policy documents, as well as literature found via Google Scholar or Smartcat, will help to get knowledge on this subject, as well as societal relevance, academic relevance and the introduction of this thesis. These sources will also help to already get an insight/answer on the first sub-questions in this research.
Database	A database will be created to ensure that all useful information and knowledge is stored. This database will for example contain links to useful websites, but also pdf files which are useful, as well as policy documents.
Primary data	I&O research has gained knowledge on the public perception and opinion about nuclear energy in the Netherlands. This organization is a prominent organization and therefore reliable. This data is publicly available and it is representative for the Dutch society and therefore useful.
Development of scenarios	After answering all sub-questions, various possible scenarios will be developed to meet the future electricity demand in the Netherlands. This will be done with the concepts in this thesis.

Table 2: Research framework.

3.5 Unit of analysis

The unit of analyses, or the case, is determined by defining spatial boundary, theoretical scope, and timeframe (Yin, 2003). The spatial boundary of this case is the whole of The Netherlands (excluding Saint Martin, Bonaire, and Curaçao) and the electricity network and demand of the citizens of The Netherlands. A division between various parts of the Netherlands will not be made. Potential areas in the whole of the Netherlands will be analysed to get knowledge about possible locations for nuclear power plants. As stated before, the theoretical scope is limited to various concepts which will be used throughout this thesis. The concepts are of importance due to the necessary background information, provided in the previous section. Furthermore, the methods used in this thesis are limited to secondary data collection and analysis and primary data collection. Background knowledge used in this thesis is about climate change, sustainability, energy transition, electricity demand, and nuclear energy. Concepts within this research are: '*Scenario Planning*', '*Transition Management*' and *'Dynamic Adaptive Policy Pathways approach'*. This research will run from November 2021 until June 2022. Secondary data collection will be done in February and March, and primary data collection will be done in April.

3.6 Expected results

This research can be valuable for the national government to get an insight in the (dis)advantages of nuclear energy. It will also give an insight in whether or not the implementation of a nuclear power plant is beneficial or that the government should invest in other sources of sustainable energy such as wind energy and solar energy on the long-term to meet the future electricity demand. Besides this, the spatial component plays an important role in the possible scenarios since not every location is suitable. It takes quite some years to implement a nuclear power plant. This means that when an area is designated to build a nuclear power plant, this particular are needs to be preserved for quite a long time. That might result in difficulties because of the fact that the Netherlands is a densely populated area. Also, a policy advice will be given on the basis of lessons which can be learnt from other countries in which nuclear energy is a useful source. For example, lessons from France can be valuable, since nuclear energy and nuclear power plants is widely used. The advice based on these lessons will provide knowledge about the implementation of nuclear power plants, as well as the level of involvement from the government and/or private parties. Several scenarios will be developed to meet the future electricity demand in The Netherlands with the use of sustainable sources. It might be very well be the case that nuclear energy is a promising electricity source in the future of The Netherlands. A combination is also possible, in which nuclear energy can be used next to solar energy and wind energy. This research will lead to an elaboration on the energy debate in the Netherlands and especially with regard to the potential use of nuclear energy. Furthermore, this research will provide an insight in the usefulness of nuclear energy in the Netherlands and it tries to develop future scenarios in which future uncertainties are taken into account. Furthermore, this research will give an insight in whether or not nuclear energy is needed to meet the future electricity demand. With this, various scenarios will be provided which can be of value for the Dutch government, to get an insight in the various possibilities to meet the future energy demand.

4. Findings

4.1 Advantages & disadvantages of energy sources

4.1.1 Wind energy

Wind energy is the conversion of energy from wind into useful energy. This process of obtaining energy requires that the kinetic energy of the moving air be converted into mechanical energy and then into electrical energy through the use of wind turbines (Ellabban et al., 2014). Wind energy is seen as a clean, ecological, inexhaustible source and it does not contribute to greenhouse gas emissions. All forms of energy have an environmental impact; however, impacts related to wind energy are generally less problematic than impacts associated with other energy sources (Sahin, 2004). Table 3 gives an overview of various components with regard to the implementation of energy sources. Those seven components are of importance within the energy transition and implementation of energy sources. Therefore, those components are chosen to use in this research. With the production of wind energy, there is no greenhouse gas emission, which is very positive. The amount of produced electricity wind turbines is sufficient, which means that it is not as much as other energy sources, but some energy sources produce even less energy. The space needed with wind energy is also sufficient, which means that some energy sources require less space, but other energy sources require more space. The reliability is very negative, because of the intermittency problem. If there is no wind, there is no electricity production. The costs are negative, since wind turbines and wind farms are quite costly. The nuisance is very negative, because wind turbines make noise and create shadow due to rotating blades. Therefore, wind turbines cannot be placed too close to residential areas. The ecological impact is negative, since wind turbines can kill birds or scare them away, which have negative consequences for the ecological surroundings (Milieu Defensie, 2022).

WIND ENERGY

1 = Very negative, 2 = Negative, 3 = Sufficient, 4 = Positive, 5 = Very positive

	1	2	3	4	5
Avoiding greenhouse gas emission					X
Amount of produced electricity			X		
Space needed			X		
Reliability	X				
Costs		X			
Nuisance	X				
Ecological impact		X			

Table 3: Overview of how wind energy scores on various components.

4.1.2 Solar energy

Currently, new technologies are being employed to generate electricity from solar energy. These approaches have already been proven and are widely practiced throughout the world as renewable alternatives to fossil fuel resources (Kabir et al., 2018). The growth of solar power has increased exponentially between 1992 and 2020. It has evolved from small scale applications to mainstream electricity source. The main disadvantage is the fact that they are subject to weather intermittency (Rabaia et al., 2021). Table 4 gives an overview of the components, similarly to the section about wind energy. With the production of solar energy, there is no emission of greenhouse gases and therefore it is labelled as very positive. The amount of electricity produced is not that high compared to other sources and therefore it is labelled as negative. Also, solar fields require much space compared to the amount of produced electricity. The costs of one hectare of solar panels are an investment of about 600.000 to 1 million euros (VLB, 2018). If solar energy and wind energy are compared to each other, it can be concluded that wind energy is more efficient in terms of land use and from the spatial viewpoint. Wind turbines and wind farms take up a relatively small amount of space compared to solar parks. Besides this, to generate a similar amount of electricity, solar parks are also more expensive than wind turbines or wind farms. The reliability is very negative, because of intermittency problems. The nuisance and ecological impact are both sufficient, because there is not really nuisance from solar panels because it for example does not make any noise, but some nuisance can be that solar fields are often placed at the expense of other land-use purposes.

SOLAR ENERGY

1 = Very negative, 2 = Negative, 3 = Sufficient, 4 = Positive, 5 = Very positive

	1	2	3	4	5
Avoiding greenhouse gas emission					X
Amount of produced electricity		X			
Space needed		X			
Reliability	X				
Costs		X			
Nuisance			X		
Ecological impact			X		

Table 4: Overview of how solar energy scores on various components.

4.1.3 Nuclear energy

Several advantages of nuclear power plants are analysed through time. First of all, nuclear power plants are one of the few energy production methods that is not air-polluting (Akyuz, 2017). Another advantage of nuclear power plants is the reliability. That is because when a nuclear power plant is functioning properly, it can run uninterrupted for a long time. The running of the nuclear power plant is also not contingent of weather or foreign suppliers, which makes it more stable than other forms of energy (Koval & Chala, 2018). Table 5 gives an overview about the components and how this relates to nuclear energy. With electricity production from nuclear energy, there is no emission of greenhouse gases and therefore this is very positive. The amount of produced electricity is much more with the use of nuclear energy than with solar and wind energy, and therefore this is also very positive. Also, the amount of space needed compared to the amount of produced electricity is low, which is positive. The only disadvantage regarding space is that it is not allowed to build residential buildings in the vicinity of a nuclear power plant. With nuclear energy there is always a reliable production of electricity, and there are no disadvantages with regard to intermittency as with solar and wind energy. One problem with reliability could be that there is a small chance of accidents. Compared to solar and wind energy, nuclear energy is very expensive with regard to building, implementation, and maintenance and therefore the costs are very negative. The nuisance and ecological impact are both sufficient.

NUCLEAR ENERGY

1 = Very negative, 2 = Negative, 3 = Sufficient, 4 = Positive, 5 = Very positive

	1	2	3	4	5
Avoiding greenhouse gas emission					X
Amount of produced electricity					X
Space needed				X	
Reliability				X	
Costs	X				
Nuisance			X		
Ecological impact			X		

Table 5: Overview of how nuclear energy scores on various components.

