MASTER ENVIRONMENTAL AND ENERGY MANAGEMENT

EXPLORING PUBLIC ACCEPTANCE OF NUCLEAR ENERGY AND MODELLING POLICY INSTRUMENT IMPACT: A CASE STUDY IN GELDERLAND

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Abstract

The objective of this study is to illustrate how the functioning of certain policy instruments are impacted, by the current public acceptance of nuclear energy. The case study focuses on the Province of Gelderland to achieve this understanding. This was accomplished by a combination of desk research, expert interviews, a public survey, and computer simulation of policy scenarios. Literature on the public acceptance theory highlighted various approaches that were merged into a single approach, including, personal demographical factors, contextual factors, and socio-psychological factors (Bronfman et al., 2012; Devine-Wright, 2014). Additionally, desk research showed that public acceptance should be identified and analysed in the first step of the policy process. This involves finding factors that influence public acceptance, analysing data, consult experts, engage stakeholders and understand the problem and its causes (Anderson, 2022; Benson & Jordan, 2015). Consulting experts was done through four interviews. Which resulted into many risks and benefits that are connected to nuclear energy. In addition, survey data highlighted demographic influences on public acceptance, with gender and age playing significant roles, while factors like residence and education have minor effects. Trust and knowledge emerged as influential factors, and waste-related concerns stand as top perceived risks. However, these risks do not impede social acceptance according to the scenario simulation analysis. Nevertheless, survey results showed an acceptance of nuclear energy among the majority of the participants Furthermore, scenario simulations of policy instrument implementation displayed an increase in trust, knowledge and economic aspects. Beside the policy instrument implementation, the simulations also revealed unforeseen effects of nuclear plant implementation, with a political crisis as the main concern. Limitations of the study encompass survey participant size, limited scope to nuclear energy within the energy mix and a simplified model compared to reality. Recommendations involve enhancing the simulated socio-technical model, investigating public participation, further exploring policy implementation, quantifying nuclear energy's role in the energy mix. Ultimately, these findings contribute to an informed understanding of public acceptance, guiding policymakers and stakeholders in their decision-making processes and how to further investigate the topic.

ACKNOWLEDGEMENTS

As I wrap up this thesis, a mix of emotions fills me. It's the end of a really fulfilling phase of my life, one I've thoroughly enjoyed. When I started working after my bachelor's, I felt like something was missing. Therefore, driven by my passion for energy, I started this part-time master's two years ago. Along the way, I've picked up practical skills and grown more passionate about energy topics. The diverse group of international peers added a lot to my learning experience. Working with people from all over the world not only brought fun times but also boosted my professional abilities.

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Furthermore, I want to thank my family and friends for their unconditional support, even when I prioritized my study above them sometimes. I am also truly thankful to the interviewees who generously shared their time and inspired me greatly on the topic of nuclear energy. And lastly, my sincere thanks to the survey participants for their time and insights.

I dedicate this research to my beloved father. Who, even though he is not with us anymore, was my biggest motivation throughout my masters.

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LIST OF ABBREVIATIONS

FCM: Fuzzy Cognitive Maps

NPP: Nuclear Power Plant

EZ: Evacuation Zone

SDG: Sustainable Development Goals

STS: Socio-Technical System

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1. INTRODUCTION

A major negative impact of globalisation is industrialisation and uncontrolled population growth (WCED, 1987), leading to the need to tackle challenges that encompass social development, economic growth and environmental protection. These three pillars were part of a new concept: sustainable development, which, for the energy domain, means that the global energy demand of the current generation should be met without compromising the ability of future generations to meet their energy needs (WCED, 1987). However, this idea was interpreted differently by each nation. For instance, nuclear energy was considered sustainable by some countries, while the others excluded it from their energy mix (Verbruggen et al., 2014). Alongside the normative fundaments of sustainability, the concept was later translated into operational goals, called the Sustainable Development Goals (SDGs). There, energy was brought under SDG7, namely: affordable, reliable, sustainable and modern energy for all, and is connected to almost all of the other SDGs (United Nations, 2015). This shows how important energy is for sustainable development and society. Therefore, countries with favourable geographical locations with respect to fossil fuels, can abuse their power on countries that depend on their energy supply. History and present shows the consequences of this vulnerability (Grivach et al., 2017).

After the 2022 Russian invasion of Ukraine, Europe imposed economic sanctions against the Russian State. One of these sanctions was to cut off oil and gas payments, which was one of the largest incomes to finance the war. As a result, energy prices have skyrocketed. (Benton et al., 2022). This induced an energy crisis in Europe and an increased inflation with macroeconomic effects, which brought the European economy and progress of the SDG's for 2030 to a retardation (Caldara et al., 2022; Pereira et al., 2022). There was no other way than to boost the energy transition in Europe, as for the Netherlands. People began to recognise the geopolitical risks and the added value of energy independence. Local energy sources, such as wind and solar power, became increasingly popular. Moreover, Germany and Belgium even delayed their out-phasing of nuclear plants (de Jong & van de Graaf, 2022). Moving towards an energy independent future, comes along reliable energy sources. For this reason, the weather dependency of green energy makes them an intermittent thus unreliable source (Haluza & Slovak, 2010). Hence, nuclear energy has resurged into the energy debate. The European commission is currently changing its view on nuclear power, potentially labelling it as green energy under certain conditions (BBC News, 2022; Haahr, 2022). Nevertheless, it remains a sensitive subject, because of the risks, as well as the ethical and political concerns it entails. One of the main and most feared concerns is human extinction, caused by a nuclear war, or by unsafe nuclear power plants (NPPs) (Kareiva & Carranza, 2018). In fact, previous accidents concerning nuclear energy had a big social and environmental impact on the entire world (Denning & Mubayi, 2017; Steinhauser et al., 2014). Consequently, public acceptance is critical to the success of future nuclear energy re-implementation (Lehtonen et al., 2020; Weinberg, 1972).

Due to the rapidly increasing demand for reliable alternatives for fossil fuels, nuclear energy might be reconsidered. However, there is a lack of empirical studies looking into the status quo of public acceptance and their drivers. Therefore, this research is focused on the current public acceptance of nuclear energy among the people living in Gelderland. Additionally, policy adaptation barriers are identified, and influences of public acceptance are tracked down, which is useful for further policy making regarding nuclear power in Gelderland. This thesis uses nuclear policy in the Dutch province of

Gelderland as its case study, as it is a suitable candidate for a nuclear power plant, due to the large rivers flowing through the province, as visible on the map in Figure 1.

Figure 1 Map of the Dutch Province of Gelderland (Tiggelaar, n.d.)

Strong social attitudes impact the policy cycle regarding nuclear energy. Consequently, the level of public acceptance is crucial in determining if and how nuclear energy should be incorporated into the energy mix. Hence, determining the influences, and the impact of implementing targeted public policy instruments on public acceptance becomes crucial. This is achieved by predicting future scenarios through the modelling of these instruments into a fuzzy cognitive map. Policy makers can use this information to anticipate the level of public acceptance when setting up nuclear power facilities in the future. As a matter of fact, it can be used to pinpoint primary influences on people's opinion, and to precede accordingly. In this case, the scenario tool might help to give insight in what possible policy instrument choices might cause.

2. PROBLEM DEFINITION

In this chapter, the importance and relevance of conducting this research is discussed. Following that, the research objectives are presented, outlining the specific goals and purposes of the study. Finally, the research questions are introduced, providing a clear direction for the investigation.

2.1 RESEARCH OBJECTIVE

2.1.1 Project Context

Because of the desire to become independent of Russian gas, and to achieve the European Commission climate goals to become climate neutral by 2050, a reliable alternative for electricity generation is necessary (Crowley-Vigneau et al., 2023; European Commission, 2020). This resulted into the reconsideration of adding nuclear energy to the energy mix. However, this necessitates thorough consideration; beside the possibilities, also risks and uncertainties are intertwined with nuclear power. They require constant safeguarding during operation, with waste disposal and even after shut-down of the plant. Another topic to address is non-proliferation, which can otherwise impose large consequences during times of political instability (Mourogov, 2000). Contrarily, nuclear energy also has some advantageous characteristics: it can deliver dependable and consistent power, when the sun or wind aren't available to generate green energy and it can contribute to reduce GHG emissions and fossil fuel consumption, and reduce energy costs (Jenkins et al., 2018).

On top of that, public acceptance has played a huge role in the implementation of nuclear energy. For a long time, nuclear energy has been feared due to accidents at NPPs, like Chernobyl and Fukushima. Also, the risk of terrorist attacks influences the level of acceptance of this technology (Y. Kim et al., 2014). Another reason for people to have doubts about reconsidering nuclear energy is because of the dependency of the authorities, if the country becomes unstable, there is more chance of attacks. This has to do with the world view, if the view is very negative and the authorities are not trusted, people will most likely oppose to NPPs. Furthermore, the population in the Netherlands is very dense, which means that there are always many people living relatively close to the plant (Peters & Slovic, 1996).

Public acceptability of nuclear energy has been the subject of extensive research in the past. Meanwhile, more accurate information regarding risks and possibilities have been provided in the recent years, causing different opinions nowadays (Wheatley et al., 2016; Wilkerson, 2016). Therefore, and due to the need for reliable power generation, reintroducing nuclear energy might be a potential solution. Hence, there is a need for further in-depth research on public acceptance of nuclear energy, what motivates individuals to form such a view and how certain policy instruments can influence these views. When this is known, the province can act accordingly. This resulted in the following research objective.

2.1.2 Research Objectives

This research intends to offer recommendations to the Province of Gelderland for policy adoption regarding public acceptance of NPPs, before adding the technology to the energy mix, by assessing the current public acceptance of nuclear energy in Gelderland and predicting various policy instrument effects. This iwas accomplished through a combination of approaches. Initially, a literature study laid the conceptual foundation of the research and guided the initial development of a Fuzzy Cognitive Map (FCM) of nuclear power and public acceptance as a complex socio-technical system (STS). Following that, specialists, such as engineers and scientists on nuclear energy were interviewed, adding information on the primary causes and impacts of public acceptance of nuclear power, integrated as concepts within the FCM, and to gain knowledge about possible policy instruments. An additional literature study was conducted to investigate the credibility of their replies, and to further inspect the potential effectiveness of the policy instruments. This was also important for setting up a subsequent public acceptance survey to further develop the linkages, weights, and coverage of the FCM. Thus, the survey results reflected the present level of public acceptability and offered final information to the development of the FCM, in particular, the initial weights of and between the concepts. Lastly, potential policy instruments are modelled in the FCM, which developed and simulated scenarios that can provide to policymakers perspectives on the effectiveness of relevant policy instruments when applied.

