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Optimum location for a nuclear power plant in the Netherlands

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1 Abstract

The Dutch government is closing most of its fossil fuelled power plants, even though it does not have an efficient replacement for the base-load of power. This paper argues that nuclear power is the best alternative and tries to find the optimal location for a new plant in the Netherlands. To answer this question the multi criteria decision making method is used on three locations that are available for future nuclear power plant (NPP) development in the Netherlands. Out of the three locations: Borssele, Eemshaven and Maasvlakte, the latter two scored nearly the same (71.46% versus 71.53%). Borssele scored lower (54.85%), which is remarkable considering it scored very low in the safety requirements whilst currently accommodating the only NPP in the Netherlands.

2 Acknowledgements

I would like to thank my supervisor, Susan Vermeulen, for guiding me through the multiple stages of writing this paper.

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3 Introduction

Optimal location for a nuclear power plant in the Netherlands

The Dutch government has implemented a policy to reduce the amount of emitted CO_2 by 49% in 2030 compared to 1990 (Nederlandse Overheid, 2019). The ultimate aim is to have a CO_2 free electricity system in the Netherlands by 2050. In order to reach the goal, two main objectives have been established. Firstly, the existing fossil fuelled plants have to be closed. Secondly, the gap should be replaced with sustainable and CO_2-free sources. These sources include mostly wind and solar energy, which are already widely used in the Netherlands.

Three types of loads are required for an electrical system to operate: base, intermediate and peak. In addition, a fourth type variable must-run can be added. The base load is the type of electricity that is produced by a source that is constant, predictable and has low operating costs. The downside to this is that most of the time the process can not easily be turned on and off. This is the type of power that provides electricity for everyday use. In this category coal powered, nuclear, and to some extent, hydroelectric plants are most commonly used. The intermediate load is characterized by, similar to the base load, having a fairly constant and predictable supply of electricity. In contrast, the operating costs are high and there is a possibility to stop and start the process easily. Thirdly, the peak load is used in emergencies when immediate satisfaction of demand is required. The downside to this load is its high operating costs, although it can be stopped and started easily. Natural gas-powered plants are most commonly used for this load. The last type, must-run, is characterized by only working under certain conditions, although operating costs are very low the source is highly unpredictable. In this category wind and solar energy sources are classified. (Bosselman, 2007)

Attempts to make a so called “green” base load seems like a run back to pre-historic measures (Rozendaal, 2018). At the moment, the largest quantity of green energy in the Netherland is produced by burning wood together with coal in old coal powered power plants, this is also known as bio-mass energy. Wooden pallets are produced from trees that are cut down in the US. These are then shipped by sea to the Netherlands to burn it and produce electricity. The Impact of this attempt is: “(…) an increase in CO_2, worsening global warming over the critical period through 2100 even if the wood offsets coal (…)” (Sterman, Siegel, & Rooney-Varga, 2018, p. 8).

In short, the way this is going seems not sustainable on the long run. While the Netherlands has clear plans to close down all of its coal powered energy sources, a viable alternative to produce a CO_2 free base load is lacking. As mentioned by Bosselman (2007) the best alternative for this base load is nuclear energy.

Although a nuclear power plant (NPP) is the best alternative (Bosselman, 2007), the government and media do not often speak of it in a positive way. Most often, news about nuclear energy revolves around disasters or timely discoveries of faults in the system. Consequently, the public formed a perception of risk associated with nuclear power (Clark, Michelbrink, Allison, & Metz, 1997). This implies that the public will never consider nuclear power as a cost-effective alternative. Despite the fact that, building an extra NPP will make the transition to a CO_2-free electricity system cheaper than other alternatives like increasing windmill farms on sea (van Santen & van der Walle, 2018).

The main research question of this paper is: What is the optimal location to build a new nuclear power plant (NPP) in the Netherlands?

The start of the paper will consist of a literature overview where multiple electricity production sources are specified and compared. This overview is continued with the economic effects of nuclear power plants in respect to housing prices, income/employment and the public's perception of risk. Thirdly an overview of site-specific criteria required for a nuclear power plant are given. The fifth chapter consists of a case study to find which of the chosen sites is the most recommendable. The end of the paper consists of a conclusion, with relevant policy advice to the Dutch government.

The aim of this paper is to provide the Dutch government and municipalities in the Netherlands with a relevant policy for the siting of a new NPP. Existing literature will be analysed to find the positive and negative effects of an NPP on its surrounding area. In addition, site specific requirements will be analysed. These effects and requirements will be used in a case study for the Netherlands to come up with the optimal location. This location is restricted to three locations that are accepted by the Dutch government for future NPP development: the Maasvlakte, the Eemshaven and the town of Borssele. (Tweede kamer der staten-generaal, 2008-2009).

4 Literature review

This chapter will start with an overview of the suitable alternatives for nuclear power. This is done by comparing the prices of all sources of electricity production in the Netherlands. This is followed by a literature review of economic effects of a nuclear power plant in respect to housing prices, income and employment. The last piece of this chapter consists of a literature review of the risk that the public perceives towards nuclear activities.

4.1 Overview and comparison of electricity production alternatives

As already briefly explained in the introduction, an electricity network consists of 4 types of loads. The base load is the type of electricity produced with a relatively constant and predictable demand (Bosselman, 2007). In the Netherlands Gas and Coal powered plants are the most used for this type of load (50.7 and 24 Percent (Table 1: Gross Electricity Production in the Netherlands for 2018 .)). While the government is making plans to close coal and gas plants, a clear replacement for the base load is lacking. This absence is forming a gap which has to be closed, which if not done, could lead to an electricity deficit (Power Technology, 2019).

Source	**TWh[1] production**
Fossil – Natural Gas	57.5
Fossil – Coal	27.2
Fossil – Other	4
Renewable – Solar	3.2
Renewable – Wind	10.5
Renewable – Biomass	4.7
Renewable – Hydro	0.07
Nuclear	3.5
Other (Example: burning household waste)	2.8

Table 1: Gross Electricity Production in the Netherlands for 2018 (CBS, 2019).

4.1.1 Price comparison between all loads

To start with, the sources that are currently used in the Netherlands will be reviewed to find their cost per MWh[2]. The objective is to show that renewable sources are very expensive and that nuclear energy has the same price range as fossil fuelled plants. Firstly, a detailed overview of the costs will be given. Secondly, these costs will be compared to the cost of nuclear energy.

4.1.1.1 Build-up of the cost

The cost of producing electricity depends on four main cost centres: Investment cost, fuel cost, operations and maintenance cost, and waste management cost. The last cost centre can be divided into two parts: the cost for physically deposing waste and, for CO2 emitting plants, the cost of emitting CO2. The latter is a price set by the European Union on industrial activities (including the power generation sector) for emitting one metric tons of carbon dioxide. This price is expected to increase between 2019 and 2030 because many countries in the EU will either increase their industrial processes or increase carbon intensive energy production (European Environment Agency, 2019).