Figure 5 is a matrix in which the four most important components are stated and how wind energy, solar energy, and nuclear energy are located in the spectrum. These four components are the most important within this research since these components are closely related to the conditions which must be met to implement new nuclear power plants in the Netherlands. The other three components are also important, but the score of the component with regard to greenhouse gas emissions is for each of the electricity sources the same, and therefore it is not necessary to include this in the figure below. The components about nuisance and ecological impact are especially necessary when looking at the local scale. Since this research focuses especially on national scale, it is not necessary to take nuisance and ecological impact into account in the figure. The figure shows a comparison between the energy sources and how these relate to each other with regard to space needed, electricity production, reliability, and costs. With this figure, it is possible to get an indication which source is most valuable in terms of for example reliability and which source is for example the most expensive. This knowledge can be valuable to develop future scenarios to meet the electricity demand in the Netherlands.

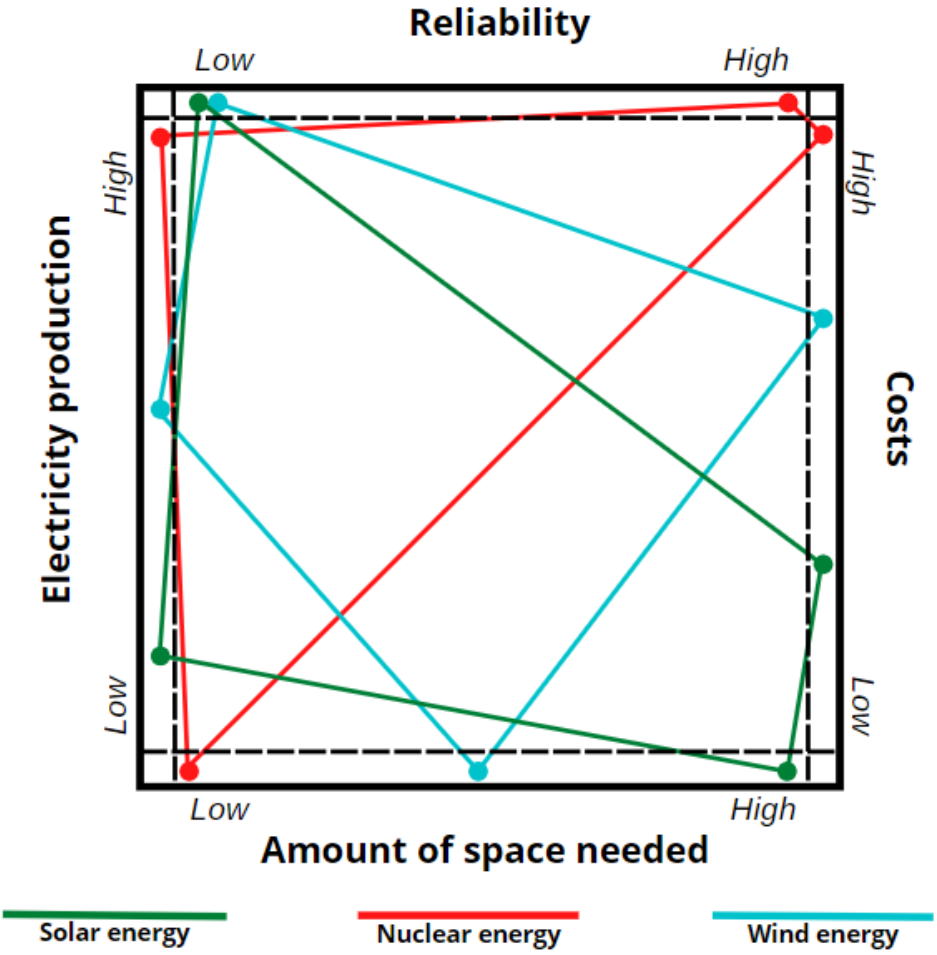

Figure 5: Visualization of comparison between wind energy, solar energy, and nuclear energy regarding reliability, costs, amount of space needed, and electricity production (Author, 2022).

4.2 The spatial component of nuclear energy

The Dutch government has plans to keep the current nuclear power plant in Borssele open for another ten or twenty years, and besides that, implement two more nuclear power plants in the Netherlands (Nuclear Nederland, 2021). However, until this day it still only is a plan. Potential locations for new nuclear power plants are also not clear yet.

But it is important to already take a look at possible locations for nuclear power plants when the Dutch government wants to invest in a second, and or even a third nuclear power plant in the Netherlands. It is possible to build a nuclear power plant anywhere in the Netherlands, but it has to ensure that the safety requirements are met and that the zoning plan it allows. It is even the case that in the Netherlands, two locations have been designated where spatial developments may not lead to obstruction of nuclear power plants, the so-called guarantee locations, which is defined in the Third Structure Scheme Electricity Supply: SEV III (ANVS, 2021). These locations are Borssele and Maasvlakte I. Previously, there were three guarantee locations, which also included the Eemshaven in Groningen. However, on 10 March 2021, a motion has passed in the House of Representatives to remove the Eemshaven from the SEV III as a possible location for a nuclear power plant (Laka, 2021a). The reason for this, is that the consequences of the gas extraction are still too high and the earthquakes still occur in province of Groningen. The problems with the gas extraction and earthquakes in Groningen resulted in distrust in the Dutch government among the local residents in Groningen, and therefore there is definitely no support base for a nuclear power plant in that region. Also, the nuclear power plant in Dodewaard is no option, since that location also has no support base from the local residents to open up the nuclear power plant again.

There are several practical and legal requirements that influence the possible integration of a nuclear power plant on a specific location. There must be possibilities for the supply and removal of uranium and nuclear waste, but the location must also be easily accessible for emergency services. Another requirement of the potential location for a new nuclear power plant, is that it is located next to water because a lot of cooling water is needed when a nuclear power plant is operating (ANVS, 2021). However, it is expected that it will be difficult to integrate a nuclear power plant close to a river or close to the Ijsselmeer and other inland waters. A location close to the sea is more suitable, and thus then again Borssele and the Maasvlakte I are interesting potential locations. The reason why the implementation of a nuclear power plant close to a river or inland waters is difficult, it because the high temperature of the surface water is the most restrictive precondition for a nuclear power plant with regard to cooling water discharge. It is expected that it even becomes more restrictive in the future due to climate change (Laka, 2021b).

Although the Maasvlakte I is a potential location for a new nuclear power plant, there is resistance from the municipality. The municipality of Rotterdam is not in favour of nuclear energy. The city council believe that a broad mix of sustainable energy sources is needed to reduce greenhouse gas emissions and achieve the climate goals, but nuclear energy is not part of the Rotterdam Climate Agreement. This is an agreement which the municipality concluded with more than 100 companies and social organizations in 2019 (Gunneweg, 2021). Besides this, the space in the Port of Rotterdam is limited. Rotterdam prefers to focus on a European hydrogen hub for industry. A new nuclear power plant on the Maasvlakte I would constrain other sustainable developments (Gunneweg, 2021).

It is already an option to build two other nuclear power plants in Borssele, next to the already existing one. The so-called third generation nuclear power plants have a capacity of 1.500 MW each. These new nuclear power plants cost about eight to ten billion euros and supply three times as much power as the current nuclear power plant (Omroep Zeeland, 2020). The two new nuclear power plants can be built in the immediate vicinity of the existing nuclear power plant. EPZ, the owner of

the existing nuclear power plant, reports that building the two new nuclear power plants at the same time is the most optimal strategy. That is because then you can take advantage of economies of scale and gradually train the required technical employees from the existing organization (Omroep Zeeland, 2020).

The optimal location in the Netherlands to implement one or even two new nuclear power plants is Borssele, which is visualized in figure 6. There is already an existing nuclear power plant, but there is room for more. Also, the public opinion regarding nuclear energy is good and the owner of the existing nuclear power plant have options to build new nuclear power plants. The Maasvlakte I location is not a suitable location, due to resistance from the municipality of Rotterdam and because there is limited space in that area. The Eemshaven could be a good potential location, but only if there is enough support base which is now definitely not the case. The people in Groningen have had enough setbacks regarding the gas extraction in that region, so there is a lot of distrust towards the national government. Therefore, a new nuclear power plant is not a suitable option in the Eemshaven.