2.2 RESEARCH QUESTIONS

Public acceptance plays a large role within the policy cycle. Due to the risks and previous experiences on nuclear energy, as well as the need for a reliable alternative for renewable energy sources, the current social acceptance on this topic should be tested. This research studies the current public acceptability of nuclear energy implementation in Gelderland. Thereafter, potential policy instruments are integrated into a fuzzy cognitive map, to find out its consequences on public acceptance.

The conceptual design, literature review and research framework are elaborated in previous chapters. This chapter reveals the main question of the study, which serves as a guidance for the remainder of the research. Thereafter, the sub questions are mentioned.

- Main questions:
  - "How will specific policy instruments for nuclear energy in the Dutch province of Gelderland function, given the current degree of public acceptance?"

The research's supporting questions are provided below. Each of these questions adds context to the primary topic and supports in its resolution.

- Sub questions:
  - "What is nuclear energy, what might be its risks and benefits, and what is the current status of nuclear energy plants in Gelderland?"
  - "How is public acceptance intertwined in the policy cycle? And what policy instruments can be useful for nuclear energy adoption?"
  - "What is influencing the public acceptance of nuclear energy, consisting of personal, social-psychological, and contextual factors?"
  - "What is the current public view on nuclear power and how can future policies anticipate on its acceptance when planning to implement nuclear power plants?"

3. BACKGROUND

This section provides a background for nuclear energy technology in the specific context of Europe, outlining and discussing its barriers and possibilities. Thereafter, the current status of nuclear energy in Gelderland is presented.

3.1 NUCLEAR ENERGY TECHNOLOGY

Nuclear energy emerged in 1932 when Sir Frédéric and Madam Irène Joliot-Curie discovered radium like elements, by attacking materials with neutrons. With this knowledge, other scientists started experimenting, and finally discovered the complete rupture of the nucleus, also called fission. By the year of 1938, it became possible to generate a self-sustaining nuclear reaction. Subsequently, because of the emergence of the Second World War, fission was primarily used to investigate and create atomic weapons (Rhodes, 1986).

The first nuclear reactor that was used for energy generation was built in the U.S, and was used to power aircrafts and submarines for the navy in 1954 (Kazimi, 2003). Thereafter, in 1956 the first European nuclear power plant emerged in England, where the plants were used to produce energy as well as Plutonium-239, which was used to build nuclear weapons (Alam et al., 2019). Because of fission it was possible to force atoms of U235 (Uranium) in a reactor to split, and release a lot of heat. With this heat, steam was created to drive a turbine, with the spinning motion electricity was generated. In the decades after that, the number of nuclear energy plants rapidly increased in Europe (Hultman, 2011; Krivit et al., 2010). Figure 2 illustrates the operation of typical nuclear power plant, using nuclear fission technology (Martin, 2013).

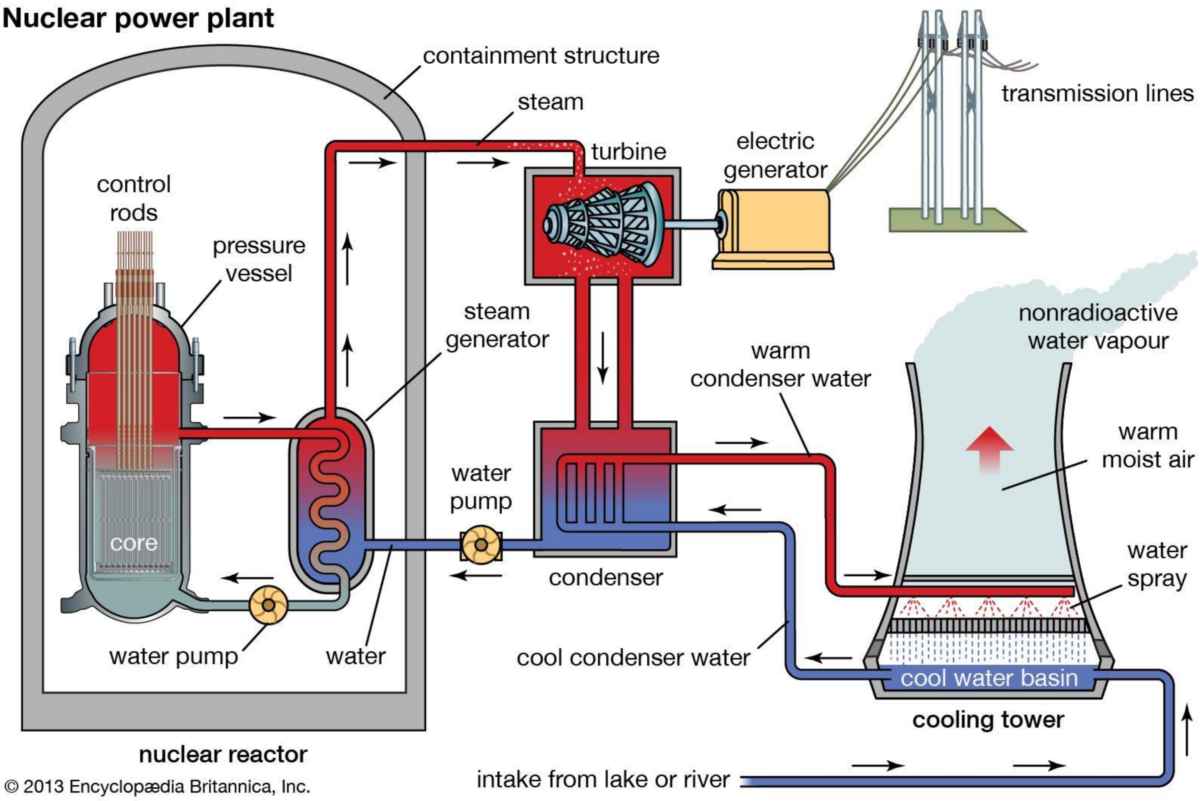

Figure 2 Representation of the operation of a nuclear power plant, based on nuclear fission technology (Martin, 2013)

3.1.1 Risks

There have been several accidents with nuclear power. The worst disasters happened in Three Mile Island, Chernobyl and Fukushima. In 1989, a meltdown occurred in Unit 2 reactor of Three Mile Island.

An operated relief valve released too much coolant, resulting in the meltdown of the unit, with the final result of radiation exposure of the nearby areas However, the public was only exposed to a little bit of radiation. Subsequent research revealed that the human health effects were negligible (Fushiki, 2013). The Chernobyl accident happened in 1986, while one of the reactors was used for a test on coolant pump operability. During the tests, the core of the reactor became too hot due to reduced cooling, which resulted into a melt-down. This lead to steam explosions and the cover of the reactor to blow off. The accident resulted into about 30 direct deaths due to and overdoses of radiation, and approximately 300 people were treated for burn injuries due to radiation (Alexander, 2006). Long terms effects showed an increase in thyroid cancer cases, for children that were exposed at the time of the disaster, which is also visible in the surrounding countries (Cardis, 1996). Loss of powers and cooling caused by a huge earthquake resulted in radioactive material release at the Fukushima accident in 2011. Besides the investigations that showed that there were no deaths or significant radiation exposure reported on humans (Baba, 2013), the ocean was highly contaminated by radiation leakage (Yamazawa & Hirao, 2021). Although, people's acceptance of nuclear energy was already decreasing in the 1970's, the accidents worsened their opinion towards the technology (Bolsen & Cook, 2008; H. P. Peters et al., 1990; ROSA & DUNLAP, 1994; van der Pligt, 1985).

Apart from the three most recent major accidents (Högberg, 2013), various other incidents occurred. One notable example is the SL-1 accident in Idaho in 1961, where the removal of a control rod resulted in a disastrous power rise leading to a steam explosion within the SL-1 boiling water reactor. This incident led to the unfortunate loss of three lives (Horan & Gammill, 1963). Another incident took place in the Fermi Unit 1, in Michigan in 1966, where a blockage in the coolant flow of two fuel channels resulted in a meltdown of a part of the assemblies. While no fatalities occurred, it was close to a much worse outcome (Sovacool, 2008). Similarly, in California in 1959, the sodium reactor experiment experienced a partial meltdown as a result of a blockage in the cooling flow, leading to the reactor's temperature rising uncontrollably (Pickard, 2009). Moving to Europe, a significant accident unfolded in Cumbria, UK, in 1957. This incident involved a fire and meltdown of the core at Windscale Unit 1, resulting in the release of substantial amounts of radioactivity into the neighboring area. The effects extended to the mainland of Europe and contributed to 200 cancer-related deaths (Nelson et al., 2006) Despite the numerous safety measures in place today, including technical and human dimensions, these incidents underscore the reality that nuclear energy plants can yield unforeseen consequences. As a result, nuclear energy may still be viewed as hazardous (Nakamura & Kikuchi, 2011).

As the previous paragraph implicates, NPPs require a hierarchical and centralized control by the authorities to manage and maintain the plants, to ensure reliability and safety. Because the public safety is in hands of the authority, it can make an area fragile to political conflicts. NPPs are great targets for terrorist and political opponents (Cravens, 2002). Furthermore, when there is not enough Uranium to generate the chain reaction, possibly Plutonium will be used to run the reaction. However, beside the fact that it is harder and riskier to recycle this element, it might also be used to build atomic weapons, which might cause even more danger to civil society (Winner, 1980).

When plants are at the end of their operation life-time, they have to be decommissioned, which require safe and sustainable approach, managed by the authorities. After a plant is decommissioned, nuclear waste that is remaining has to be stored at a safe place, which require time, maintenance, funding and monitoring to ensure safety for decades more (Park et al., 2022). Currently, 93 percent of radioactive waste is still in storage until it is safe to dispose it. This means that much more waste is to come, and high volumes of waste have to be handled. These activities will impose large costs, and therefore, a stable financial economy is critical. Hence, nuclear plant decommissioning and nuclear waste will create technical, social, political, environmental and financial challenges (Samseth et al., 2012). These factors create responsibilities for the coming decades, which might burden future generation.

The previous risks are large scaled and high-impact low-probability events, while nuclear power also generates smaller scale barriers. One of those obstacles is the likelihood that, with a limitless supply of nuclear power, people may make less effort to consume less energy. Resulting into a slower transition to a anti-consumerism society, and large amounts of nuclear waste (Hill, 1976). In addition to nuclear weapons, radiation may be used to poison particular populations, also known as the neutron weapon, which might be employed during political conflicts (Segall, 2007). Furthermore, incidents within the plant can still occur due to human error, even though the technology became safer (Sethu et al., 2021). Other barriers are mining of Uranium, which brings along public health risks (Sarkar, 2019). And finally, nuclear energy is not renewable (Sarkodie & Adams, 2018).