While many of the cost centres are variable cost, which means they change when the volume of the input changes, the investment costs are fixed. Costs per output for fixed costs can be calculated by dividing the total costs by the total output in the lifecycle of the investment. The calculated total

[1] TWh (*Terra-watt per hour*) = 10^{12} Watt per hour
[2] MWh (*Mega-watt per hour*) = 10^{6} Watt per hour

investment cost also depends on the discount rate[3]. A high discount rate increases the cost of capital. Thus, the cost per output for sources with a relatively high amount of investment costs will be volatile to the discount rate.

Fuel costs for fossil fuelled plants will most likely increase in the near future because of scarcity. World bank has forecasted the price of European natural gas to increase about 17% between 2019 and 2030 (The World Bank, 2019).

4.1.2 Overview of costs per source

This sub-chapter will review the current costs of creating electricity per source. The goal is to show that nuclear energy is one of the cheapest sources in the Netherlands.

Table 2 shows a summary of the cost per cost-centre in USD per MWh. Column one shows the main sources of electricity production in the Netherlands. The second and third column show the investment cost at two different discount rates. The fourth column consists of the Operations and Maintenance costs. This thus includes labour cost to run a plant as well as cost for maintaining proper function of the plant. The fifth column shows the estimated fuel cost and the two final to last columns show waste management cost divided in two sections. The first section shows the cost for processing physical waste. The second section shows the estimated cost for emitting CO2.

As shown, even at a low discount rate the investment costs for solar energy are remarkably high in relation to the output. To put it in perspective, residential solar electricity is almost 1000% more expensive than nuclear energy. In addition, it shows that economies of scale apply when scaling up solar power projects from residential to industrial. This reduces the investment costs by 24% and the O&M costs by 30%.

Fuel costs are the highest for biomass and gas-powered plants. Compared to the sources that use fuel, nuclear fuel is the cheapest. Even though nuclear waste is quite often perceived as a burden, the current costs are low.

[3] In case of 100% debt financed investment, the discount rate equals the debts interest rate. In case of a 100% equity investment the discount rate equals the minimal expected return the stockholders request.

Source	Investmen t cost with discount at 5%	Investment cost with discount at 10%	O&M cost	Fuel cost	Waste man. physical	Waste man.CO2 cost.	Total
Fossil – Natural Gas	8	18	1	61	0	10	80 - 90
Fossil – Coal	19	38	3	27	0	23	72 - 91
Renewable – Solar industrial	430	665	35	0	0	0	465 - 700
Renewable – Solar residential	565	875	50	0	0	0	615 - 925
Renewable – Wind Onshore	67	103	19	0	0	0	86 - 122
Renewable – Wind offshore	118	185	9	0	0	0	127 - 194
Renewable – Biomass	57	80	6	70	0	Exempted	133 - 156
Nuclear	39	81	15	6	1	0	61 - 103

Table 2: An overview of the levelized costs of electricity in the Netherlands (OECD, NEA & IEA, 2010, p. 77).

4.1.3 Nuclear power compared to other sources in the same price range

From table 2 it can be deducted that four sources fall into the same price range (61 – 122), namely natural gas, coal, onshore wind and nuclear power. Currently, nuclear energy is (with low discount rates) the cheapest source. Although, when using a higher discount rate, it shoots over gas and coal powered plants because nuclear power plants require more investment cost. Onshore wind sits on the top of the range being about 40 percent more expensive than nuclear electricity.

As previously stated, plans are made and executed to close natural gas and coal powered plants. The Dutch government has already accepted a law to prohibit the use of coal from 2025 in old-generation plants and from 2030 in new-generation plants (Eerste kamer der staten-generaal, 2018). Similar conclusions have been made by Powers (2010) who stated that because of the fact that coal-powered electricity production is the largest contributor of greenhouse gas emissions in the US it has become the main target for climate change legislation.

Therefore, the trade-off for future power lies between nuclear and on-shore wind when comparing prices.

4.1.4 Nuclear power compared to onshore wind.

Having established that the two main alternatives for the future are nuclear and on-shore wind power, the question rests which one is the best in filling the gap for the base load.

The characteristics of base-load energy is that it is constant and fairly predictable. This type of load is required for sources of demand that are relatively constant in its demand at any given time (Warkentin-Glenn, 2006). A common myth is that wind power will never be able to provide this load. The main argument is that when the wind does not blow there is no output of electricity. A solution to this problem is to build wind farms on multiple locations with different wind regimes. Diesendorf (2007) states that replacing a 1000 MW coal-fired power plant will require the capacity of about 2600 MW of wind mills. This implies that the actual price of onshore wind energy is about two and a half times larger than previously estimated when compared to nuclear or coal powered plants.

Another solution to use wind power as a base load is to use the output to power an air-compressor. This compressed air can then be used to generate electricity in times without adequate wind speeds. Without looking at the price of such a plant the price for this solution is also higher than previously estimated. Compressing air and using it to generate electricity reduces the efficiently drastically. For example, such a plant in Huntorf (Germany) had a round-trip efficiency of 42% in 1978 (International Renewable Energy Agency, 2017). This means that 58% of the energy was lost in the process of storing and using it. Similar figures are seen at the plant in McIntosh, Alabama (United States) which had a round-trip efficiency of 54% in 1991. The International renewable energy agency (2017) has stated that, in the best possible circumstances, the efficiency of a compressed air plant in 2030 to be around 70%. This implies the cost of wind power as a base load to be 30% higher excluding the cost of the plant itself.

4.2 Minimum site requirements

Evaluating the suitability of a site for nuclear power should be carried out by studying various aspects. In particular the safety of people and environment should be considered (Verma & Gundlapalli, 2008). In the following paragraphs the main aspects of safety and site requirements are explained.

4.2.1 Site requirements

A site that is feasible for nuclear power plant development should have certain basic characteristics. Most important is the proximity to high-quality cooling water. Without this, operating a nuclear power plant is extremely expensive or near impossible. Besides evaluating the availability of cooling water, the effect of the warmer output on the surrounding environment should be considered (IAEA, 2012). In addition, the availability of basic infrastructure is a preferable characteristic which otherwise would result in additional construction cost.

4.2.2 Safety

In respect to safety it is preferable that a site is not within 10 Km from a large city or industry that handles toxic chemicals and waste.