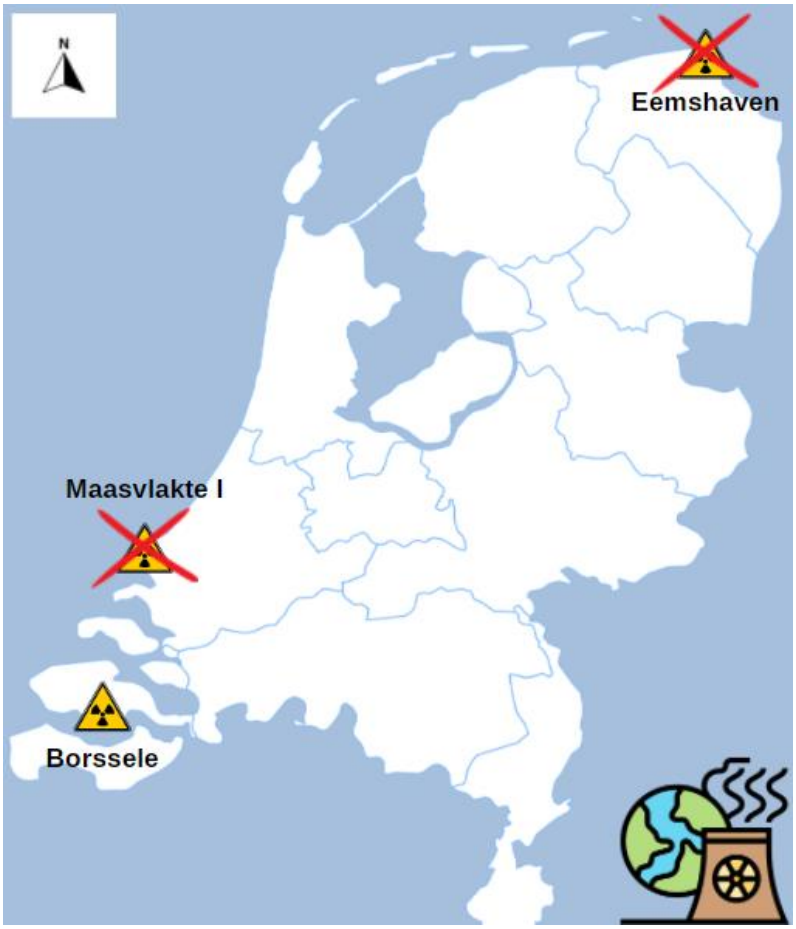

Figure 6: Potential location nuclear power plant in the Netherlands (Author, 2022).

4.3 The societal perception towards nuclear energy

To implement a new nuclear power plant, there has to be public support base. It is important to get an insight in the general public perception towards nuclear energy and the support base towards the implementation of new nuclear power plants. To gain knowledge about this, I&O research (2021) did research about nuclear energy perception and other sources of energy. As mentioned in their report, the results are nationally representative and therefore useful for this research. The research is published in November 2021, which means that the research is already done more than 6 months ago. However, this is the most recent report about the perception towards nuclear energy in the Netherlands. A total of 1.110 aged 18 or older participated in this research (I&O research, 2021).

The most important finding within the research is that it turns out that half of the Dutch society (50%) is in favour of nuclear energy production with the use of the nuclear power plant in Borssele (Figure 7). 17% of the population is not in favour of nuclear power production. Furthermore, about half of the population is in favour of more nuclear energy. The other half is either neutral or against this form of energy generation. According to this research, it is possible to say that the Dutch society is more in favour of nuclear energy than against nuclear energy (I&O research, 2021).

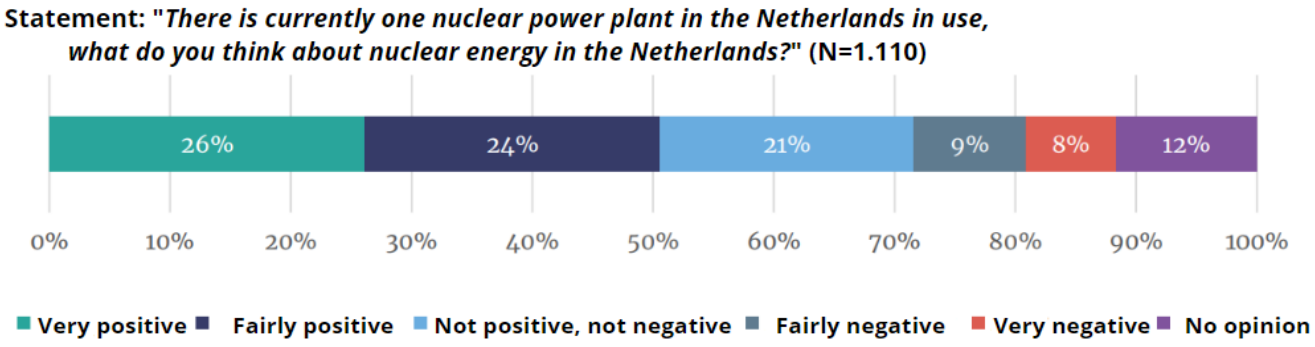

Figure 7: Opinion of Dutch society about nuclear energy (Author, 2022).

Another important finding is that almost half of the Dutch society (46%) think that the Dutch government need to invest in more nuclear energy (Figure 8). Only 11% of the population think that we should not use nuclear energy at all. The most popular energy sources are solar panels and offshore wind turbines. Gas and coal are by far the least popular (I&O research, 2021). Dutch people who are in favour of more nuclear power plants mainly use two arguments. A large proportion of the population cite the fact that nuclear energy is a relatively clean way of energy production because there is no emission of greenhouse gases. Besides this, they argue that nuclear energy is a stable form of energy with a high efficiency. Others argue that it is simply necessary, because they believe that there is no alternative since it is impossible to generate all energy from renewable energy sources. Opponents cite they fear a nuclear disaster or they are against the nuclear waste (I&O research, 2021).

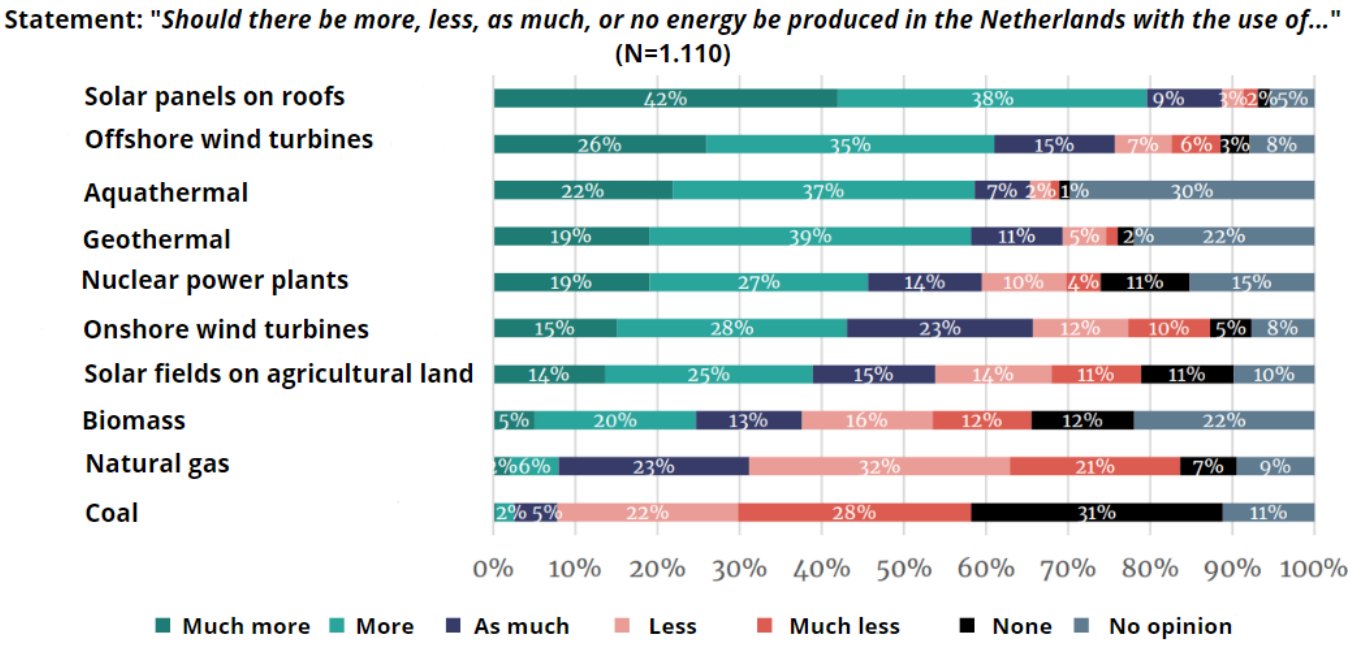

Figure 8: Popularity of various energy sources among the Dutch society (Author, 2022).

One of the statements in the research is "*In order to meet the energy demand, more nuclear power plants need to be implemented in the Netherlands*." At the moment of the research, in November 2021, 49% of the participants agreed with this statement (I&O research, 2021). Various statement and the responses are visualized in figure 9.