A risk associated with low dose ionizing radiation, is the increased chances on certain mental or physical diseases. This risk is dependent on the duration of exposure, the dose of radiation received, the type of radiation and personal susceptibility. On the contrary, small radiation doze might also induce positive outcomes, which was showed on the better reproduction of certain animals (Cuttler & Pollycove, 2009; Shephard et al., 2018). However, the influence of low dose ionizing radiation is still uncertain and not yet resolved by research nor adequately studied (Tang & Loganovsky, 2018). Lumniczky et al. (2021) studied the effects of low dose ionizing radiation on the immune system. They claim that low dose radiation can harm T cells, and affect their function. Furthermore, the immune system's response to infections and inflammation may also be altered by low dose radiation, this can lead to either positive or negative consequences. Therefore, they suggest that more research is required to fully understand these effects and their implications on human health.

Yet another risk related to the implementation of NPPs that use cooling water from nearby surface water, is the potential disturbance of its aquatic ecosystem. This disruption is primarily caused by thermal emissions, leading to damage ranging from 3% to 90% of the ecosystem quality, as reported by Verones et al. (2010).

The emerging risk of cyber-attacks on NPPs is gaining significant importance. Such attacks raise serious safety concerns when hostile forces take control of the plant. For instance, Iran witnessed an attack that destroyed the centrifuges of its uranium enrichment facility, while the Davis-Besse plant in the US faced an inoperable safety indicator system for five hours due to an attack. In Korea, a cyber-attack took over the computer network and resulted in the theft of the power plant's design and manual, among other things (S. Kim et al., 2020).

Finally, high dose radiation exposure to the human body can lead to immediate effects such as organ damage, skin burns, radiation sickness and in some cases, even death. Long term effects may include an increased risk of developing certain types of cancer, genetic mutations, and potential fertility problems (United States Environmental Protection Agency, n.d.).

3.1.2 Possibilities

The safety of nuclear power technology is on the rise. Accidents like Chernobyl are less likely to happen due to safety measures. When the control of a reactor is lost, it slows down instead of speeding up. Also, the building of Chernobyl was open, which lead to a lot of radiation exposure to the surroundings (Krivit et al., 2010). Nowadays, the safety measures easily transcend the measures of the times when the disasters happened. Examples are that buildings are closed to minimize the risk of radiation exposure, and water is placed on top of the building, for when cooling pressure is lost. Furthermore, safety measures are taken for zones around the plant, for example, in a radius of 5 km around the plant, quick evacuation is possible. Also, reactors have less power density and low excess reactivity in the core of the reactor, which reduces unexpected power rises (Vijayan et al., 2013). Yet, even with safeguards, unforeseen events like environmental disasters or poor management can occur. This was evident at Fukushima, where the plant's design didn't foresee the scale of the 2011 tsunami (Hollnagel & Fujita, 2013)

Compared to fossil fuels, there are less deaths when for nuclear energy, shown in Figure 3. The comparison includes mining, transportation, construction of the plant and maintenance. The fact that fossil fuels still dominate the energy market is also taken into account. Therefore, the amount of deaths is proportionately adjusted to the generated energy (Ritchie, 2020).

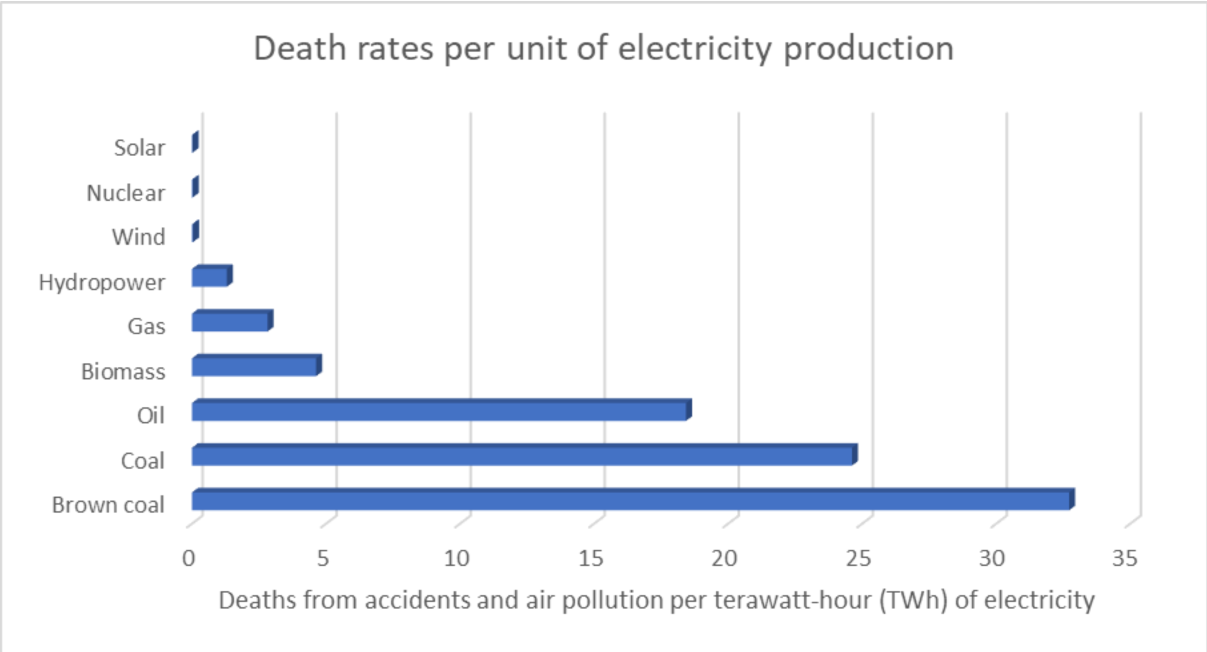

Figure 3 Death rates per unit of electricity production, based on Ritchie (2020)

Furthermore, no greenhouse gas (GHG) emissions are released during the process. Which makes it a clean technology regarding global warming. Additionally, it is a reliable energy provider, which can meet the demands during peak times, while renewable resources cannot (Sarkodie & Adams, 2018). Besides, the amount of Uranium required for this process is far less than the amount of fuel required to create the same amount of energy (Krivit et al., 2010). This is advantageous for the remaining nuclear fuel, which Touran (2020) claims to be sufficient for many more centuries.

3.1.3 Current Status in Gelderland

Gelderland used to have one nuclear power plant in Dodewaard, which was one of the two total NPPs in the Netherlands. It was built in 1969, being the first NPP of the Netherlands and operated for 28 years. After that, the plant was no longer profitable in the liberalized production market and therefore had to be decommissioned (Autoriteit Nucleaire Veiligheid en Stralingsbescherming, n.d.). The plant would be put into a “safe enclosure” for 40 years, where the radioactivity level has time to decrease. Thereafter, the plant would be dismantled (de Haas, 2002).

At the time of the shutdown, people were not so eager about nuclear energy due to the accidents, and a lot of effort was put into the proposal of the plans for the people living around the plant (de Haas, 2002). Any recent sources about the public view of nuclear energy in Gelderland, or even the

Netherlands, is not are scarce. However, there are broader studies that looked into the public attitude towards nuclear energy within several countries. According to Wang and Kim's (2018) research, there are more people in the Netherlands who oppose to nuclear energy, compared to those who support it, while the majority has no preference. The scarcity of knowledge regarding nuclear energy acceptability in the Netherlands demonstrates the importance of more research into this topic.

While starting this research, there was no interest within the Province of Gelderland to reintegrate NPPs into the energy mix. There have been discussions about it, but the plans have been thrown out during a debate due to insufficient support. A part of the parties wants to leave the decision to the house of representatives, and another part is completely against, to the chagrin of several parties who were supporting the plans. Therefore, there will be no further inquiry or policy on the implementation of a nuclear power plant in Gelderland unless the house of representatives requests it. Even though, according to a poll on the Omroep Gelderland website, there are twice as many proponents of nuclear energy as opponents (Peelen, 2022). Subsequently, the news revealed that the Dutch Government was doing research about whether to place several smaller NPPs, or one larger plant. The aim is to have a new nuclear plant operational within eight years. Some scientists prefer a smaller plant in Gelderland due to available cooling water from Gelderse rivers. However, cost concerns make successful implementation of smaller plants uncertain, making a larger plant a more viable option. Experts remain skeptical about nuclear power and emphasize the importance of continuing to focus on solar and wind energy alongside nuclear energy (Heller, 2023). Due to the large rivers, Maas and Rijn, flowing through Gelderland, it might make a good candidate for nuclear energy, and is therefore the focus of this research.

4. CONCEPTUAL FRAMEWORK

4.1 PUBLIC ACCEPTANCE THEORY

Public acceptance is also known as ‘social acceptance’, ‘public attitude’, ‘public opinion’ and is associated with many other terms. In general, the meaning of these terms is nearly the same. The meaning of the terms in this study is explained in this paragraph.

Several frameworks have been developed for explaining social acceptance. One of them is the framework of Bronfman et al. (2012), in his research he found out that there are significant linkages between social acceptance, perceived benefit, perceived risks and trust in the authorities. The linkages are illustrated in Figure 4, creating a causal model of trust. Trust in the authorities can either positively affect social acceptance, negatively influence the perceived risks and positively influence the perceived benefits. Therefore, risk perceptions have a negative influence on acceptability and benefit perceptions have a positive influence.

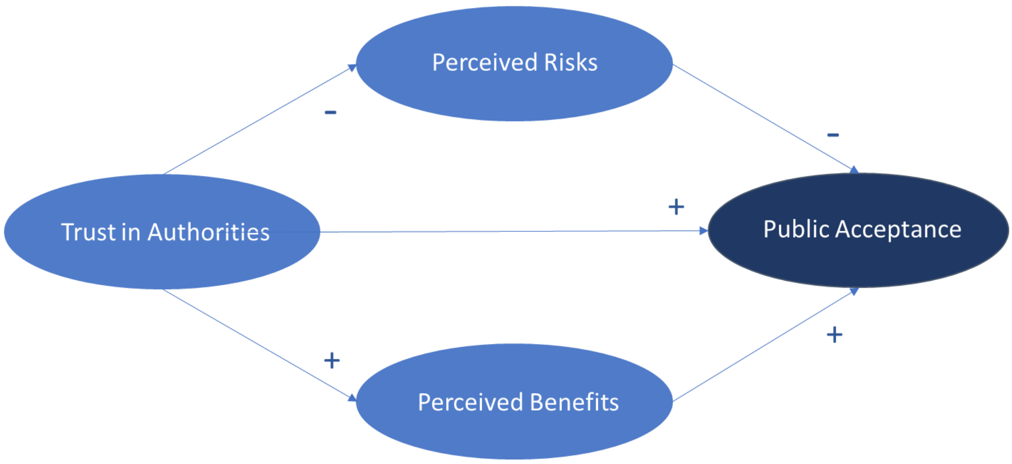

Figure 4 Linkages between 'Trust in Authority', 'Perceived Risks', 'Perceived Benefits' and 'Public Acceptance' (Bronfman et al., 2012)

The factors that influence social acceptance are described by Devine-Wright (2014). He groups them in three main categories, namely, personal, social-psychological and contextual. Table 1 gives a complete overview of the categories and factors. Although, Devine-Wright mentions social class as a personal factor, this research diverted into education. Education affects the overall level of knowledge and is a key indicator of social class (Winkleby et al., 1990). In order for the public to establish an opinion about a certain technology, it is crucial that the gathered information is sufficient. When the gathered information is incomplete, a misperception may occur (Stoutenborough et al., 2013). The factors that fall under the socio-psychological category, are derived from the research of Bronfman et al. (2012). Here, trust in employees is added because of its contribution to the public acceptance. This includes operators of the nuclear plant, supporting staff, and scientists, that further develop the technology. The last category that influences public acceptance is the context of the technology, which in this study entails the scale, type and ownership. With ownership it is meant if the nuclear power plant is privately or state owned. This may also influence the level of acceptance (Devine-Wright, 2014).