Another way to decrease the risk is to take natural induced events into consideration (IAEA, 2012). The most important to consider for the Netherlands are seismic hazard around the province of Groningen and risk of flooding. The disaster of the Fukushima Dai-ichi plant in 2011 triggered multiple programs all over the world to ensure plant safety in case of extreme situations like an earthquake (Katona, 2016). Stress-tests were aimed to ensure nuclear power plants could withstand enormous forces caused by earthquakes. Although seismic hazard seems like a large risk to nuclear power plants most countries do not have restrictions for the siting of a plant other than not placing it nearby the source (OECD, 2019).

4.3 Economic impact

The following sub-chapters will focus on the economic effects of an NPP on housing prices, income and employment. In particular the effect of proximity to an NPP will be investigated.

4.3.1 Effect on housing prices

As described by Clark, Michelbrink, Allison and Metz (1997) the impact of a facility that is associated with hazardous activities may be positive or negative. This depends on whether the benefits of being close to the power plant overwhelm the loss of utility associated with the perception of risk. In the research from Clark et all (1997), two nuclear power plants have been examined: The Diablo Canyon and the Rancho Seco power plant both in the state of California in the US. Both plants had a positive effect on the housing prices in an area 25 miles from the plant.

The area around the Diablo Canyon plant had an increasing housing price premium until 23 miles from the plant. Though, this positive effect on housing prices could be on the account of less urbanization around the plant. The proximity to the Rancho Seco plant, a more visible plant than the previous examined, also had a positive and increasing effect on housing prices. At the start of the chosen time span the prices began to increase from eleven miles onwards. In the five following years this point has moved away two miles. This could imply that aversion to the plant is decreasing.

An important conclusion from this research is that surveys regarding proximity to nuclear facilities usually show a high number of respondents that are unwilling to live near a nuclear power plant. Although, this negative image has not reduced property values.

A similar study has been carried out by Bezdek and Wendling (2006). Four power plants located in Texas, Louisiana, Kansas and Missouri (United States) have been examined to find the effect of the power plant on property values. Bezdek and Wendling start with a list of factors that affect property values in general, all on which the presence of a nuclear power plant has a positive effect. Quality of the real estate is most of the time a very important factor in determining its price. Due to higher than average paying jobs in the area around the power plant, the quality of the newly constructed houses is higher. This has a positive effect on the property's value. Secondly, the presence of the power plant in Kansas protected the property values in economic unstable times because of steady employment.

The main conclusions from this research are: housing prices were higher than before the opening of the nuclear facilities. Furthermore, the economic stability and steady employment caused by the plant prevented property prices from declining as much as in other areas. Although it has to be said that this effect might not be present at every location around the world.

4.3.2 Effect on income/employment

The effect of a nuclear power plant on the direct employment and thus income can be measured by examining expenditure on labour costs. A rough estimation of the employment and income is explained below and can be divided into three phases: construction, operation and deconstruction (OECD & IAEA, 2018).

In the construction phase about 70-75% of the labour is spent on field work and the rest on non-field work. The estimated direct number of jobs generated by building a nuclear reactor is about 12 jobs per year per MW. The first order indirect number of jobs is about 9 per year per MW. To put this into perspective the Nuclear Power Plant in Borssele, The Netherlands has a capacity of 485 MW (N.V. Elektriciteits-produktiemaatschappij Zuid-Nederland EPZ, n.d.). The construction of such a power plant would provide, according to the estimation of OECD & IAEA (2018), 5820 direct and 4365 indirect jobs for a duration of 7-10 construction years.

During the operation phase an average of 700 employees work at a 1-unit power plant with 960 and 1640 for two and three units respectively.

The decommissioning phase will take about 15 years estimated by EPZ. During this time about two thirds of the costs can be allocated to labour costs (OECD & IAEA, 2018). To put this into perspective the nuclear plant in Borssele will be examined again. EPZ, the company exploiting the plant in Borssele, has set up a fund with the goal of having 600 million euros by 2033 to pay for the destruction of the plant. (EPZ, 2017) A simple calculation gives the outcome of 40 million per year with about 27 million euro for labour costs. At an average yearly expenditure of 60.000[4] euro per employee, about 450 jobs will be provided for 15 years.

4.4 Social effect of the public's perception of risk

The public has an intense negative image about anything associated with the words "Nuclear" and "Radioactive" as described by Clark and Allison (1999). This negative imagery is expected to be accompanied by exaggerated adverse economic responses. This way of thinking is the effect of survey data that shows that people have unwillingness to live, visit or operate a business near nuclear related facilities (Clark, Michelbrink, Allison, & Metz, 1997). Based on the study on the previously mentioned Diablo Canyon and Rancho Seco plant this effect is non-existent. Though it is fair to say that the reason this perception of risk might not have been translated into adverse economic response has to do with better neighbourhood amenities. To put it another way, the negative social effects are smaller than the positive economic effects.

This means that policy makers might be negative about nuclear activities because of the negatively loaded survey data, even though it has been shown that this aversion has no economic effect. "Only when policy makers and planners are able to respond knowledgeably on the basis of both survey data and studies (…) will they be able to generate greater public dialogue, public acceptance and political approval." (Clark, Michelbrink, Allison, & Metz, 1997, p. 509).

This vision is also shared by OECD (2010) who state that a well-informed public is critical for any future developments of nuclear energy. This study used Eurobarometer polls on energy technology to compare a wide selection of European citizens. On questions regarding energy-related issues most people relate their concerns to energy prices and a steady supply of electricity. Only 8% of the respondents stated "nuclear energy". However, when asked if they were in favour or against nuclear energy about one third said to be clearly against it.

The barometer also looked if people perceive any value from nuclear power. 50% of the respondents agreed that it ensures lower and stable energy prices and 46% agreed that nuclear energy helps to limit global warming. Still about one third is against it. The reason for this has also been asked with 74% of the people answering that terrorism is the biggest risk followed by risk of disposal of radioactive waste, at last the misuse of radioactive materials is seen as a risk. All three of these responses are not related to the activities at a nuclear power plant but rather to "by-products" of nuclear energy.

In this pole it has also been studied which information about energy related issues are trusted the most. On this question the source scientists are the most trusted. Together with the fact that 87% of the people see the television as their main source of information this might be a great opportunity to inform the public about nuclear safety.

4.5 Conclusion of the literature review

The main conclusions from this chapter is that nuclear power currently is the most cost-effective alternative to replace the base-load gap formed by the closure of gas and coal powered plants. Secondly, it has been shown that American housing prices increase around nuclear facilities. This effect may be present because of higher than average paying jobs in the area around the plant (Bezdek & Wendling, 2006). In addition, a nuclear power plant will create direct jobs in all three of its

[4] In the building sector the wages lie between 13.63 and 17.22 euro per hour for normal employees (CAO Bouw & Infra 2018-2019, 2018). This means a yearly wage between 28 and 36 thousand euro. With employers paying about 30% extra on additional costs for employees (Informer, n.d.), the yearly costs lie between 40 and 50 thousand euro excluding extra costs like administration, insurances and pension costs.

stages. Lastly, it has been shown that the perception of risk the public has for nuclear activities can be overcome by informing the public right through the type of media that they mostly use as a source of information.