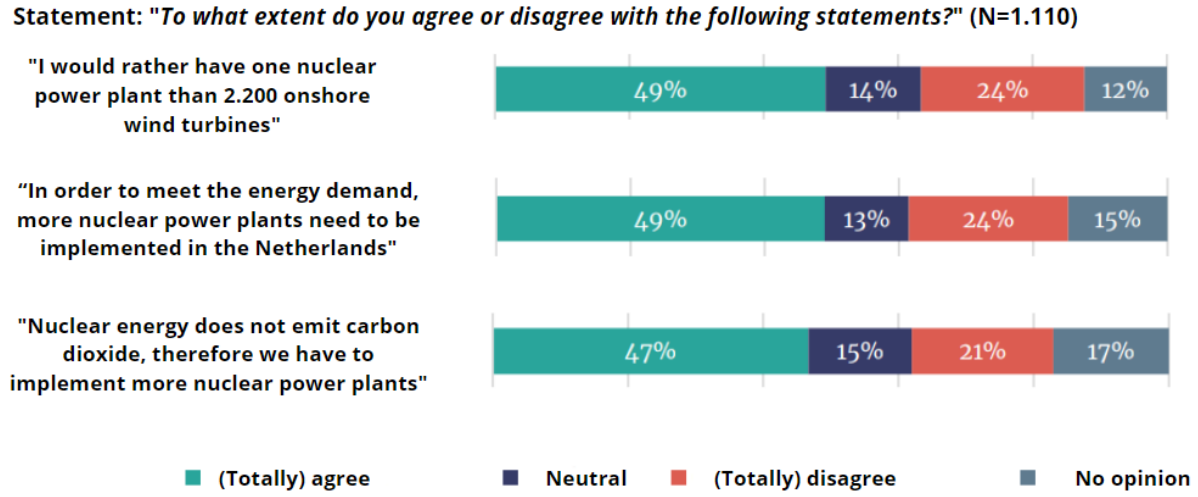

Figure 9: (Dis)agreement of Dutch society with various statements about nuclear energy (Author, 2022).

A more recent factor which influences the energy transition is the geopolitical tensions with gas supplier Russia. The Netherlands is dependent on natural gas from Russia. However, due to the tensions with Russia and the invasion in Ukraine, society and the government think that the Netherlands have to be much less dependent on gas from Russia, and therefore investments in own energy generation sources are needed to be more independent with regard to energy generation and use. But the hasty disconnection of fossil fuels and thus gas from Russia, as well as the limited contribution of solar and wind energy are causing energy poverty and headaches for citizens, industry, and the Dutch government. Therefore, hope is based on nuclear energy (WNL, 2022).

4.4 The role of the Dutch government

As stated before, the need for renewable electricity sources in The Netherlands is important, since currently only 26 percent of the produced electricity, is sustainable electricity. The aim of the Dutch government is that this percentage should increase to 70 percent by 2030 and that the emission of greenhouse gas emissions will decrease with 49% in 2030 compared to 1990 (Vos, 2021; Rijksoverheid, 2019). The Netherlands already makes use of nuclear energy, but the share of nuclear energy in the electricity system is not high compared to other countries. To get an understanding why the Netherlands has only one nuclear power plant and what the role of the Dutch government is, a historical overview is helpful to get an insight in the past of the Netherlands and nuclear energy and how this might influence the future of the Dutch electricity system and the potential increase of nuclear energy.

4.4.1 Historical overview

After a long time lobbying from the nuclear industry, the *'wet tot financiering van de bouw en inrichting van een kernreactor in Nederland'* came into force in August 1954, which is basically the act for the financing of the construction and installation of a nuclear reactor in the Netherlands. The Dutch government would finance half of the costs, and the other half would be borne by the industry and other stakeholders involved. Although there was opposition against the plans and this act, the political way was paved for nuclear energy in the Netherlands (IsGeschiedenis, 2022). In 1955 construction began on the Netherlands' own research reactor, the High Flux Reactor (HFR) at Petten. HFR was intended to help the country gain knowledge of nuclear technology and operations through materials research. The Ministry of Economic Affairs had a strategy to develop a national industry capable of designing, manufacturing and exporting nuclear power technology and the ultimate aim was that nuclear power would be introduced from about 1962 to gradually replace much fossil fuel electricity generation. In May 1965, construction started on the first nuclear power reactor in the Netherlands, at Dodewaard. This nuclear power plant was connected to the grid in October 1968.

The second nuclear power project in the Netherlands was the reactor at Borssele. The construction of this nuclear power plant started in July 1969 and the nuclear power plant began producing electricity for national consumption in 1973, when it was connected to the grid. It was designed and built by Siemens, it is operated by Electricity Generating Company for the Southern Netherlands (EPZ) and it was owned by Essent and Delta Energie, who both had 50% of the stakes (WNA, 2022d). Because the Netherlands has a fairly minor nuclear program, the amount of radioactive waste is not that much. The Central Organization for Radioactive Waste (COVRA) is responsible for the waste management related to nuclear energy generation. COVRA's duty of care is to protect people and the environment while housing conditioned low, intermediate, and high-level waste in interim storage (Sanders & Sanders, 2021).

Although there were plans that initially called for increasing nuclear power generation in the Netherlands, this was not realized due to the nuclear accident in Chernobyl in 1986. This accident dampened the public enthusiasm and support. A large-scale protest movement against nuclear energy started and the anti-nuclear energy movement wanted the nuclear power plants in the Netherlands to be closed because they were unsafe and the radioactive waste from the nuclear power plants was harmful for human society and the environment. In addition, the anti-nuclear energy movement opposed against nuclear weapons, the impact of technology on society and the undemocratic nature of nuclear decision-making (IsGeschiedenis, 2022). The negative expressions of the public towards nuclear power as well as economic reasons led to the closing of the nuclear power reactor at Dodewaard (Sanders & Sanders, 2021; WNA, 2022d). The nuclear power plant in Borssele was still able to operate since there was no agreement on an end-date to close that nuclear

power plant. After various lawsuits and parliamentary decisions, the nuclear power plant is still in use.

4.4.2 Nuclear energy policy

In 1994, the Dutch government voted to phase out the nuclear power plant in Borssele by 2003. However, the problem for the government was that there were some legal difficulties to implement that decision. In 2003, the ruling conservative government coalition moved the closure date back to 2013, and in 2005 the phase-out decision was abandoned. In June 2006, the Dutch government signed an agreement with operators and stakeholders of the nuclear power plant in Borssele. This agreement ensured that the reactor would be allowed to operate until 2033 under certain strict conditions. The conditions were that the reactor should be maintained to the highest safety standards, and that the stakeholders (Essent & Delta) agreed to invest 250 million euros towards sustainable energy projects. The government added another 250 million euros, avoiding the compensation claim they would have faced if they continued towards early shutdown (WNA, 2022d). According to the operators, it is even possible that the nuclear power plant in Borssele remains open and operating after 2033. However, the condition is that the government should invest money in the nuclear power plant. So, according to EPZ, the operator of the nuclear power plant, a lifespan extension after 2033 is possible (Laka, 2020).

Besides the strict conditions, various laws and regulations are applicable to the governance of radioactive waste management and nuclear energy use. The Nuclear Energy Act is the most prominent. It governs the appropriate use of nuclear activities, as well the proper management of nuclear materials. The law lays out rules of application, provides for the protection of human society and the environment, and entitles competent authorities with roles and responsibilities (Sanders & Sanders, 2021).

Electricity production and consumption in the Netherlands has been liberalized. That means that the market is completely open and it does not matter which electricity supplier you choose. The Authority for Consumers and Markets have supervision over the market. The ACM is a governmental organization and must ensure that energy companies comply with rules and regulations (EnergieVergelijken, 2022). As stated before, the owner of the nuclear power plant in Borssele is EPZ and that is a joint venture of PZEM and Energy Resources Holding BV, which in turn is part of the German energy company RWE. However, the national government wants to guarantee public influence and authority for the nuclear power plant in Borssele and therefore the government has concluded an agreement with the shareholders of EPZ (ANVS, 2022). Several market parties have indicated their interest in building a new nuclear reactor in the country. Because of exhaustion of the natural gas fields and increasing public acceptance of the environmental advantages of nuclear power, there was a marked shift in the position of some political parties in favour of new nuclear power plants. In September 2006, the environment minister on behalf of the economics minister submitted to parliament a document entitled, *Conditions for New Nuclear Power Plants.* An accompanying statement said that the government wanted to move to a sustainable energy supply and that the abandonment of its earlier phase-out policy (deferring Borssele's shutdown to 2033) was part of a transition strategy, and that nuclear power could reduce greenhouse gas emissions. A new nuclear reactor could be fitted into this transition model (WNA, 2022d).

In March 2008, the main advisory body of the Dutch government on national and international social and economic policy said that the government should consider expanding nuclear energy in two years when it is due to evaluate its climate policies. In the official government statement on taking office in October 2010, the incoming prime minister stated that the security of energy supply would remain a policy spearhead, along with efforts to cut carbon dioxide emissions in line with European

targets. Hence the government will be open to issuing permits for new nuclear power plants. Regarding energy supply, the Netherlands must become less reliant on other countries, high prices and polluting fuels. Energy security must be increased and more attention must be paid to the potential profitability of energy. To reduce greenhouse gas emissions and energy dependence, more nuclear energy is necessary (WNA, 2022d).