Categories	Factors
Personal	Age Gender Education
Socio-psychological	Risk perceptions Trust in employees Trust in Authorities Benefit perceptions
Contextual	Scale Type Ownership

Table 1 Categories and factors that influence social acceptance, based on Devine-Wright (2014) and Bronfman et al. (2012)

4.2 POLICY PROCESS

Making policies is not a standardized, repeatable procedure. Every policy problem calls for a different strategy. Which is about changing the available methods and theories connecting knowledge and action. These theories and methods represent the creation of ideas from conducting research to describe, explain and predict an aspect of the policy process. Due to the different offered perspectives on the policy cycle by most theories, it is important to use multiple theories in order to achieve a comprehensive view of the policy process, which can enable a customized theory (Weible & Sabatier, 2018). Therefore, this study explores several theories to be able to find the most suitable approach on the policy process of public acceptance.

Public policy refers to decisions made by the government or governmental-like authorities, to achieve specific goals. This includes laws, rules, and regulations. These policies can cover a range of means and goals, spanning from procedural to substantial and from symbolic to practical. When studying policy processes, researchers can focus on one policy or many. These policies are closely tied to politics as they translate and change societal values. This involves a complex ongoing interaction of activities, like defining issues as problems and getting them on the government and public agendas (Baumgartner et al., 2006; Weible & Sabatier, 2018). This involves data gathering and analysis, consulting experts and engaging stakeholders to understand the problem and its causes (Anderson, 2022; Benson & Jordan, 2015).

Policy formulation is part of the pre-decision phase of the policy process. Once a problem has been identified, the next step is to set clear goals and objectives for the policy. This helps to ensure that the policy is focused and has a clear direction. Also the attendees, biases and difficulties of policy formulation are identified (Anderson, 2022; Benson & Jordan, 2015). Policy formulation entails identifying and creating specific collections of policy instruments that represent potential strategies. It involves crafting the legislative or regulatory text for each option, presenting the instruments—such as rights, grants, sanctions, etc.—clarifying their scope, targets, and effective dates. The process of selecting a smaller subset of workable solutions, from which decision-makers will ultimately choose, involves assessing the options using various criteria, such as their workability, political viability, costs, benefits, etc. Policy formulation and policy decision stands as a critical phase within the policy process, as it culminates in the selection of the one policy instrument among the presented alternatives, which would require a solid examination (Fischer & Miller, 2006).

When policies are being created or changed, these interactions involve negotiation, force, conflict, and cooperation. They also include putting policies into action, which means regulating behaviour, sharing resources, changing perception, and providing public services. Finally, it also involves judging whether policies are successful or not and assigning responsibility for this. These interactions include debating about the policy issue and public discussions (Weible & Sabatier, 2018). This leads to a cycle in the policy process, where problems of implementation are assessed and policies are improved (Anderson, 2022).

In summary, the policy cycle consists of five steps, illustrated in Figure 5, forming a policy framework (Anderson, 2022; Hoefer, 2021). The explanation of each step is briefly described as follows:

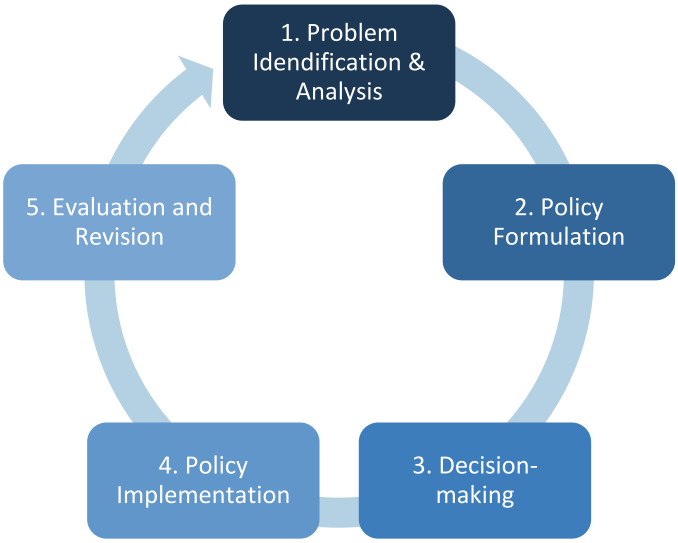

Figure 5 The policy cycle, consisting of five steps

1. What issue will be worked on?
2. What is the desired outcome, and what policies can be developed for that?
3. How is a policy chosen and why?
4. How is the policy put into practice?
5. Is the policy effective and how should it be changed?

The efficacy of these steps are influenced by actors, studying the policy process involves people, thus actors, that are actively involved in the process. This can be either the policy makers, as the public that influences the implementation of the policy instrument that might result from the process. Also media, academia, legal bodies and many more actors play a role in shaping the policy process, from providing recommendations to shaping the public (Weible & Sabatier, 2018). Furthermore, institutions influence the process, which are formal and informal regulations, rules and norms, that have influence on the actors (Peters, 2005). Networks and subsystems, which are the policy makers that are using information acquired from academia, experts and think thanks. Where one policy maker can favour another source over to the other, which might create biased information (Jordan et al., 2004). Additionally, ideas or beliefs of the targeted public or the policy makers themselves might influence the policy, and its success. The personal notions can be obtained from the media, are the result of certain personal demographical factors, or other factors (Cairney et al., 2022). The policy context also influences the policy process, which is the related environment in where the decisions are made. For example, economical conditions of a government have influence on the budget. Hence, possibly influencing the policy decision, and even the problem identification due to lack of funding for data collection (Hofferbert, 1974). Finally, events influence the policy processes, which include anticipated and unanticipated events. For example, upcoming elections can influence the decisions on certain policies. Unanticipated events can also influence the policy decisions, but also the success of a certain policy. Examples are, related to this research, the Russia-Ukraine war and European Union climate goals to pollute less. This phenomenon is further explained by Bressers and Klok (1988), they suggest a simplified framework that shows the influences of the chosen policy instrument on the effects. As shown in Figure 6, there are central circumstances that directly have consequences on the effects, and are influenced by external circumstances. Hence, the central circumstances together with the external circumstances induce the effects. Central circumstances are situations that are influenced by the chosen instruments and events outside of the procedure. This is a simplified theory, that limit the number of situations that will occur.

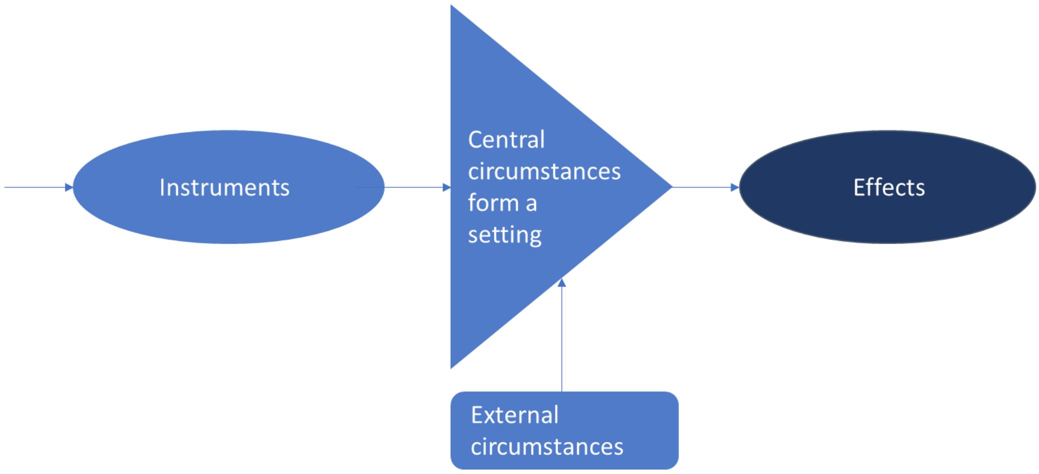

Figure 6 policy instrument implementation effects and their influences. Based on Bressers and Klok (1988)

4.2.1 Policy Instruments

In this research, the policy instruments that will be developed, primarily relate to public acceptance rather than nuclear energy technology itself. This places them within the domain of social policies rather than energy policies. The study specifically examines their impact on the acceptance of nuclear energy, partly driven by its unique health and safety concerns. As a result, the approach differs from how public acceptance of other clean energy sources is addressed (Bruggink & Zwaan, 2002).

Different policy instruments can be used to tackle a certain problem. There are three main instruments for public policies: (1) regulatory instruments, (2) economic and financial instruments, and (3) soft instruments' according to Borrás and Edquist (2013). For regulatory instruments, legal tools are used to regulate social and market interactions. Types of policies are directives, laws and rules. Additionally, they are obligatory, with clear boundaries. If one does not follow the rule, law or directive, sanctions follow. Economic and financial instruments are used to achieve a certain social and economic goal. They are supported by positive or negative stimulations. Such as, subsidies, cash transfers and reduced-interest loans (positive), or taxes, fees and charges (negative). Finally, soft instruments are often on non-coercive and voluntary basis. They provide information and recommendations, which can be in the form of public partnerships, codes of conduct and campaigns. These instruments serve as a persuasion tool and have no further consequences. Besides, it is possible to use a mix of these instruments to achieve the desired goal (Borrás & Edquist, 2013).

5. METHODOLOGY

The stepwise methodology of the policy cycle, explained in the previous chapter, is used as research framework. This approach will lead to a well-defined and sequential research process, with the utilized methods explained in every step of the policy process.

5.1 PROBLEM IDENTIFICATION AND ANALYSIS

The problem of the research is identified by the literature review, which is presented as background in this research. As mentioned in the influences of the policy cycle, beliefs and ideas are important to the success of the implementation of nuclear power plant(s) in Gelderland. Therefore, the research object is the current public acceptance of nuclear energy in Gelderland.