5 Case study

5.1 Methodology

5.1.1 Intro

As previously mentioned in the introduction, according to Dutch regulations the three locations that are open to future nuclear facility development are the Maasvlakte, Eemshaven and Borssele. Which of these three suits best, will be researched in this chapter. To start with, possible models to use in the case study will be identified and explained. This will be followed by the actual case study which has the goal to find the optimum location.

5.1.2 Economic Decision making

5.1.2.1 Cost-Benefit Analysis

To make a decision in general one must know the goal, criteria and alternatives. In financial decision making for example, one of the main goals is to choose the project with the most profit. This is done by filling in the criteria for every alternative and look for the alternative that fits the best to the goal. In this example that would be to find the alternative that has the highest expected profit.

5.1.2.2 Limitations to C-B analysis

The main problem with such a way of decision making is the inability to have multiple criteria points. If one alternative dominates on criteria A and another alternative dominates on criteria B it is hard to make a decision, because they both look good. This can be solved by considering a compromise between the solutions (Zavadskas & Turkis, 2011). This is what multi-criteria decision making (MCDM) does.

5.1.3 Multi-criteria decision making

5.1.3.1 How MCDM works in general

The main problem that MCDM tries to solve is: "evaluating a finite set of alternatives in order to find the best one, to rank them from the best to worst, to group them into predefined homogeneous classes, or to describe how well each alternative meets all the criteria simultaneously." (Zavadskas & Turkis, 2011, p. 405). All MCDM models try to solve this in a different way but have some of the strategy in common. MCDM models use weights to show the importance of the multiple criteria points. Secondly, by these weights the models try to choose the best alternative. Some models even introduce additional parameters that affect the solution. (Zavadskas & Turkis, 2011).

5.1.3.2 Analytical Hierarchy Process (AHP)

One of the MCDM models created is the Analytical Hierarchy process (AHP). AHP is a systematic and comprehensive approach to decision making (Saaty, 2013). In this method, the criteria and the sub-criteria are being compared pairwise to derive the weights each has in the hierarchy. This is followed by summing up the alternative with their corresponding criteria points after which this can be multiplied by the corresponding weight. Adding all the scores per alternative will give a final score from which the alternatives may be ranked. The best alternative will be the one with the highest score.

5.1.3.3 Process of pairwise comparisons

In step one of the pairwise comparisons used in the AHP, the criteria points will be compared in pairs. This is done by giving the relation a number from 1 to 9. With 1 being both as equal important and 9 being the first to be extremely favourable over the second criteria. The whole scale is represented in Table 3. After the comparison the weights can be computed by calculating the eigenvectors. (Saaty, 2013) The same process has to be repeated for the sub-criteria.

Number	Definition
1	Equal importance
2	Weak
3	Moderate
4	Moderate plus
5	Strong
6	Strong plus
7	Very strong
8	Very strong plus
9	Extreme

Table 3: scale for pairwise comparison

5.2 Methodology for the case study

In this study the AHP method will be used. The reason being that AHP is an applicable method because it takes tangible and intangible criteria into consideration (Aras, Erdogmus, & Koc, 2004). Thus, it is useful when including criteria that do not have an effect that can easily be measured by a number. A mathematical explanation of the process is given in appendix 3.

For intangible criteria points the alternatives will be ranked from best to worst. The best will get 100% of the score, the second 50% and the last 25%. Conditional criteria points will give a score of 100% for alternatives that meet the condition and 0% otherwise. In cases where it is difficult to rank two or all of the alternatives a shared rank is possible.

Image 1 shows the hierarchy as described in 5.1.3.2. Four main criteria points have been chosen from the main themes mentioned in chapter 4.2-4.4. The “geographical characteristics” sub-criteria are a translation from the main points discussed in 4.2.1. The sub-criteria of “economic impact” is a translation from chapter 4.3. The “social impact” with its sub-criteria public perception of risk is a translation from chapter 4.4, and at last the sub-criteria “safety” is a translation from 4.2.2.