In September 2008, Delta announced that it wanted build a second unit at Borssele. In June 2009, it embarked upon seeking preliminary approvals for it from the Ministry of Housing, Spatial Planning and the Environment. Delta proposed to start building in 2013 and have it operational in 2018. However, due to economic uncertainties, Delta put the project on hold for 2-3 years and it has to proceeded since (WNA, 2022d). After years of negotiation the Dutch government decided to invest more in offshore wind energy and solar energy instead of nuclear energy, and therefore there is still just one nuclear power plant left in the Netherlands. It is still possible for market parties to invest in nuclear power plants, but they have to meet strict regulations based on safety, security, peaceful purposes, and they have to ensure that they have enough money to demolish the nuclear power plant after it has been closed (Rijksoverheid, 2022a).

4.4.3. Investing in nuclear energy

Market parties in the Netherlands are interested in building a new nuclear power plant, however not without any financial help from the Dutch government. The inventory whether or not companies are interested in building a nuclear power plant made clear that the market parties are willing to build one, but with a lot of conditions. These conditions consist of financial support, but also hedging of risks and guaranteeing operating return. Furthermore, there are non-financial conditions which are demanded such as no changes in the nuclear energy policies regarding law and regulations, and permanent guarantee of sufficient social support. The financial, non-financial, and risk covering conditions are as follows (Laka, 2021b):

Financial conditions

The Dutch government should provide guarantees for financial risks, investment protection, and financing structures with price guarantees. During construction, the government should already provide a compensation to the investor and in the exploitation phase, turnover certainty is necessary. In addition, the government must ensure that the available knowledge and expertise are retained.

Non-financial conditions

There must be, and remain, sufficient public support, the government must guarantee stable policies with regard to nuclear energy and that important reputational risks must be resolved by the government. An example of a reputational risk is that the government should come up with a long-term solution for radioactive waste management.

Covering risks

The government should guarantee to cover dismantling costs in the event of early bankruptcy of the operator. Also, the government should guarantee to cover unforeseen cost increases of dismantling a nuclear power plant. Risks arising from interim changes in legislation, regulations, and changes in the costs of waste processing must also be borne by the government.

4.5 Lessons from France

4.5.1 Nuclear energy in France

France is one of the leading countries in the world regarding the use of nuclear energy. France derives about 70% of its electricity from nuclear energy, due to a long-standing policy based on energy security (WNA, 2022c). Therefore, the use of nuclear energy in France can be seen as a best practice and other countries such as the Netherlands might be able to learn from their experiences with nuclear energy. Two of the reasons why nuclear energy production can be seen as a best practice in France are listed below:

- In 1999, a parliamentary debate reaffirmed three main planks of French energy policy: Security of supply, respect for the environment, and proper attention to radioactive waste management. This resulted in a law in 2005 which established guidelines for energy policy and security (WNA, 2022c). These planks and guidelines resulted in the success of nuclear energy production in France.
- France is the world's largest net exporter of electricity due to its very low cost of generation, and gains over 3 billion euro per year from this. Much of the produced electricity is going to Italy, since they do not have any operating nuclear power plants. Also, the UK has become a major customer for French electricity (WNA, 2022c).

Financing of the nuclear power plants in France is for the largest part done by Électricité de France (EDF). This is a state-owned vertically integrated utility with a near-monopoly on electricity production and supply, operating within a clear regulatory framework. Before 1980, the French government financed part of EDF's investments directly through capital increases. From 1980, EDF was authorized to borrow up to 40 billion euros from commercial sources without government guarantees. In fact, electricity consumers were taking most of the risks and rewards of the utility's policies and management through the setting of tariffs. The government controlled the sharing of risks between consumers and EDF (OECD, 2009). In the 1990s, French electricity rates were far than in most European countries. Thus, having taken the financial risks, consumers were rewarded through lower prices. The technical success of the nuclear program was a major contributor to the viability and efficiency of this model. EDF chose an established and standardized design, set up an appropriate industrial organization and kept construction costs and schedules under control. The government provided support through a clear and constant policy in favour of nuclear generation. As of the end of 2008, the government retained some 85% of EDF stock, with employees holding 2% and other investors about 13% (OECD, 2009).

in France, the public opinion supports nuclear energy production (NRC, 2022). One of the reasons for the support is that the French people like to be independent. To get this independence, French policy makers saw only one way for France: nuclear energy. Another reason why nuclear energy is so popular in France is because the French authorities have worked hard to get people to think of the benefits as well as the risks of nuclear energy. Television advertising as well as campaigns reinforce the link between nuclear power and the electricity that makes modern life possible. This also helped to let the French people know that the country has many experts in the nuclear energy field which make the French population feel more secure (Palfreman, n.d.).

4.5.2 Inspiration and learning from France

Although nuclear energy production in France is a useful example for countries where nuclear energy is not that well developed yet, it is not easy to directly use the same method of implementation in other countries. A common assumption behind best practices such as nuclear energy production is that they are equally applicable and effective in another setting. However, the large number and diversity of European member states, where there are substantial differences in governance, administrative cultures, and professional capacities, make such an assumption questionable (Stead, 2012). Another reason that nuclear energy production is not per definition successful in every country, is because of the complexity of nuclear energy production. The more complex a policy or programme, the harder it will be to transfer (Dolowitz & Marsh, 1996). Nuclear energy policies can be seen as complex because of the discussion about whether or not it is sustainable, but also because of security and safety reasons, the presence of nuclear waste, and rules and regulation variations in different countries. Furthermore, planning as one component of the political and administrative system, has always been shaped primarily by the respective national context constituted by national law, the structure of public administration and political culture (Reimer & Blotevogel, 2012). That is also the case with nuclear energy planning, since it is highly dependent on national law, regulations, and energy policies. Also, differences in path dependency per country is important. Each governance path is marked by its own pattern of dependencies, which enable and constrain future transformation options and thus each governance system has unique capacities for learning and adaptation (Van Assche et al., 2020). In France for example, the present electricity generation mix is a result of the French government deciding in 1974, just after the first oil shock, to rapidly expand the country's nuclear energy capacity (WNA, 2022c). Because of these reasons, the perception of what is a successful policy or approach is always context specific. However, the Netherlands can always learn about nuclear energy of France, and therefore it might be very useful to look into their policies and implementation strategies.

Another aspect which should be understood is that governance networks differ between countries. Governance networks can be described as the public policymaking and implementation that occurs through a web of relationships that exists between government, businesses and civil society actors (Verweij et al., 2013). What might work, is that the Netherlands can study familiar problems in an unfamiliar setting, which can expand ideas and inspire fresh thinking about what is possible at home (Dolowitz & Marsh, 1996). Therefore, getting inspiration about nuclear energy possibilities and policies can be more successful for the Netherlands than directly copying because there are substantial social, economic, and institutional differences between EU member states (Stead, 2012). Besides this, there is a certain degree of distrust or scepticism in this best practice and thus there are concerns about issues of transferability of this best practice due to differences between countries in their social/legal systems, governance systems and governance networks (Stead, 2012).

Furthermore, the aspect of societal perception towards nuclear energy and the societal patterns behind it is important. These societal patterns can be related to various aspects such as public opinion but also to other difficulties related to nuclear energy. The societal patterns might result in increased complexity and thus less transferability. What the Netherlands can learn from France, is the way how people feel about nuclear energy and it might be useful for the Dutch authorities to invest in public support with the use of media or campaigns. One similarity between the French people and the Dutch people is that both like to be independent. So, this perspective could help Dutch society to embrace nuclear energy, because then the import of gas or other energy sources

from other countries is not needed anymore. The French have the expertise, knowledge, and experience to help the Netherlands, if the Netherlands needs that help.

4.6 Scenarios to meet the future electricity demand

The aim of this research is to investigate whether or not nuclear energy is a useful electricity source on the long-term in the Netherlands. After identifying various conditions which must be met before a new nuclear power plant can be implemented in the Netherlands, it can be concluded that these conditions can be met and therefore it is possible to implement a new nuclear power plant in the Netherlands. Nuclear energy has advantages compared to wind energy and solar energy, there is a possible location, there is public support for new nuclear power plants, and the role of the Dutch government with regard to financing is clear. Now it is possible to develop scenarios with regard to the future electricity demand in the Netherlands, and the use of non-greenhouse gas emitting energy sources. We have already seen that the energy transition from fossil fuels to renewable, sustainable, or non-greenhouse gas emitting sources is necessary. We have also seen that the future energy demand in the Netherlands is still unclear and uncertain. However, the estimation is that the Dutch electricity consumption will be almost 15% higher in 2050 than today. In 2020, the electricity consumption in the Netherlands was about 111 billion kWh (CBS, 2021b). If the electricity consumption will increase with 15% until 2050, the electricity consumption will increase to about 128 billion kWh. We have also seen that problems regarding intermittency can be solved with nuclear energy. In this sense, nuclear energy can contribute to affordable climate-neutral electricity and a stable electricity network (EPZ, 2020).