To analyse the phenomenon of public acceptance, qualitative data was gathered through a background study which examined scientific literature through the SCOPUS database, about the factors influencing public acceptance of nuclear energy. This was done using the PRISMA method, which stands for "Preferred Reporting Items for Systematic reviews and Meta-Analyses" (Liberati et al., 2009). Public acceptance can be influenced by many different aspects and is therefore subdivided in three indicators. These indicators can be seen as drivers of opinion formation. Each of them has several aspects that will be used to assess public acceptance in this research. The first one is personal factors, which is used for the demographic analysis and entails age, gender, income and education. The second one is social-psychological factors, where the experience and perceptions, and political beliefs are considered. According to Bronfman et al. (2012) there are strong links between risk and benefit perceptions, trust in the authority and public acceptance, which results in the causal model of trust. And finally contextual factors, which include the type of technology and its scale (Devine-Wright, 2014; Kim et al., 2014; Ho et al., 2019). This formed the base of the public acceptance framework, shown in Figure 7.

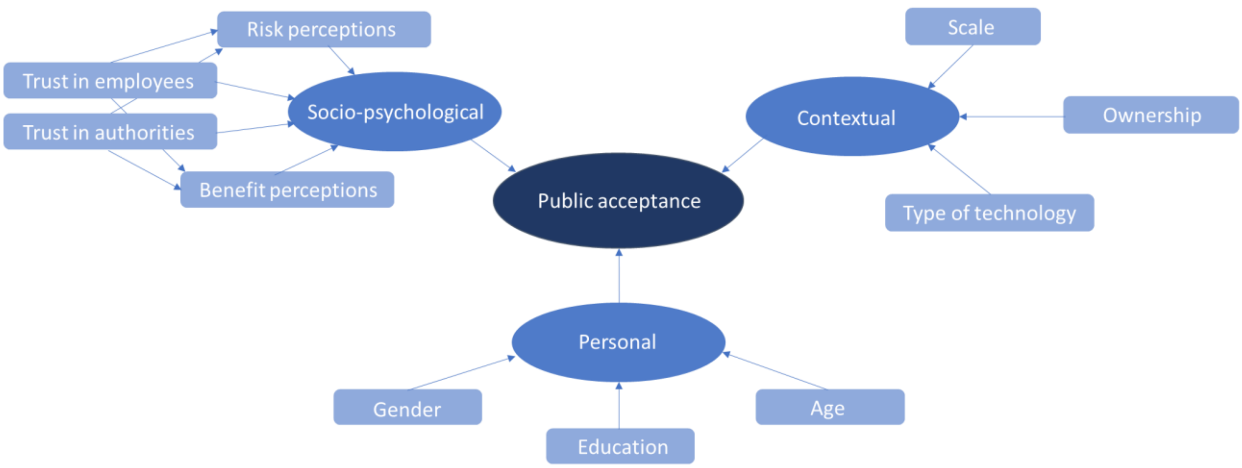

Figure 7 Public acceptance framework

Subsequently, experts in nuclear energy were engaged in semi-structured interviews to delve deeper into the nuances of nuclear energy's risks and benefits. This qualitative data was then analysed and organized into distinct risk and benefit dimensions.

Thereafter, the accumulated insights were used to construct a quantitative questionnaire-based survey. This survey aimed to illustrate the present level of public acceptance in Gelderland. The public acceptance framework guided the survey's structure and the risks and benefits of nuclear energy gained from the interviewees were used, so that the survey participants could indicate their level of acknowledgement on these factors. The quantitative survey results were processed and analysed using Excel.

5.1.1 Survey Sample

Survey participants were gathered using an online link, which was shared through the social platforms, LinkedIn and Facebook. Furthermore, the link was shared through WhatsApp. To gain more variety in the sample, printed QR-codes, which would lead to the online survey, was distributed in the city of Arnhem.

A total of 122 participants completed the survey, comprising 78 (64%) male and 44 (36%) female respondents. It is noteworthy that this gender distribution differs from the equal 50/50 male-female split in the Gelderland population (CBS et al., 2022). The age distribution of the participants is presented in Figure 8, along with the corresponding percentages of age groups in Gelderland. As illustrated in the figure, the majority of participants fell within the 25-44 years age range.

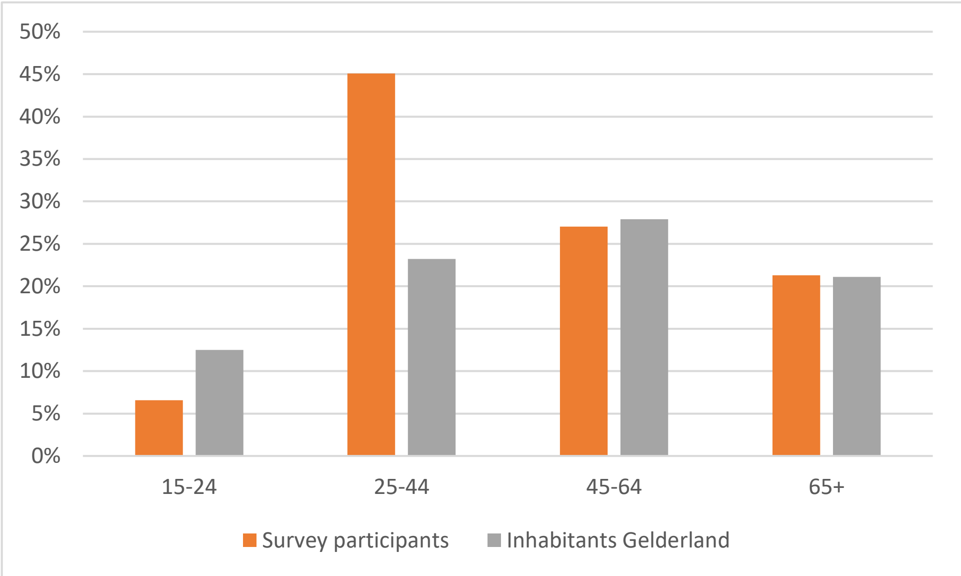

Figure 8 demographic analysis of participant age groups versus representation in Gelderland

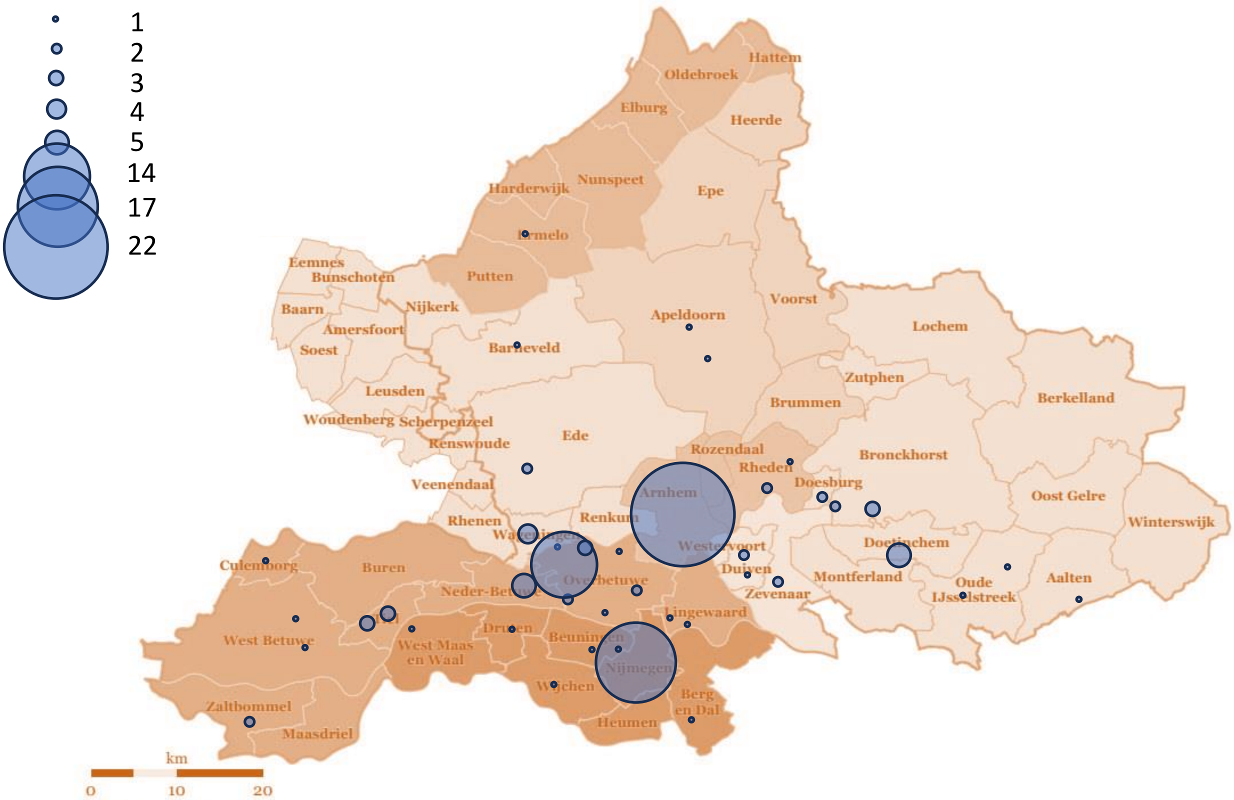

Figure 9 Locations and number of survey participants

The map provided in Figure 9 displays the approximate locations of the participants. The sizes of the bubbles on the map indicate the number of participants from each respective area. Notably, a significant portion of participants originate from Arnhem, Nijmegen, and Zetten, while the remaining participants are distributed across various regions within Gelderland.