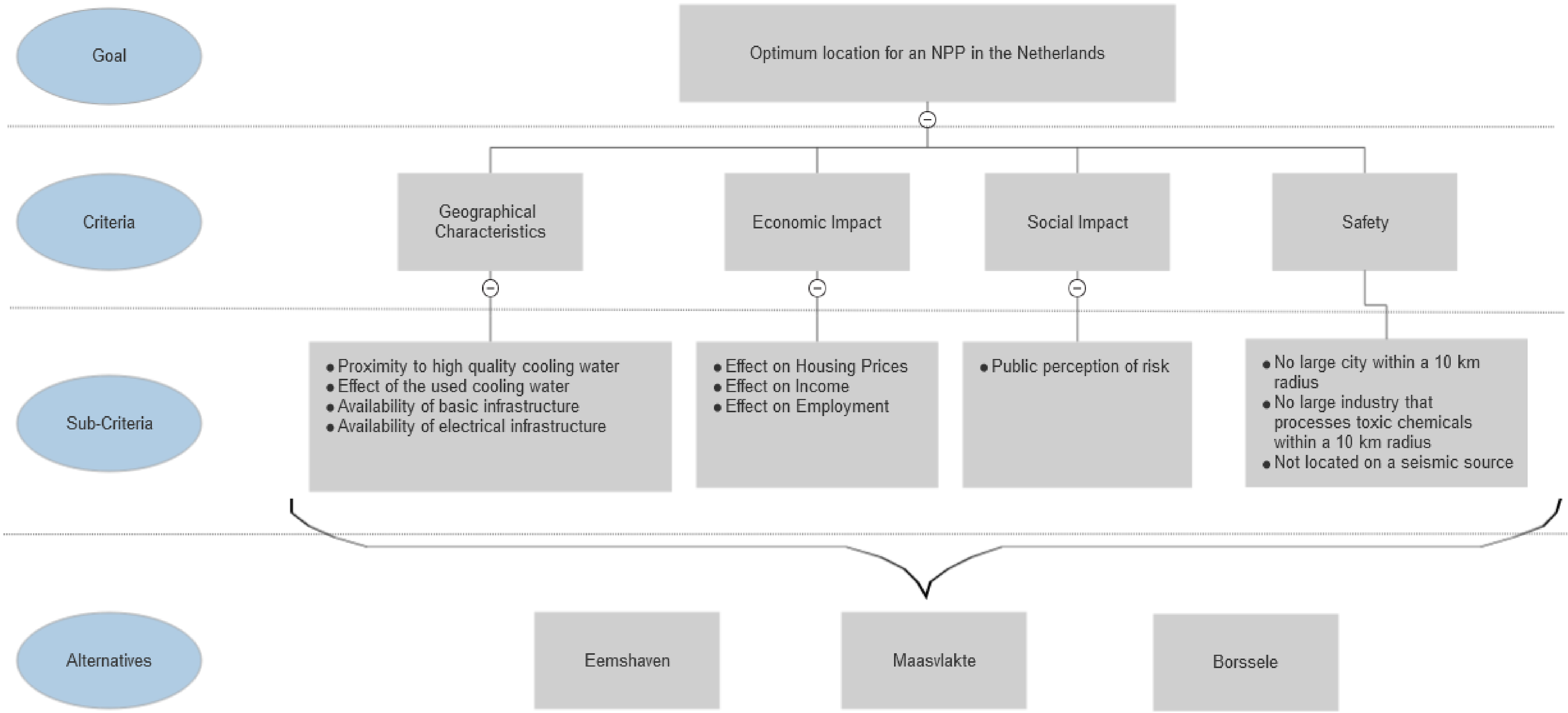

Image 1: Hierarchy

5.3 Pairwise Comparison

5.3.1 Comparison of the Criteria

The first step in the AHP process is to compare the criteria pairwise.

An important starting point in the decision making is consulting reports about the effect on public health and environment after the construction and commissioning of an NPP (Ministerie van Economische zaken, 1986). This means that above all the safety should be prioritized. In the pairwise comparison, safety will be very strongly preferred over the other criteria.

In a similar study in Lithuania, the economic feasibility was given the highest weight (39%) (Streimikiene, Sliogeriene, & Turskis, 2015). In this study the geographical characteristics are closely associated with the economic feasibility. The conclusion for the scores is that geographical characteristics are strongly preferred over the economic and social impact.

Between the economic and social impact there is a lack of information in respect to priorities. Both will receive equal importance.

The mathematical translation of the above outcomes is shown in table 2.1 (appendix 2) and the computed weights are shown in table 4.

Criteria	Weight
Geographical	0.23
Economic Impact	0.07
Social Impact	0.07
Safety	0.63

Table 4: Computed criteria weights of the main criteria.

5.3.2 Comparing Geographical sub-criteria

As mentioned in chapter 4.2.1., proximity to high-quality cooling water is the most important geographical characteristic. Besides the availability, the effect of the used cooling water should also be considered. As the proximity is the most important it will be very strongly preferred over the availability of basic infrastructure as well as availability of electrical infrastructure and moderately preferred over the effect of the used cooling water.

At a location without basic infrastructure nor electrical infrastructure both should be constructed. At the same time, it is likely that the availability of an electrical infrastructure is not possible without basic infrastructure. As such, basic infrastructure is moderately preferred over electrical infrastructure.

To give the proposal of an NPP more chance of success in passing within the government the environmental effect of the used cooling water should be considered moderately over the availability of infrastructure.

The mathematical translation of the above outcomes is shown in Table 2.2 (appendix 2) and the computed weights are shown in Table 5.

Criteria	Weight
Cooling water availability	0.59
Effect of used water	0.22
Basic infrastructure	0.12
Electrical infrastructure	0.07

Table 5: Computed criteria weights for the sub-criteria of the geographical characteristics.

5.3.3 Comparing Economic Impact sub-criteria

Bezdek and Wendling (2006) concluded that property values remained stable in unstable times due to steady employment. Secondly, they concluded that the quality of newly constructed houses in the area around an NPP is higher than average due to higher than average paying jobs.

Because of these conclusions it is reasonable to state that both the effect of income as well as the effect on employment are strongly preferred over the effect on housing prices.

At last, the effect of income and employment should be compared. Both are very related to each other. Chapter 4.3.2 described the number of employees required during all 3 phases of an NPPs lifecycle. The effect of income is less observable. The effect of employment will be weakly preferred over the effect of income.

The mathematical translation of the above outcomes is shown in table 2.3 (appendix 2) and the computed weights are shown in table 6.

Criteria	Weight
Housing prices	0.08
Income	0.36
Employment	0.56

Table 6: Computed criteria weights for the sub-criteria of the economic impacts.

5.3.4 Comparing Social sub-criteria

The criteria group social only has only one sub-criteria which is the public perception of risk. As this is the only one it will be given weight 1.

5.3.5 Comparing Safety sub-criteria

The most important safety rule for the location of an NPP is that it is not located within a 10 Km radius of a large city or industry that processes toxic chemicals. Because of this rule the two sub-criteria “no large city within 10 Km radius” and “no large industry that processes toxic chemicals within a 10 Km radius” will be considered as equal importance.

As shown in chapter 4.2.2. the only restriction for citing an NPP is not to place it directly above the source. This implies that it is not discouraged to place an NPP in an area that has a higher probability of a seismic activity. All three sub-criteria will be considered to be as equal importance.

The mathematical translation of the above outcomes is shown in table 2.4 (appendix 2) and the computed weights are shown in table 7.

Criteria	Weights
Large city within 10 Km	0.33
Industry of toxic waste or chemicals within 10 Km	0.33
Near Seismic source	0.33

Table 7: Computed criteria weight for the sub-criteria of the safety requirements.

5.3.6 Conclusion of the pairwise comparison

All of the criteria have been weighted according to the method described in Chapter 5.2. The final weight, which is the weight of the main-criteria multiplied by the sub-criteria, is shown in table 8.

Sub-criteria	Main-criteria weight	Sub-criteria weight	Calculated weight
Cooling water availability	0.23	0.59	0.136
Effect of used water	0.23	0.22	0.051
Basic infrastructure	0.23	0.12	0.028
Electrical infrastructure	0.23	0.07	0.016
Housing prices	0.07	0.08	0.006
Income	0.07	0.36	0.025
Employment	0.07	0.56	0.039
Public perception of risk	0.07	1	0.07
Large city within 10 Km	0.63	0.33	0.208
Industry of toxic waste or chemicals within 10 Km	0.63	0.33	0.208
Near Seismic source	0.63	0.33	0.208

Table 8: calculated weight of the sub-criteria.

5.4 Description of the alternatives

5.4.1 Geographical Characteristics

5.4.1.1 Proximity to high quality cooling water

The Availability of adequate supply of cooling water is an important consideration (IAEA, 2012, p. 24). The required quality of the cooling water depends on the cooling system, the power of the plant and the temperature of the cooling water.

This research does not distinguish between different types of NPPs. This means the first two characteristics that translate into the required quality of the cooling water will not be taken into consideration. Descriptive statistics on the temperature of the water near the three locations is shown in table 9 (Rijkswaterstaat, 2018).