Because the Netherlands is densely populated, there is not much space left which can be used for electricity generation. Therefore, a new nuclear power plant can be suitable in the Dutch energy landscape since a nuclear power plant does not take up much space, compared to solar and wind energy. Figure 10 gives an overview of how much space it would take to implement new solar panels or wind turbines instead of two nuclear power plants. To get an insight in the future developments and scenarios regarding the Dutch electricity consumption and production, four scenarios are developed with the use of scenario planning, in which alternatives will be investigated to get an insight in suitable options for the future. In figure 11, the various scenarios and pathways are visualized. These scenarios serve as a tool to see what the possibilities are with nuclear energy in the future.

With three of the four scenarios, nuclear energy can be a useful electricity source in the Netherlands. That is because nuclear energy can be helpful to get rid of fossil fuels. Furthermore, nuclear energy is an efficient energy source with regard to the amount of space needed. With one nuclear power plant, relatively a small area is needed to generate a relatively large amount of electricity. To add, nuclear energy can help to get more independent with regard to electricity generation and consumption. Nuclear energy can replace the need for gas import from Russia, which will make the Netherland less reliable on other countries such as Russia. At this moment, two new nuclear power plants can be implemented, both in Borssele next to the already existing nuclear power plant. However, it might happen that the Dutch government decides that two new nuclear power plants are too expensive with regard to uncertainties and therefore it can happen that only one new nuclear power plant will be implemented. With one scenario, nuclear energy is not useful in the Netherlands. That is when a nuclear disaster happens, because that will result in a drop of the public support base towards nuclear energy. When this scenario happens, it will be impossible to use nuclear energy within the energy transition in the Netherlands.

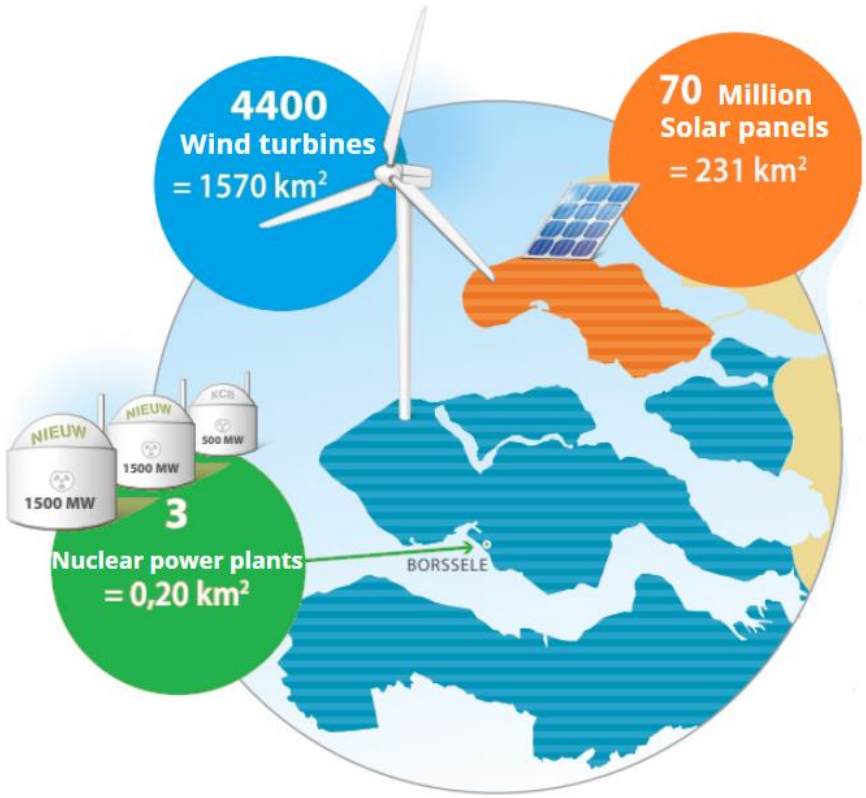

Figure 10: Visualization of the number of solar panels and wind turbines and the space needed to produce the same amount of electricity as three nuclear power plants in Borssele (EPZ, 2020).

Scenario 1:

- **It is agreed to get rid of a part of the fossil fuels, to have a more reliable energy source than solar and wind energy, and to use less space for electricity production. Therefore, two new nuclear power plants are needed.**

In 2021, the electricity production from fossil fuels was about 75 billion kWh. At this moment, there is only room in the Netherlands for two new nuclear power plants in Borssele. Other locations in the Netherlands such as the Maasvlakte I and the Eemshaven are not suitable options at this moment, as explained before. Two new nuclear power plants can both have a capacity of 1500 MW, which is three times the amount of the current nuclear power plant in Borssele. The current nuclear power plant of 500 MW has a capacity to produce about 4 billion kWh of electricity. This means that two new nuclear power plants with a capacity of 1500 MW can produce 24 billion kWh of electricity. This will result in a total capacity of 28 billion kWh of the three nuclear power plants together. Besides this, the Dutch government wants to produce about 35 billion kWh from solar- and wind energy in 2030 (Rijksoverheid, 2022b). This is already an important step within the Dutch energy transition. With developments in the amount of solar- and wind energy, it might very well be the case that in 2050 an even bigger amount of electricity is produced with solar- and wind energy. But to reach the expected total electricity consumption of 128 million kWh, a mix of electricity sources is needed and therefore the implementation of two new nuclear power plants is necessary. With a mix of solar energy, wind energy and nuclear energy in which the share of nuclear energy increases from 4 billion kWh to 28 billion kWh, it might be possible to get rid of the fossil fuels in the future. However, there are conditions which must be met. With regard to financing the new nuclear power plants, the Dutch government has an important role. Without guarantees for financial risks, investment protection, and guarantees for dismantling costs, there would not be a contractor willing to invest in new

nuclear power plants. If the Dutch government does not support the new nuclear power plants from a financial viewpoint as well as a non-financial viewpoint, it is impossible to build two new nuclear power plants, and that would make the Dutch energy transition even harder. Another condition is that the Dutch society, and especially the residents in the surroundings of Borssele, still support the implementation of two new nuclear power plants. If there is no support base, it will be very difficult to implement new nuclear power plants. The last condition is that the Dutch company which stores nuclear waste has enough capacity. However, when two new nuclear power plants will be implemented, this company can also expand, so this would not be a problem. Important to mention is that it is necessary to run the new nuclear power plants on full capacity, since otherwise it would not be attractive for the government as well as private parties to invest in nuclear power plants. Besides this, it is even necessary to run on full capacity since the Dutch society just need all the nuclear energy when fossil fuels are not used anymore.

Scenario 2:

- **The Dutch government wants to become more independent with regard to electricity consumption and production. Therefore, nuclear power plants are needed to rely less on other countries.**

The share of electricity produced from natural gas was about 55 billion kWh. The import of Russian natural gas is about 15% of the total amount of natural gas consumption in the Netherlands, which equals about 8,25 billion kWh. (VRT, 2022). With already the implementation of one new nuclear power plant with a capacity of 12 billion kWh of produced electricity, it is possible to get rid of the natural gas from Russia and thus the Netherlands can become more independent with regard to electricity production. There will be still some dependence on other countries when there will be two new nuclear power plants, because of the uranium that is needed. That cannot be mined in the Netherlands, and therefore the uranium has to be imported from other countries. However, when the Netherlands will be less dependent on other countries with regard to electricity production, there is less political pressure when conflicts happen such as the current invasion of Ukraine from the Russian army. This independence is also something of which can be learnt from France, because due to the nuclear energy use in France, they are very much independent with regard to their electricity supply. Conditions which are necessary for the implementation of one or two new nuclear power plants are the same with scenario 2 as with scenario 1, namely that the Dutch government is responsible for financial and non-financial guarantees. Furthermore, there has to be support from the Dutch society. However, with for example the Russian invasion in Ukraine at this moment, Dutch citizens want to cut the gas import from Russia to the Netherlands. So, if nuclear energy can be the solution to get more independent with regard to electricity production and consumption, the assumption is that people in the Netherlands would be in favour of this.