As used by CBS et al. (2022), the educational categories represent the following levels, according to the Dutch educational system:

- Lower education
    - Primary education
    - VMBO, first three years of HAVO / VWO, MBO1
- Secondary education
    - HAVO, MBO2-4
    - VWO
- Higher education
    - University of Applied Sciences, bachelor
    - University, bachelor, master or PhD

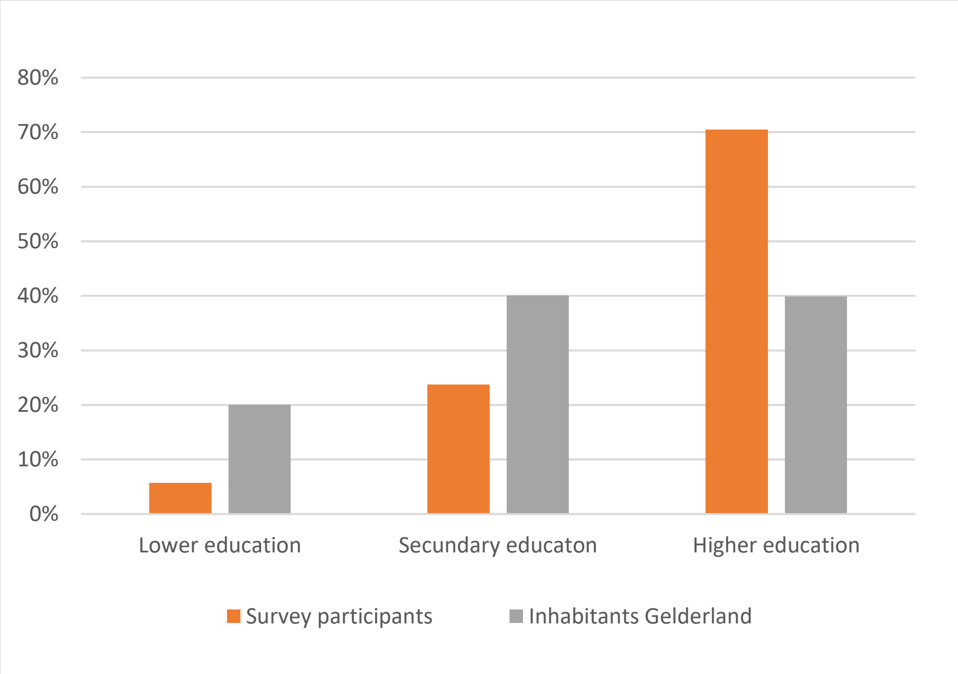

Figure 10 Highest completed education among participants versus representation within Gelderland

Figure 10 illustrates the comparison between the highest completed education level among the participants and the general population of Gelderland. A substantial proportion of the participants (86 individuals, representing 70%) have attained a higher education qualification. This is not in line with the representation in Gelderland, where a lower proportion finished higher education.

5.2 POLICY FORMULATION

After collecting data on public acceptance of nuclear energy in Gelderland, the focus shifted to developing potential policy instruments aimed at influencing this acceptance. Information about viable policy instruments was collected through earlier conducted desk research, and from earlier conducted interviews with the nuclear energy experts.

As previously mentioned, policy formulation and decision-making represent critical stages within the policy process, demanding thorough exploration of available possibilities. Subsequently, the next phases of the policy cycle involves decision making and simulating the policy instruments in a model, that generates possible outcomes of how it influences aspects on nuclear energy. This simulation is essential not only for gaining insight into potential outcomes but also due to the sensitive nature of the subject matter. It assists in the identification of potential negative consequences that could arise from instrument implementation, enabling adjustments, revisions, or the introduction of new measures to mitigate adverse effects.

5.3 DECISION-MAKING

The information gathered in the previous step was further evaluated through desk research, utilizing the SCOPUS database. This exploration aimed to identify the policy instruments that had the greatest potential for fostering broader acceptance of nuclear energy. Which is achieved by examining how similar policy instruments had been implemented in comparable contexts, thus pinpointing the most potentially successful options. Furthermore, these three policy instruments, were added to the survey, in order to find out what policy instrument was preferred by the public.

5.4 POLICY IMPLEMENTATION

This chapter explains how the chosen policy instruments were simulated within the Fuzzy Cognitive Map (FCM), which represents the implementation of the policy instruments. Leading to an interaction within the public acceptance framework and simulating their possible effects. Why and how FCM is utilized, is explained in the following section. The first part introduces and describes why complex systems and FCM's are useful in modelling and analysing public acceptance. The second part describes the format details of FCM. The final part describes the simulation strategy used in FCM expert.

5.4.1 Introduction of FCM and its Applicability on Public Acceptance

FCM's are mathematical models that simulate human processes by representing concepts as nodes connected by causal relationships (Kosko, 1986). Where conventional modelling tools fall short for such complex systems, FCM can integrate knowledge and concepts in a sophisticated and dynamical manner (Stylios & Groumpos, 2004). FCM's are used in various fields, such as artificial intelligence, decision making, and system dynamics. They provide a visual representation of the relationships between concepts and combine qualitative and quantitative data. Furthermore, one of the main applications of FCM is future scenario creation. FCM's can be used to model possible future states of a system based on current conditions and relationships between its components (Bousquet & Tricaud, 2016).

FCMs use nodes to represent variables or concepts, and directed arrows to represent causal relationships between them. The strength of the relationship between two nodes is represented by a weight, which often is a number. Furthermore, a distinction is made between the influence of factors on concepts and the concepts influencing other factors. Indicators are variables that measure the state or impact of a concept. They are used in FCMs to make the relationships between concepts more specific and concrete (Kosko, 1986). To give an example of this FCM, concepts related to trust in the government and NPP employees were integrated as "public trust". When the survey reveals the current level of trust, weights can be assigned to concepts like "perceived benefits" and "perceived risks" which are influenced by trust.

For example, in a FCM related to the public acceptance of nuclear power, the concept of "personal influences" might have indicators such as "age" and "education". These indicators can then be used to assign a weight to the relationship between "personal influences" and other concepts in the FCM, such as "socio-psychological influences".

Several scientists already performed research on energy generation methods and/or social acceptance using fuzzy cognitive maps. Kyriakarakos et al. (2014) created an FCM that serves as a decision support tool, for the planning of local renewable energy sources. They integrated all parameters that can affect the investments of renewable energy sources in local communities. The tool is able to show the decision maker possible qualitative investment outcomes. Additionally, Sánchez et al. (2019) used a multilevel fuzzy cognitive map to perform research on public opinion and examined the maps' competencies. By using this tool, it is possible to assess the public opinion quality where biological, technical and social concepts are included in the model in order to better understaJetter & Schweinfort (2011)rmed. Jetter & Schweinfort (2011) developed a FCM method for complex causal maps, where cognitive mapping techniques are combined with quantitative analysis. This helps scenario designers to get around processing restrictions on information derived from qualitative input. Finally, Kermagoret et al. (2016); Kokkinos et al. (2018) and Sacchelli (2014) researched the social acceptance of certain power generation methods by use of FCMs, each with a different perspective. By using questionnaires and interviews, they looked at the perception of various stakeholders regarding the selected technology. The development of the FCM, which includes concept connections and variable selection, results in an innovative tool that is important for energy production plant implementation planning. As yet, there are no studies found on social acceptance of nuclear energy using FCM. Nevertheless, using FCM for complex STS proved to be effective in other similar studies (Bobryakov et al., 2018; Dranko et al., 2021).

5.4.2 FCM Setup

Building an FCM consists of six steps (Jetter and Kok, 2014): 'Clarification of project objectives and information needs, plans for knowledge elicitation, knowledge capture, calibration and detailed design of the FCM model, and finally model use and interpretation', shown in Figure 11. Each of these steps is further explained below.

Figure 11 Six steps of FCM development

The FCM is constructed through an analysis of the objectives of the model. Beside the use of prior information, gained from literature review, it should be open to recommendations from experts. When the objectives are established, a model boundary chart should be created to indicate boundaries. Furthermore, the required information to build the model should be stated in the form of questions. And finally, the timeframe should be clarified (A. J. Jetter & Kok, 2014).

A way of knowledge elicitation is to interview and survey experts (Rodriguez-Repiso et al., 2007). Additionally, documents can be analysed to generate variables that can be used for the interviews and surveys. Afterwards, the most important variables can be included in the FCM (Özesmi & Özesmi, 2004). In addition, the meaning of the concepts have to be clarified in to prevent misunderstandings (A. J. Jetter & Kok, 2014). In this research, the concepts were created from the results of the background study and the interviews with experts.

The relation between the variables is examined through literature review and expert knowledge, that is obtained through a face-to-face interview whereby a cognitive map is drawn. A downside of this method is that it is time consuming of both the interviewee and the researcher. Also much preparation is required in advance of the meeting. (A. J. Jetter & Kok, 2014; Özesmi & Özesmi, 2004). An alternative is to limit the interactions between interviewees, and let written questionnaires guide the FCM structure (A. Jetter, 2005). This research determined the interrelationships between the concepts through the background study, and the interviews.

There are different methods and software used to support the modelling activity, for software methods, Mental modeler and FCMapper are great options (A. J. Jetter & Kok, 2014). This research will use FCM Expert.

A numerical method is used to integrate the retrieved data into the model, based on Özesmi and Özesmi (2004). First, cognitive map is created including concepts, that are retrieved from interviewees, with their causal relationships, which are indicated by weights between -1 and +1. The exact value of these weights is gained from the survey results. When the vector is > 0, there is a positive causality. When the vector is < 0, there is a negative causality, and when the vector is 0, there is no causal relation (Nápoles et al., 2018). To assess a cognitive map, it is possible to count the number of connections (C) and variables (N). Nevertheless, there is more to it than that, which is the index of connectivity. This shows the level of connectivity of a FCM (D), where D stands for density. This can be calculated use of one of the following formulas:

$$D = \frac{C}{N(N-1)} \quad Or \quad D = \frac{C}{N^2}$$

As a result, the amount of relations is divided by the maximum amount of potential relations between variables (N). The maximum number of relations is N^2 when variables can have causal effects on themselves. There are many causal connections between variables, when there is a high density. If some groups have more relationships, it means that they are able to have a high impact on change.

It is important to know what kind of variables are present in a map, in order to know how these variables behave towards others. There are three types, driver variables (purpose to force other variables), receiver variables (variables that use) and regular variables (which are the means). Their indegree [id(v_i)], which are the arrows in, *and* outdegree [od(v_i)] which are the arrows out, define these variables. Indegree displays the total weight of all connections (a_{ij}) that point to a concept. And is the sum of absolute weights of a variable. The total amount of variables is represented by N.

$$id(v_i) = \sum_{k=1}^{N} \bar{a}_{ki}$$

Outdegree displays the total weight of all connections that point away form a concept. It is the row sum of an adjacency matrix variable's absolute values.

$$od(v_i) = \sum_{k=1}^{N} \bar{a}_{ik}$$

Driver variables have zero indegree, and a positive outdegree. Receiver variables have it the other way around. Regular variables have neither of both, so the outdegree and indegree is zero. The summation of the outdegree and indegree, depict the centrality. This shows the contribution of a concept in a FCM, how connected it is to other concepts, and its increasing weight. It can be, that the weight of fewer connections is larger, and can therefore be more central compared to more connections and with weight.

$$C_i = td(v_i) = od(v_i) + id(v_i)$$

The complexity of a FCM is determined by the number of receivers. Many receivers means many outcomes. An hierarchical system is indicated by a large number of drivers, and also indicate that arguments between the relations are not well explained. Complex maps are indicated by a large ratio of driver and receiver variables. This complexity can be also measured by the hierarchy index (h):

$$h = \frac{12}{(N-1)N(N+1)} \sum_i [\frac{od(v_i) - (\sum od(v_i))}{N}]\text{^}2$$

The map is completely hierarchical when h=1 and the map is completely democratic when h=0. N is again the number of variables. Due to their high degree of integration and reliance, democratic maps are significantly better able to adjust to local environmental changes (Özesmi & Özesmi, 2004). Thereafter, the model is finetuned, which entails adding and deleting connections, adjusting variables and rename concepts (Jetter & Kok, 2014). Also compromises are made between contradicting believes of interviewees using scientific knowledge. Aspects to take into account are conditional causality and time-lags, if two concepts together are causing another concept, it should be visible in the FCM. Furthermore, all links should be considered in the same time frame.