The water near the Eemshaven looks the best because it has the lowest average as well as the lowest minimum. This is followed by the water near Borssele which has the second lowest average and minimum. At last we find the water near the Maasvlakte with the highest average and minimum.

The difference in temperature is not very large, so it is hard to give one a better score than the other. In addition, information about the optimal temperature is lacking, nor has the effect of a 1% increase been investigated. The result is a full score for all the alternatives.

Location	Average Degrees	Min	Max
Eemshaven	12.45	2.36	22.12
Maasvlakte	13.22	4.67	21.09
Borssele	12.73	3.68	21.53

Table 9: Average degrees (Celsius) of water near the location for 2018.

5.4.1.2 Effect of the used cooling water

The effect of used cooling water, which is a few degrees warmer than before, is both positive and negative. The higher temperatures may enhance faster hatching of eggs and will also enhance algal blooms. In addition, it might cause species to leave the area. (IAEA, 2012). A clear study on the effects in Dutch waters is lacking which is why all three locations will be given the same score.

5.4.1.3 Availability of basic infrastructure

All three locations are located in or near a port. Ports usually have good accessibility for large road going vehicles like trucks. All of the locations must leave the possibility for an NPP open by law.

The location in Borssele is already being prepared for an NPP. These preparations are aimed to withhold the location from becoming unusable for building in the future. This includes a ban on buildings that could block the construction of an NPP (Ministerie van Economische Zaken, Landbouw en Innovatie & Ministerie van Infrastructuur en Milieu, 2011)

The government of the province of Groningen has to keep a location open for an NPP. At the moment they do not see enough support in their government for an NPP in the Eemshaven (Gemeente Eemsmond, 2013).

Similar to the Eemshaven the Maasvlakte has to keep a location open for a future NPP. Clear plans are not available.

Borssele will receive the highest score of 100% because there are clear plans for multiple locations available. The other two alternatives will receive 50% of the score because it is difficult to clearly rank one above of the other. Both have a good accessibility but are lacking a location policy.

5.4.1.4 Availability of Electrical infrastructure

As shown on the image 7 in Appendix 1 all three locations are connected to the 380-kV power grid. This means there is enough capacity to connect a power plant. All locations are surrounded by power plants which means also the local electrical infrastructure is in place. As such the three alternatives will be given the same score.

5.4.1.5 Conclusion of the geographical characteristics

Criteria	**Full score**	**Maasvlakte**	**Borssele**	**Eemshaven**
Proximity to cooling water	0.136	0.136	0.136	0.136
Effect of used cooling water	0.051	0.051	0.051	0.051
Availability of basic infrastructure	0.028	0.014	0.028	0.014
Availability of electrical infrastructure	0.016	0.016	0.016	0.016
Total	0.231	0.217	0.231	0.217

Table 10: Calculated score for the alternatives in the criteria group geographical characteristics.

As seen in table 10, Borssele received the full score and the other two alternatives follow very close. There is a difference only because Borssele has clear plans on where to place its second NPP.

5.4.2 Economic impact

5.4.2.1 Effect on Housing prices

As seen in chapter 4.3.1 there is an indication of a positive effect on housing prices around multiple NPPs in the US. Assuming that the absolute effect on housing prices is larger in an area with more houses, this is what will give the largest score.

In table 11, the number of houses in a radius of 10 km from the proposed plant is shown (Centraal Bureau voor de Statistiek, 2018). The greatest number of houses are in the area around Borssele which is very close to the two large cities of Vlissingen and Middelburg. Both the Maasvlakte and Eemshaven have large cities in its area namely Den Haag and Rotterdam for the Maasvlakte and Groningen for Eemshaven, though they are further away.

The highest score is given to Borssele followed by Maasvlakte and at last Eemshaven.

Location	Number of Houses within 10 KM radius
Maasvlakte	11306
Borssele	27739
Eemshaven	2910

Table 11: Number of houses within 10 km of the given location.

5.4.2.2 Effect on Income

The effect of income around the area of the NPP is discussed in chapter 4.3.2.

(Bezdek & Wendling, 2006) already saw higher than average paying jobs around plants in the US. In absolute numbers the construction of an NPP would result in the same increase for all three locations. As such the scores will be the same.

5.4.2.3 Effect on Employment

The presence of the power plant in Kansas protected property values in unstable economic times due to steady employment (Bezdek & Wendling, 2006). This effect will be larger in an area with less inhabitants because the percentage of people with a job at the power plant will be larger.

Table 12 shows the number of inhabitants within a 10 km radius of the proposed location. The area around the Eemshaven has the lowest number of inhabitants so the effect on employment in this area will be the largest followed by the area around the Maasvlakte.

Eemshaven scores 100%, followed by 50% for Maasvlakte and at last 25% for Borssele.

Location	Number of inhabitants within 10 KM radius
Maasvlakte	23180
Borssele	60359
Eemshaven	6780

Table 12: number of inhabitants within 10 km of the given location.

5.4.2.4 Conclusion of the Economic impact

Criteria	**Full score**	**Maasvlakte**	**Borssele**	**Eemshaven**
Effect on housing prices	0.006	0.003	0.006	0.001
Effect on income	0.025	0.025	0.025	0.025
Effect on employment	0.039	0.020	0.010	0.039
Total	0.07	0.048	0.041	0.065

Table 13: Calculated score for the alternatives in the criteria group geographical characteristics.

As seen in table 13, the Eemshaven has the highest score of the three alternatives. The other two follow each other very closely. The main reason Eemshaven received such a high score is because of the high expected effect on employment in the area.

5.4.3 Social impact

5.4.3.1 Public Perception of risk

The nuclear disasters of Chernobyl (1986) and Fukushima (2011) are still fresh in the mind. In Addition, the people in the province of Groningen think a lot about the recent earthquakes in the area. Both thoughts together do not make the people in the province of Groningen very eager to have an NPP in their area. Even though the disaster in Fukushima triggered programs to ensure plant safety in case of an earthquake the public still perceives a lot of risk.

The people living around Borssele will have the lowest perception of additional risk for the second plant. They are already used to an NPP in their neighbourhood. A similar reasoning can be used for the people living near the Maasvlakte. This area is full of chemical factories that have large storage of dangerous chemicals. The effect of the perception of risk for people living near the Maasvlakte is expected to be in the middle of the other two alternatives.

The highest score will be given to the location with the lowest perception of risk.

5.4.3.2 Conclusion of Social impact

Criteria	**Full score**	**Maasvlakte**	**Borssele**	**Eemshaven**
Public perception of risk	0.07	0.035	0.070	0.018

Table 14: Calculated score for the alternatives in the criteria group social impact.