Scenario 3:

- **Two new nuclear power plants are too expensive with regard to the uncertain and unpredictable future. Therefore, it is agreed to implement one new nuclear power plant.**

The third scenario is that the Dutch government does not want to invest in two new nuclear power plants, but only one. This can happen, because a nuclear power plant is expensive and thus the government might decide to agree on only one new nuclear power plant. This will of course influence the amount of produced electricity from the nuclear power plants in the Netherlands. One new nuclear power plant can produce an amount of 12 billion kWh, which is still enough to get rid of Russian gas. However, this would mean that investments in other non-greenhouse gas emitting sources are necessary such as wind energy and solar energy. This will eventually put more pressure

on the Netherlands, since it is densely populated. One nuclear power plant takes less space than for example wind farms or solar fields, so when the government decides to invest in only one new nuclear power plant, it means that there should be enough space left to also invest in solar fields and wind farms. It might happen that there is just not enough space, and that can eventually lead to pressures on the Dutch energy transition. One of the conditions for the implementation of one new nuclear power plant is again that the Dutch government take responsibilities regarding financial and non-financial guarantees. Without these guarantees, no private investor wants to invest in a new nuclear power plant since it is too uncertain and too expensive. Another condition is that the public opinion and perception towards nuclear energy stays in favour of nuclear energy. Without a support base for nuclear energy, it will be very hard to implement a new nuclear power plant. Same as with scenario 1, is that the new nuclear power plant should run on full capacity to earn the costs back as quick as possible, and to ensure that there is full electricity production to ensure that not the maximum number of solar fields and wind farms are necessary.

Scenario 4:

- **A nuclear disaster happens, and therefore the support base of nuclear energy drops and new nuclear power plants cannot be built and the plans have to be terminated.**

Scenario 4 is a kind of a worst-case scenario. Although accidents with nuclear power plants rarely happen, there is always a small chance. When such an accident happens, it can be an enormous disaster with many people suffering and with negative consequences for plenty of years. It might be the case that such a disaster happens in the future, and this will affect the support base for new nuclear power plants. Often, the perception of people to nuclear energy will become negative after a disaster. This will eventually lead to opposition against building new nuclear power plants, and thus the support base of residents will disappear. When such a scenario becomes reality, it is important to invest in other energy sources such as wind farms and solar fields. However, as said before, there is not much space left in the Netherlands and therefore this scenario can have negative consequences on the Dutch energy transition. This scenario might also cost the Dutch government much money, because they have to take responsibilities with regard to financial and non-financial guarantees. When for example the implementation and building of a new nuclear power plant has already started, it might be the case that the proposed plan will be terminated and then much money is lost. Although the chance that this scenario happens is small, it has to be taken into account.

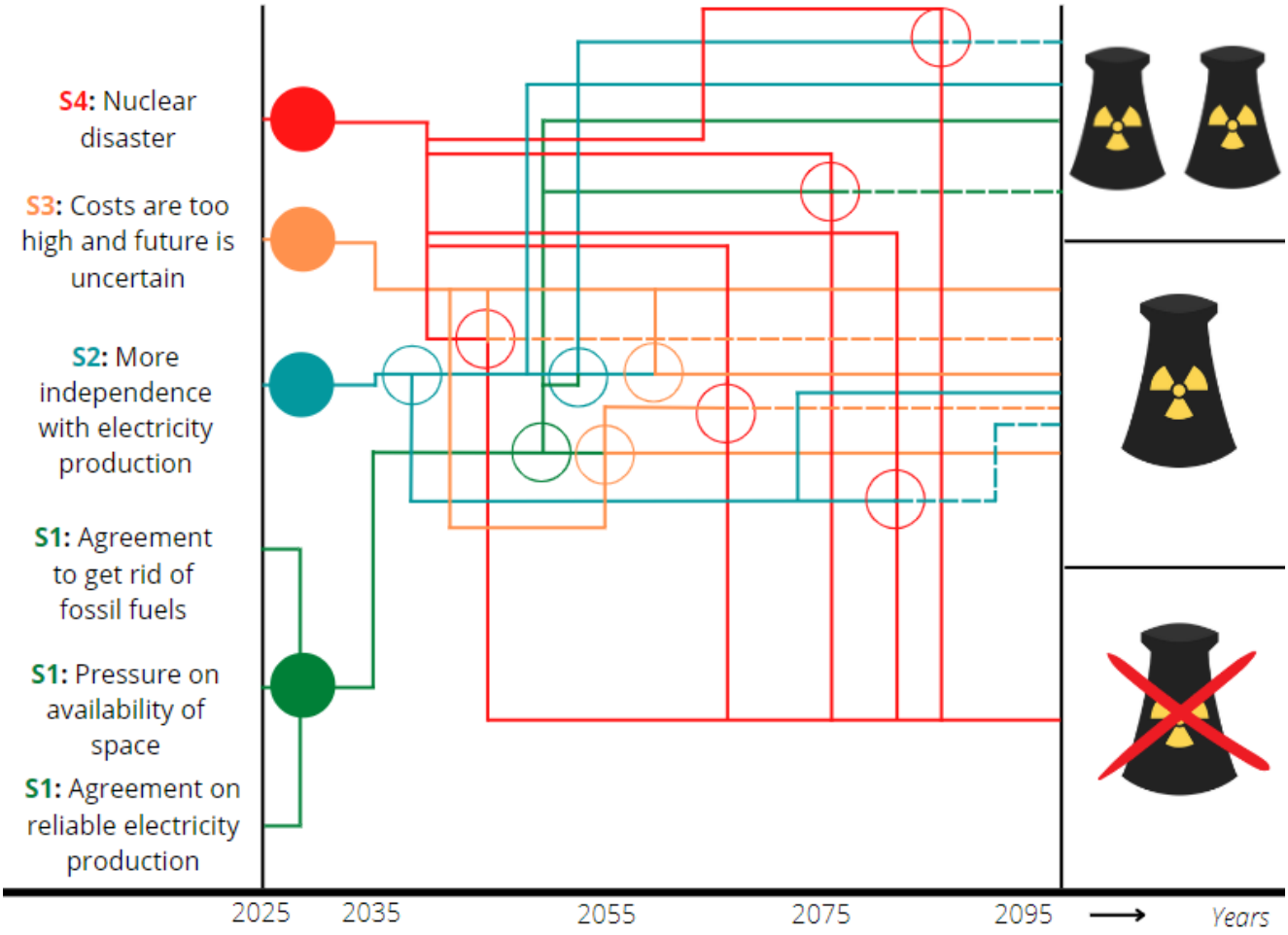

Figure 11: Various scenarios and pathways which can lead to 0, 1, or 2 nuclear power plant(s) (Author, 2022).

5. Conclusion & Discussion

5.1 Conclusion

Due to the increased urgency of dealing with climate change, nuclear power has found its way back on to policy roundtables and into the media. Also on national level, there is a need for an energy transition from fossil fuels to climate neutral energy sources. The focus in this research is on the Netherlands, where solar- and wind energy are already well-known electricity sources. However, only solar- and wind energy is not enough. Because of the need for an energy transition from fossil fuels towards non-greenhouse gas emitting energy sources, nuclear energy might be a useful energy source in the Netherlands. At this moment, there is only one nuclear power plant, which generates electricity, located in The Netherlands, in Borssele. This nuclear power plant provides about 4 percent of the electricity used in The Netherlands. However, before implementing a new nuclear power plant in the Netherlands, it must be made clear whether or not nuclear energy can be seen as a useful energy source within the energy transition. Besides this, there are various conditions which should be met before it is even possible to implement a new nuclear power plant in the Netherlands.

The aim of this explorative study is to investigate whether or not nuclear energy is a useful energy source on the long-term in the Netherlands, and to develop various scenarios to meet the electricity demand in the future of the Netherlands. The long-term in this sense is the energy transition from this moment on, towards the end of the 21th century. To add, the aim is to investigate which possible scenarios are available to meet the future electricity demand in the Netherlands with a combination of non-greenhouse gas emitting energy sources such as wind energy, solar energy, and nuclear energy when it is possible to meet all of the conditions which are needed to make nuclear energy useful in the Netherlands. Therefore, the main research question is:

"Under which conditions can nuclear energy on the long-term play a feasible role within the energy transition in the Netherlands to meet the future electricity demand in combination with reducing greenhouse gas emissions?"

First of all, it was needed to explain several important topics which serves as the basis for this research, to build a particular understanding about climate change, sustainability, energy transition, and the predicted electricity demand. Besides this, nuclear energy was explained as well as why this can be seen as a useful energy source within the current energy transition although it is not renewable. After this, four key conditions were identified which must be met before it is even possible to focus on new nuclear power plants in the Netherlands. When these conditions cannot be met, it is almost impossible to make use of nuclear energy in the Netherlands within the energy transition. The first condition is that it should be clear what the advantages and disadvantages of nuclear energy are compared to solar energy and wind energy and how the disadvantages of nuclear energy can be solved or at least how to deal with the disadvantages. The second condition is that there are possible locations in the Netherlands where new nuclear power plants can be implemented. The third condition is that there is a public support base from the Dutch society with regard to the implementation of new nuclear power plants. The fourth condition is that the Dutch government also supports production of electricity with nuclear energy and thus the implementation of new nuclear power plants. Next to the conditions, information was collected about nuclear energy in France. The reason for this is because France is one of the leading countries in the world with regard to nuclear energy. From the knowledge about nuclear energy in France, lessons can be learned to further develop nuclear energy use in the Netherlands.