After the fine tuning is completed, the model should be calibrated. This can be done by use of a simplified cognitive map, with comparable simplified cases, that can be well understood. If this behaviour does not match the actual model, it should further modified. When this is done, the model can be tested experimentally by changing variables and decide if the behaviour of the model is acceptable (Dickerson & Kosko, 1996). When the results are not according to expectation, no further modifications should be performed. Instead, the modeler should gain insight in the behaviour of the model, and should take it as feedback for further research. The main purpose of a FCM is to create information that the modeler might not have thought about, and therefore be compatible to conventional theories (A. J. Jetter & Kok, 2014).

FCM is particularly applicable for projects that tend to combine qualitative and quantitative data, to produce a model that can generate certain policy effects or scenarios. Hence, it can be applied in different fields, for different applications (Mendonça et al., n.d.; Ross & Erasmus, 2013; Soler et al., 2012). The method outlined above represents the fundamental steps necessary for constructing a FCM model. In this research, the FCM expert software will be employed as the chosen modelling tool, and its functionality will be explained in the following chapter.

5.4.3 Simulation Strategy in FCM Expert

Once concepts and their interrelationships have been fully developed through interviews and survey results, the policy instruments can be incorporated to facilitate scenario simulations. However, prior to initiating these simulations, the FCM must be appropriately configured. To achieve this, the approach outlined by Nápoles et al. (2018) is adopted. Resulting in the following settings.

By running “what-if” scenarios with possible policy instruments, potential outcomes are explored. Additionally, a few parameters will be included that relate to the instruments, to create specific scenarios that are suitable for the policy instrument in question.

Kosko’s activation rule will be used for every concept, in combination with the memory option, to add temporal realism, illustrated in Figure 12. Temporal realism refers to the passing of time, showing dynamic changes, and events happening in simulations. This rule is chosen over the other two – Kosko's activation rule without self-memory and the rescaled activation rule with self-memory – due to its ability to simulate complex behaviour over time. No rescaling is applied, reflecting real-world dynamics of dominance as seen in public acceptance surveys.

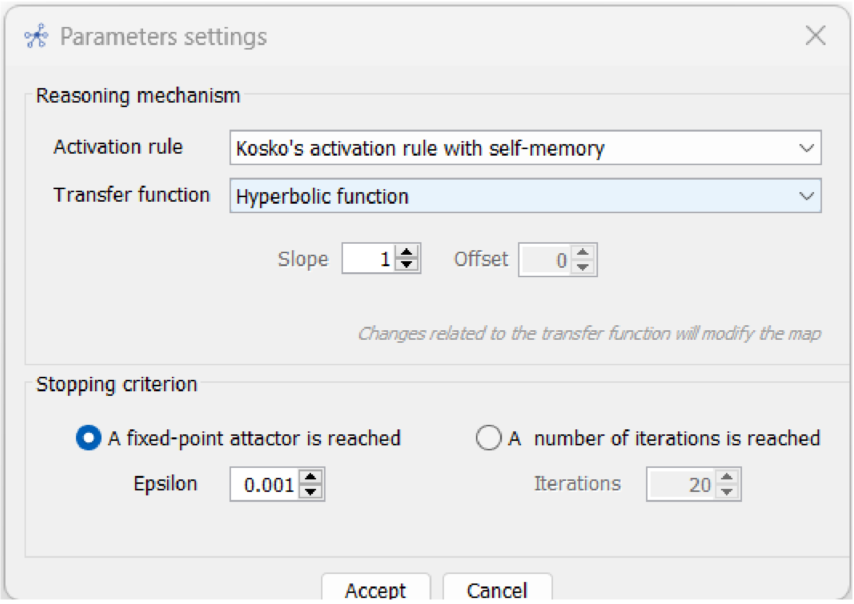

Figure 12 Kosko's activation rule, with hyperbolic transfer function and a fixed-point attractor of epsilon 0,001

The following equation is a mathematical representation of Kosko's activation rule, which determines how the FCM evolves over time. The initial state of the FCM is denoted by A(0).

$$A_i^{(t+1)} = f\left(\sum_{\substack{j=1 \\ i \neq j}}^{M} w_{ji} A_j^{(t)}\right)$$

At each step (t), a new activation vector is calculated based on the current state of the FCM. After a fixed number of iterations, the FCM will settle into one of three possible states:

1. equilibrium point, where it stabilizes
2. limited cycle, where it repeats a set of patterns
3. chaotic behaviour, where it exhibits unpredictable changes

The FCM is considered to have converged when it reaches a stable state called a fixed-point attractor. If it doesn't converge within a maximum number of iterations T, the updating process stops. This setting is shown in Figure 12, as ‘stopping criterion’.

Different functions can be used to ensure that the activation values of each concept in the FCM stays within a specific range. In this research, only the hyperbolic function is used, shown in the equation below. This function helps to keep the values of the concepts between -1 and +1, ensuring stability.

$$f\ (x) = \frac{e^{2x} - 1}{e^{2x} + 1}$$

The slope and offset parameters remain unchanged within the model. These parameters, which determine the ease and speed of concept changes, are not relevant to the current research. Similarly, the default convergence value persists until the conclusion stage of the thesis, signifying that the software stops when no further iterations occur.

None of the concepts are decision concepts, shown in Figure 13. Therefore, the default regular type ‘I am not a decision concept’ will remain. When running what-if scenarios in a simulation, it is necessary to designate certain parameters as static if they are intended to remain at a stable value throughout all iterations. For instance, if the scenario involves high incentives and the objective is to observe the effects of maintaining them at a high level indefinitely, the corresponding concept should be set as 'static' with a fixed value of 0.8. On the other hand, if the aim is to test temporary shocks or actions, leaving the 'static' option unchecked allows the concept to change dynamically along with the rest of the FCM in subsequent iterations. The decision of whether to make an action constant or temporary depends on the hypothesis and the nature of the tested scenario.

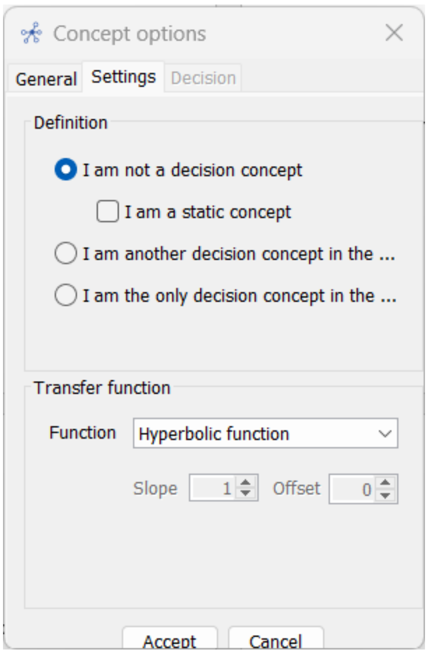

Figure 13 Concept option settings: definition and transfer function

The strength of interaction between the concepts are predetermined through the interviews and survey, eliminating the need for machine learning approaches. Hence, these techniques will not be employed in this research.

5.4.4 Initial Activation and Weights

The initial activation of the concepts, which is the actual status of these concepts, was determined by the results of the survey. The same applies for the weights between the concepts. This was achieved by using questions in the survey using the Likert scale. Most of them offered the opportunity to respond from "Strongly Agree" to "Strongly Disagree," which was converted into numerical values for the weights, ranging from 1 to -1, based on the specific question. When the answer could only be either positive or negative, a distinction in the degree of agreement was established using a scale from 0 to 1 or 0 to -1. For questions that didn't utilize a Likert scale for responses, the percentage of replies to a particular answer was divided by 100. This division resulted in a weight that could be assigned to an answer, potentially converted to a negative value depending on the nature of the question. Furthermore, the information gathered from the public on the three policy instruments, indicated the weight of the connections from the instrument to other concepts within the FCM. Chapter 7.2.2.1 provides a more detailed explanation of the assigned weights.

5.5 POLICY EVALUATION AND REVISION

This final step involves the actual simulation of the policy instruments within the FCM model. The resulting data was processed and analysed through Excel, which would reveal the influence of public acceptance of nuclear energy, on the functioning of tax incentives, public information campaigns and public participation.

Following the analysis, conclusions were drawn, limitations were acknowledged, and recommendations were formulated. These recommendations are intended to guide future research and implementation of the policy instruments for the Province of Gelderland.

6. MODELLING AND POLICY ETHICS

Modelling decisions are often shaped by value assumptions. This has consequences for the design of the model, the data selection, and the interpretation of the results. Therefore, it is important to be transparent about these assumptions, and to acknowledge the limitations of the model (Parker & Winsberg, 2018). The assumptions in this research include the interrelationships of the FCM concepts and the unintentional exclusions of certain aspects that might be connected to public acceptance, that a more comprehensive investigation might reveal. Furthermore, models are a simplified, idealised and conceptualised representation of the real problem, in order to create a more accessible scheme that is appropriate for simulation. Leading to implications for the interpretation of the results. As a result, it is the responsibility of the modeller to communicate any ethical concerns to the public and prevent any potential misinterpretations (Knuuttila & Boon, 2011).

The purpose of this model is to provide policy makers with angles on the potential effects of policy instruments on the public's acceptance of NPPs. The model's findings offer additional insights to complement existing desk research and experiences from similar situations. Nevertheless, it should only be regarded as a tool for policymaking, rather than a definitive guide for decision-making. Therefore, it is policy-relevant instead of policy descriptive, and does not dictate what policymakers should do. Additional steps, such as stakeholder workshops, are necessary to involve the public in the decision-making process, which earlier research showed to have a positive effect on social acceptance (Guo & Wei, 2019a; Keramitsoglou & Tsagarakis, 2013).

Politics can be biased due to the limited access of certain scientists to politicians, and at the same time, the very few scientists that do have access. Oftentimes, policymakers only consult with scientists who share their own political beliefs, or who are funded by interest groups with specific agendas. This can result in a small range of perspectives being considered, which might lead to policies that are not based on the best available evidence. This disproportionality might only benefit certain groups, and leave other groups behind (Choi et al., 2005). In addition, it is important that policymakers make a concerted effort to consult with a diverse range of experts from various disciplines and backgrounds, in order to make well-informed and equitable policy decisions. In the meantime, policymaking is irritational and rational, which include very complex systems, and thus should not be based on evidence alone (Cairney, 2017). This implies that ethical concerns, stakeholder input and broader societal impacts that cannot always be fully captured or measured by quantitative methods, must be considered. The integration of these qualitative and quantitative approaches will result in the most ethically grounded and successful policy decisions (Carroll & Brown, 2022).