In this category Borssele scored the best because the people in this area are used to living close to an NPP. (Table 14)

5.4.4 Safety

5.4.4.1 No large city within a 10 Km radius

Below are 3 images (image 2,3 & 4) of the area withing a 10 km radius of the alternatives. Neither the area around the Maasvlakte and the Eemshaven have large cities within the radius. The already existing plant in Borssele has part of the city of Vlissingen and Middelburg within its 10 km radius. As the location for the second plant is right next to the existing one this applies for the new plant as well.

The conclusion is negative for Borssele and positive for Maasvlakte and Eemshaven.

Image2*, 3 & 4: circle of a 10km radius around the three alternative locations. (Eemshaven, Maasvlakte, Borssele)*

5.4.4.2 No large industry that processes toxic chemicals within a 10 Km radius

The area's will be tested on three categories of toxic chemicals: ammonia, explosive substances and storage locations of large dangerous substances. The number of hits per category within 10 km is shown in table 15 below.

The Maasvlakte is part of the port of Rotterdam. In the Europoort area, which is within 10 km of the Maasvlakte, there are multiple storage locations for dangerous substances. Most of them are oil refinery companies. Secondly, Next to the proposed location for the NPP in Borssele is the largest oil refinery of the port of Vlissingen. Next to this there are a few smaller chemical companies in the area. At last, the port of Eemshaven is not as dense as the other two ports in relation to companies that handle toxic chemicals. As this is a conditional criterion, and none of the alternatives pass the condition, all will be given a score of zero.

Location	**Ammonia**	**Explosive substances**	**Large storage locations of dangerous substances**
Maasvlakte	8	0	32
Borssele	3	0	9
Eemshaven	2	0	2

Table 15: number of locations that deal with any of the three chosen categories of toxic chemicals (Ministerie van Justitie en Veiligheid & Ministerie van Infrastructuur en Waterstaat, 2019)

5.4.4.3 Not located on a seismic source

Image 5 below shows an overview of the seismic activity in the area around the Eemshaven. The Eemshaven, which is shown on the top right in the lightest yellow colour, is not located on a seismic source nor is it located near it. The other two locations are located in an area where earthquakes are of such rarity it can be called irrelevant.

All three locations will be given the full score as neither of them are located on a seismic source.

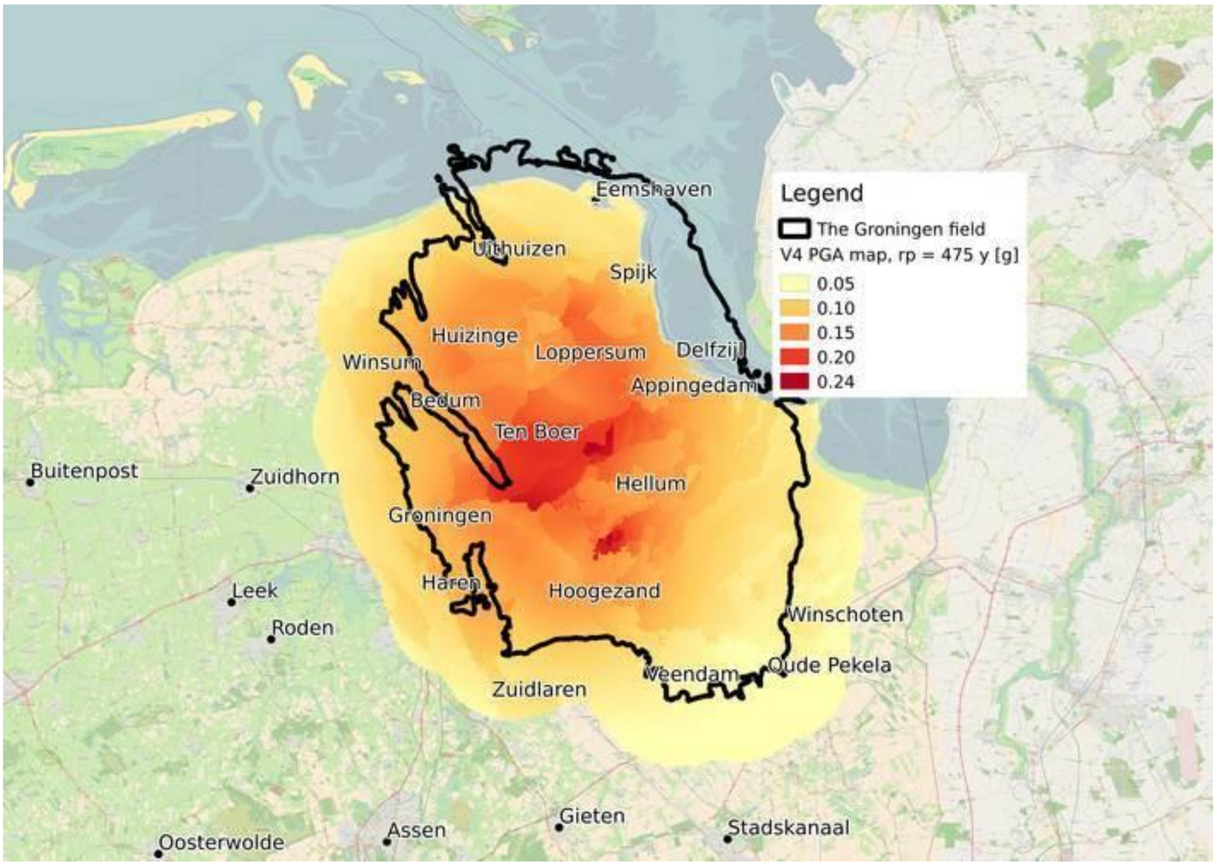

Image 5: Seismic hazard map of the province of Groningen (Nationaal Coördinator Groningen, 2017).

5.4.4.4 Conclusion of the Safety criteria

Criteria	Full score	Maasvlakte	Borssele	Eemshaven
No large city within 10 km radius	0.208	0.208	0	0.208
No large industry that processes toxic chemicals within 10 km radius	0.208	0	0	0
Not located on a seismic source	0.208	0.208	0.208	0.208
Total	0.624	0.416	0.208	0.416

Table 16: Calculated score for the alternatives in the criteria group safety

Shared first place is for the Maasvlakte and Eemshaven. The score for Borssele is unexpected considering it already has an NPP very close to the proposed location. (Table 16)

5.5 Case study results

Criteria	Full score	Maasvlakte	Borssele	Eemshaven
Geographical Characteristics	0.231	0.217	0.231	0.217
Economic Impact	0.073	0.048	0.041	0.065
Social Impact	0.073	0.035	0.070	0.018
Safety	0.624	0.416	0.208	0.416
Total	1	0.7146	0.5485	0.7153

Table 17: Score card of the scores given in chapter 5.4

According to the total scores (table 17) the Eemshaven scores just slightly above Maasvlakte. Borssele has lost mainly because of its low scores in the safety category which is a surprise considering there is already an NPP in commission.