Dealing with complexity and uncertainty is necessary within this research and this is done with the concepts '*Scenario Planning*', '*Transition Management*', and '*Dynamic Adaptive Policy Pathways Approach*', and this last concept is used to develop scenarios to meet the future electricity demand in the Netherlands.

This research is primarily based on academic literature, policy documents, and media content, so already existing literature and data. Various media sources have been analysed by reading the content of a particular media source, and then evaluating whether or not the content is useful, reliable, and valuable for this research. Furthermore, knowledge from various prominent institutes and organizations such as NASA and the World Nuclear Association is used within this research. Besides using academic literature, policy documents and media content, this research made also use of primary data. Primary data in this sense is the collection of survey results about the perception of Dutch society towards nuclear energy. This primary data is collected by I&O research, a prominent research organization in the Netherlands. They have done research about nuclear energy in the Netherlands and this data is representative for the Dutch society.

The results of this research show that nuclear energy can be a promising electricity source in the Netherlands. First of all, nuclear energy has some advantages compared to solar- and wind energy, for example that nuclear energy is much more reliable and does not have problems with intermittency. Furthermore, relatively much electricity can be produced with one nuclear power plant compared to solar- and wind energy. At this moment, there is one suitable location in the Netherlands where one or two new nuclear power plants can be implemented. This location is Borssele, next to the already existing nuclear power plant. The public opinion regarding nuclear energy is good and the owner of the existing nuclear power plant have options to build new nuclear power plants. Among the Dutch society, there is public support base for the implementation of new nuclear power plants. Half of the society is in favour of nuclear energy production. Another important finding is that almost half of the Dutch society think that the Dutch government need to invest in more nuclear energy. According to this, it is possible to say that the Dutch society is more in favour of nuclear energy than against nuclear energy. Regarding the role of the government, private market parties are interested to invest in new nuclear power plants. However, the Dutch government should provide guarantees for financial risks, investment protection, and financing structures with price guarantees. Furthermore, there must remain sufficient public support and the government should come up with a long-term solution for radioactive waste management. To add, the government should guarantee to cover dismantling costs in the event of early bankruptcy of the operator. Also, the government should guarantee to cover unforeseen cost increases of dismantling a nuclear power plant. If needed, the French have the expertise, knowledge, and experience to help the Netherlands with the implementation and use of nuclear energy. In France, nuclear energy is widely used and it can be regarded as a success.

The last part of this research is the development of four future scenarios with regard and climate neutral electricity production in the Netherlands with or without the use of nuclear energy. With three of the four scenarios, nuclear energy can be a useful electricity source in the Netherlands. That is because nuclear energy can be helpful to get rid of fossil fuels. Furthermore, nuclear energy is an efficient energy source with regard to the amount of space needed. To add, nuclear energy can help to get more independent with regard to electricity generation and consumption. At this moment, a maximum of two new nuclear power plants can be implemented in the Netherlands. However, it might happen that the Dutch government decides that two new nuclear power plants are too expensive with regard to uncertainties and therefore it can happen that only one new nuclear power plant will be implemented. With one scenario, nuclear energy is not useful in the Netherlands. That is

when a nuclear disaster happens, because that will result in a drop of the public support base towards nuclear energy. When this scenario happens, it will be impossible to use nuclear energy within the energy transition in the Netherlands.

So, the answer on the main research question is that nuclear energy on the long-term can play a feasible role in the energy transition in the Netherlands if nuclear energy has advantages compared to solar energy and wind energy, if there is a location in the Netherlands to implement a new nuclear power plant, if there is public support base, and if the role of the government is clear. Throughout this research, we have seen that all these conditions can be met and therefore it is possible and useful to implement at least one new nuclear power plant in the Netherlands. Now it is time for the government to act, so that the Netherlands will be less reliable on other countries and less reliable on fossil fuels. Nuclear energy can be valuable within the energy transition in the Netherlands, to meet the future electricity demand in combination with reducing greenhouse gas emissions in the future.

5.2 Discussion

Although this research shows convincing results that one or two new nuclear power plants can be implemented in the Netherlands, there are still some limitations. First of all, this research compared nuclear energy with solar energy and wind energy. Other sustainable, renewable, or non-greenhouse gas emitting energy sources are not taken into account within this research. To add, it can also happen that for example scientists or other developers create a whole new idea or solution to produce electricity in a sustainable or renewable way, with sources that are yet unknown or not well developed. When this happens, the use of nuclear energy might not be necessary anymore, however this is also unknown and uncertain at this moment.

Another limitation of this research is that it can happen that electricity will be used much more efficient in the future than it is currently used. It is even possible that the electricity demand will, for some reason, decrease over the years. With this in mind, it might not necessary to invest in nuclear power plants when there are also other non-greenhouse gas emitting sources available.

Furthermore, a limitation of this research is that the public perception and public opinion is a snapshot in time. When the survey was conducted, the results were that there is public support for new nuclear power plants and that in general, people are in favour of nuclear energy. However, it might happen that this will change over time. Also new developments with other sources of energy can result in a drop of the public support base.

At last, a limitation is that it is still not clear if two new nuclear power plants or one new nuclear power plant can operate at full power. It is preferable that new nuclear power plants can operate at full power because then the costs of implementation will be paid back the fastest, however it is not clear whether or not the electricity network can handle such a large amount of produced electricity next to electricity from solar panels and wind turbines. A recommendation for future research about nuclear energy in the Netherlands is to investigate how new nuclear power plants can operate in the most feasible way after implementation. Furthermore, a recommendation is to gain more in-depth knowledge about the willingness of the Dutch government to invest in nuclear energy, because without guarantees from the government, it would not be possible to implement new nuclear power plants. Shifting away from a liberalized market may also make it easier to implement new nuclear power plants, however this is also something which can be researched in the future because this is not taken into account within this research.

6. Reflection

The topic of this research was quickly chosen because I was, and still am, interested in the energy transition in the Netherlands and the role of nuclear energy. However, it was difficult to exactly know in the beginning of the research what I wanted to investigate. For me, it was useful to start right from the start with the extensive proposal. This helped me to get an insight in what I really wanted to investigate and it helped to define the main research question as well as the sub-questions. Although the proposal helped me to get started with this research, I struggled a bit with the first chapter. The reason for this was that I just delved into the literature and I collected soon much helpful information, but the problem was that it was just too much and therefore I lost the overview of which information and knowledge was needed in chapter 1 and what not. So, for the next time I think it will be helpful for me to write a few words per section about information or knowledge which needs to be included in those sections. This will help me to keep the overview, and then I can search for more specific information instead of just delving into all the literature and media content.

Besides this, I struggled with chapter 2 because I knew what I wanted to write in that chapter but in the end, it was quite a mess. The feedback helped me to improve the storyline in chapter 2, and that also improved the overall structure of chapter 1 and 2. Chapter 3 was also quite hard to write, because although I knew what I wanted to research, the methods were not clear for myself yet. However, after rewriting and improving, it became clear how I wanted to do this research. From this moment on, writing this thesis went well. However, the next time it would be useful to put more time in thinking about the structure of each chapter and it would be useful to think about the research methods more specifically in advance. After the first three chapters, I knew what conditions I wanted to research and this went well in chapter 4. I already had a structure in mind about the various conditions which needed to be researched. Also, the collection of data went well and I did not struggle with chapter 4. The only small struggle for me was that I expected more information about nuclear energy and the role of the Dutch government, but at the end I found useful sources. With the knowledge gained in chapter 4, I was able to develop scenarios for the future and this went also quite smooth. It took quite a lot of time to visualize these scenarios, but I think it clearly shows the scenarios in time with the inspiration from the Dynamic Adaptive Policy Pathways Approach.

In my opinion, the results of this research are convincing and useful. I think the identification of the four conditions which must be met before implementing a new nuclear power plant was useful. So, when deciding about new nuclear power plants in the Netherlands, it can be helpful to look at those four conditions and investigate whether or not these can be met. Also, the four scenarios are realistic and have an added value. In my opinion, it clearly shows what the scenarios are and how these can influence the implementation of two new nuclear power plants, one new nuclear power plant, or none at all. However, the future remains uncertain. So, this research can be helpful to get an insight what is needed to implement new nuclear power plants and which scenarios might happen, but this is not a blueprint of how it should happen in the future because not every event in the future can be predicted.

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