6 Discussion and Conclusion

The beginning of this research showed that nuclear energy is the only economically viable alternative to coal or gas powered powerplants in providing a base-load that does not directly emit CO2 at production. This is a source that produces electricity in a constant and predictable amount with low operating costs. The main contestant to nuclear power, on-shore wind power, at first looked like a good alternative as well. Both have a price per unit of electricity in the same price range. Later insights showed that the actual cost per unit of electricity is way higher than previously calculated when used to replace a base-load provider, like a coal powered power plant (Diesendorf, 2007). The main reason is that wind-energy on its own is not a base load as it cannot provide constant and predictable amounts of electricity, due to the unpredictability of wind speeds and sometimes even absence of operable wind itself.

To continue, there are a few economic effects that make an NPP even more economically viable. Chapter 4.3.1 and 4.3.2 has shown that there is evidence that an NPP could increase the housing prices in the neighbourhood of an NPP as well as protect housing prices in economically unstable times (Bezdek & Wendling, 2006). The latter effect is mainly due to the higher than average paying jobs for people working in the NPP.

In contrast, negative effects of nuclear energy are also present. One of which is the public's perception of risk towards it (Organisation for economic co-operation and development, 2010). It has been shown that European people state to be unwilling to live close to an NPP, although, the economic effect of it is not clearly shown. As described above, there is evidence that housing prices as well as income are higher in the neighbourhood of an NPP.

6.1 Results of Case study

The research question of this research is: "What is the optimal location to build a new NPP in the Netherlands?" According to the case study in Chapter 5, the optimal location is the Eemshaven (71.53% of the score, table 22). This result is closely followed by the Maasvlakte (71.46% of the score, table 22). The main surprise in the research is a low score in the safety category for the location in Borssele. The proposed location already has an operating NPP, although it seems that this location does not meet safety requirements. The main rule in safety for an NPP is that it should not be located within a 10 km radius of a large city nor industrial clusters that produce toxic chemicals. The location in Borssele does not meet either part of the rule. In addition, neither of the three locations meet the latter part of the rule.

Alternative	Maasvlakte	Borssele	Eemshaven
Score	0.7146	0.5485	0.7153

Table 22: Final scores of the alternatives

6.2 Limitations

Most of the literature regarding the effect of an NPP on housing prices is focussed on the United States. As such, it is hard to give a real representation of the effect in the Netherlands as it is not clear what the effect in the Netherlands will be. This could have a large effect on the quality of the results.

Secondly, this research was restricted to three locations that are chosen by the Dutch government for NPP development. Although this makes the research more feasible, it is possible that other locations could have been better.

To continue, there are also limitations in the used method that could have an effect on the results.

At first, the way the weights are computed can have a large effect on the outcome. This can be divided into two parts. Firstly, the method itself could have an effect and secondly, the outcome of the comparison could have an effect. In particular, the comparison of the main criteria could have altered the results. In this research the safety was chosen to be the most important factor, which computed 63% of the outcome (table 4).

Secondly, most of the sub-criteria are non-binary and ranking of the alternatives was difficult. Because of these limitations the choice was made to give scores according to the corresponding rank of the alternative. This limitation has undoubtably had a large influence on the results.

6.3 Recommendations for future work

Studies on the effects of an NPP in the Netherlands were absent. To strengthen the research on the feasibility of a Dutch NPP, research on all effects within the Netherlands is recommendable. In particular area specific effects could be considered.

Secondly, the optimal location could be researched without considering the limitations given by the Dutch government. In case the locations are different, the research can be used to convince the Dutch government to take the proposed locations into consideration.

At last, a different method as alternative to the AHP may be used to find if it provides a different conclusion.

6.4 Policy recommendations

The vision for the European Union is to have 80% of the electricity produced by renewable sources by 2050 (European Commision, 2018). Already this would result in a large increase in the price for electricity as shown in chapter 4.1. This paper has shown that nuclear power currently is the cheapest source of base-load electricity production.

For this reason, it is recommendable to take nuclear power into consideration as a viable alternative for future electricity production. In addition, multiple positive economic effects of proximity to a nuclear power plant has been shown. If nuclear energy is not taken into consideration there might be an electricity shortage in the future.

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8 Appendix

8.1 Appendix 1

Image 7: Power grid of the Netherlands (Tennet, 2018).

8.2 Appendix 2

Category	Geographical	Economic Impact	Social Impact	Safety
Geographical characteristic	1	5	5	1/7
Economic Impact	1/5	1	1	1/7
Social Impact	1/5	1	1	1/7
Safety	7	7	7	1

Table 2.1: Mathematical translation of the pairwise comparison between the criteria.

Category	Cooling water availability	Effect of used water	Basic infrastructure	Electrical infrastructure
Cooling water availability	1	3	7	7
Effect of used water	1/3	1	3	3
Basic infrastructure	1/7	1/3	1	3
Electrical infrastructure	1/7	1/3	1/3	1

Table 2.2: Mathematical translation of the pairwise comparison between the sub-criteria of the geographical characteristics.

Category	Housing prices	Income	Employment
Housing prices	1	1/6	1/6
Income	6	1	1/2
Employment	6	2	1

Table 2.3: Mathematical translation of the pairwise comparison between the sub-criteria of the economic impacts.

Category	Large city within 10 Km	Industry of toxic waste or chemicals within 10 Km	Near Seismic source
Large city within 10 Km	1	1	1
Industry of toxic waste or chemicals within 10 Km	1	1	1
Near Seismic source	1	1	1

Table 2.4: Mathematical translation of the pairwise comparison between the sub-criteria of the safety requirements.

8.3 Appendix 3

This appendix will describe the mathematical process followed to calculate weights from a pairwise comparison. The table below shows an example of a pairwise comparison. (Table 18)

Criteria	Criteria 1	Criteria 2	Criteria 3
Criteria 1	1	5	6
Criteria 2	1/5	1	9
Criteria 3	1/6	1/9	1

Table 18: Example of a pairwise comparison.

To start, all scores per column will be added. The total of each column is shown in table 19. To continue each score is divided by the total of the corresponding column. The outcomes are shown in Table 20.

Criteria	Column 1	Column 2	Column 3
Total	1.367	6.11	16

Table 19: total per column

Criteria	Criteria 1	Criteria 2	Criteria 3
Criteria 1	0.732	0.818	0.375
Criteria 2	0.146	0.164	0.563
Criteria 3	0.122	0.018	0.063

Table 20: Scores divided by the column's total

The last thing to do is to take the average of each row, which is the rows corresponding criteria's weight. The results of this are shown in table 21.

Criteria	Weight
Criteria 1	0.64
Criteria 2	0.29
Criteria 3	0.07

Table 21: Calculated weights