7. RESULTS AND KEY FINDINGS

7.1 INTERVIEWS

To gather up-to-date information on the risks, benefits, and potential policy instruments associated with social acceptance of nuclear energy, a series of four qualitative interviews were conducted with people working with, or doing research on, nuclear energy technology. The interviewees were sourced through LinkedIn, and in some cases, they suggested other individuals from their network who possessed greater familiarity with the subject matter. Once the interviewees were selected, the interviews took place either in person or via the Teams platform. To facilitate preparation, participants received the interview questions a few days prior to the scheduled sessions. For reference, Appendix I provides a list of the main semi-structured interview questions. Which were answered to varying extents by the interviewees, depending on their expertise in the relevant field, extensively elaborated in Appendix II.

Given the sensitivity and confidentiality of the subject, interviewees will remain anonymous and will be indicated as Nuclear Energy Professor, Energy Ethics Professor, Nuclear Engineer and Nuclear Innovation Lead, throughout the research. They represent knowledge from the Netherlands and Canada. Eventually, the results are integrated in the FCM as concepts, with preliminary connections. In other words, the interviews, combined with the literature review, provided the initial pool of concepts that compose the "knowledge horizon" of the topic (cf. Jetter and Kok, 2014). The upcoming chapter will provide a detailed explanation of the interview findings for each category. Thereafter, these findings are used for setting up the FCM concepts and preliminary relations between the, and to setup the survey, which results are mentioned in chapter 7.2.

7.1.1 Interview Results

The findings from the qualitative semi-structured interviews are summarized in Table 2 below, categorized into three main subjects: risks, benefits, and possible policy instruments. Consult Appendix I for the asked questions and Appendix II for the complete answers. Alongside each result, the corresponding interviewee who provided support for that particular viewpoint is indicated. It is important to note that the absence of an interviewee behind a particular perspective does not imply agreement or disagreement with it; rather, it signifies that the aspect was not specifically addressed or discussed during the interview.

Table 2 Semi-structured interview results, including risks, benefits and policy instrument suggestions, by Nuclear Energy Professor (NEP), Energy Ethics Professor (EEP), Nuclear Engineer (NE) and Nuclear Innovation Lead (NIL)

Risks	
Risks during wartime	NEP, NE
Location of nuclear power plants	NEP, NE
Climate risks	NEP, NE
Potential for reactor meltdown	NEP
Challenges of long-term waste storage	NEP, NE
Slow process of energy transition	NEP
Need for long term planning and large investments	NEP
Challenges of high-level nuclear waste	NEP, NE
Risks of nuclear proliferation	NEP, NE
Human error	NEP
Risks of dirty-bomb	NEP
Continuous mismatch of demand and supply	NEP
Reliance on other sources for peak demand	NEP
Need for continuous governance and management	NE
Too technical to understand for majority of people	NIL
(Unwanted) responsibility for future generations	NEP
Benefits	
Energy security and independence	NEP
Continuous energy production	NEP
Energy system optimization	NEP
Low greenhouse gas emissions	NEP, NE
Competitive to (other) green energy sources	NEP
Long lifespan	NEP
Safety measures in nuclear plant design	NEP
Reduction of deaths compared to other energy industries	NEP
Potential for advanced nuclear technologies	NEP
Potential for waste reduction	NEP
Able to react on electricity demand (dispatchable)	NE
Stable prices	NE
Potential for heat utilization by other industries/districts	NE
Policy instrument suggestions	
Financial incentives	NEP, NIL
Performance standards	NEP
Public persuasion	NEP
Ensuring participation	EEP

The policy instruments suggested by the experts are further elaborated below:

- **Financial incentives:**
  Utilizing tax breaks, incentives, and guarantees to attract investment, reduce financial risks, and enhance the economic viability of nuclear energy projects. Leading to cheaper nuclear generated energy.
- **Performance standards:**
  Setting outcome-based requirements, leaving technology choice to the industry, promoting research, and development for innovative solutions.

- **Public persuasion:**
  Engaging in strategic communication to convince the public of nuclear energy's benefits and safety through trustworthy sources and experts.
- **Ensuring participation:**
  Policies ensuring public involvement in decision-making processes, such as workshops, fostering collective responsibility in nuclear discussions.

7.1.2 Key Findings from the Interview

The table reveals that the Nuclear energy professor had the most input on each topic. Also their attitude towards nuclear energy was neutral, allowing for a comprehensive discussion on the many risks and benefits associated with nuclear energy. However, the additions of the other interviewees significantly enriches the research findings by creating a broad view and adds valuable insights to the study. However, there are a couple of interesting findings worth noting.

One conflicting view on the dispatchability of the reactor. Regarding the dispatchability of the reactor, there is a difference in opinion between the Nuclear energy professor and the Engineer. The Nuclear energy professor asserts that the reactor is not dispatchable, suggesting that it cannot be readily adjusted or controlled according to demand. On the other hand, the Engineer argues that the reactor is dispatchable. However, the Engineer clarifies that operating the reactor at a constant rate ensures optimal fuel efficiency. This distinction highlights the varying perspectives on the reactor's flexibility and the importance of maintaining a consistent operating level for fuel efficiency.

Another noteworthy result is the use of participation as a policy instrument. Which was not earlier discovered during the literature review. Also, each expert is offering different policy instrument options, due to their different professional proficiency and/or experience.

The policy instruments were further investigated by use of scientific literature. The earlier performed desk research on policy instruments, the output from the survey, and the additional desk research on these outcomes lead to the selection of three policy instruments: tax incentives, public information campaigns and public participation.

The results were integrated as concepts into the FCM, and were partly used to create the survey, which is presented in the following chapter.

7.2 SURVEY

Besides the qualitative interviews that were conducted, quantitative surveys were needed to gain information from inhabitants from Gelderland. The aim of this questionnaire-based survey was to find out what the current public opinion is on nuclear energy in Gelderland. As receiving this data was one of the two main purposes of this research, it was also required to further develop the FCM. The outcomes were used to assign weights to the concepts of the FCM. Therefore, there were seven sets of questions. First, personal information was asked for the demographic analysis. Thereafter, all remaining questions were multiple choice, with most of them in the form of level of agreement, using a Likert scale. These questions were divided into five categories, general questions about nuclear energy, ownership, risks, benefits and policy instruments. The questions were centred around the public acceptance theory, as outlined in chapter 4.1. As a consequence, the findings are presented in accordance with this theory. Additionally, there was one open-ended question that allowed participants to share any further insights on nuclear energy not covered by the previous questions. For the entire survey, consult Appendix IV.

In order to gather participants, the survey was distributed through social media platforms and WhatsApp. However, this distribution method resulted in a limited sample primarily composed of individuals within my own social circle, leading to a potential bias in age and educational background. To address this limitation, the QR-code was also physically shared on paper at Rozet, the public library of Arnhem, allowing for the inclusion of respondents who were not personally acquainted with the survey creator.

7.2.1 Survey Results and Key Findings

Besides the personal questions, six other sets of questions were asked to receive the public perspectives on socio-psychological and contextual data related to NPPs. These sets are divided into eight chapters.

7.2.2.1. Demographic Variables

Table 3 shows the survey results as demographic variables. the results are displayed based on gender, age group, settlement type, and educational background. The method for converting answers into weights is briefly introduced in chapter 5.4.4; however, this chapter provides a more comprehensive explanation.

- Settlements are subdivided by the following conditions:
  - Indicated as city when > 50.000 people.
  - Indicated as town when 10.000-50.000 people
  - Indicated as village when < 10.000 people

- The following counting is used to indicate level of acceptance:
  - Strongly agree = 1
  - Agree = 0.5
  - Neutral = 0
  - Disagree = -0.5
  - Strongly Disagree= -1

The collective average of these values serves as the ultimate score within each category. In cases where the question is posed negatively, the values are converted. As a result, the outcome reflects the level of acceptance associated with that particular category. A positive value signifies acceptance, while a negative value indicates lack of acceptance. When discussing risks and benefits, a distinct scale is employed to accommodate the inability of benefits to assume negative values, and vice versa. This scale ranges from 1 to zero, with increments of 0.25 between values.

Regarding ownership, the weight is derived from the percentages of supporters. For instance, if 52% express support for governmental ownership and control, this positively impacts public acceptance with a weight of 0.52. Conversely, private ownership and control influence public acceptance with a weight of 0.01. This is how it is used in the FCM, the table shows it in a different way.

Table 3 Survey results presented as demographic variables

	Knowledge	Trust	Risks	Benefits	Context		
					Resident within EPZ	Several smaller plants over one large plant	Ownership
Gender							
Male	0.53	0.46	-0.48	0.73	0.11	-0.13	Government
Female	0.28	0.23	-0.63	0.65	-0.08	0.02	Government
Age							
15-24	0.42	0.28	-0.43	0.77	-0.06	-0.25	Private, government control
25-44	0.38	0.40	-0.51	0.71	0.02	-0.20	Government
45-64	0.54	0.50	-0.51	0.73	0.11	0.08	Government
65+	0.44	0.20	-0.63	0.63	0.04	0.04	Government
Settlement							
City	0.45	0.36	-0.53	0.68	-0.07	-0.21	Government
Town	0.41	0.36	-0.54	0.73	0.10	-0.10	Government
Village	0.44	0.40	-0.53	0.70	0.09	0.04	Government
Education							
Lower	0.43	0.57	-0.46	0.74	0.14	0.00	Government
Secondary	0.29	0.38	-0.56	0.72	-0.03	0.10	Government
Higher	0.49	0.36	-0.53	0.69	0.06	-0.15	Government

A notable result is the difference between knowledge about the technology of men compared to women. It seems that this knowledge is influencing the risks and benefits perception. Also women seem to have less trust compared to men. For age, the younger generation seem to have less concerns about the technology, and acknowledge the benefits more. The oldest generation have the least trust, followed by the youngest participated generation, which also is the least favourable about living within the emergency zone. There is no correlation found between location and knowledge, trust and risks and benefits perception. For education, highest trust is among the lower educated people, which also are most positive about the benefits, and least concerned about the risks. Highly educated participants have the least trust, and the lowest perception about the benefits.

7.2.2.2. Knowledge

This section shows the level of knowledge on nuclear energy among the respondents of the survey. As visible in Figure 14 the majority of respondents (81%) are well-acquainted with the topic of nuclear energy. Additionally, most people (79%) possess knowledge about its advantages and disadvantages, and a smaller majority finds the topic well understandable (61%). However, there remains a notable proportion of individuals who maintain a neutral stance. For example, 22% of respondents are neutral about the difficulty of comprehending nuclear energy. Furthermore, 17% find it challenging to understand, 8% lack awareness of its risks and benefits, and an additional 5% are unfamiliar with the topic. Though these percentages may seem small, it is crucial for people to comprehend the technology fully to form well-informed opinions about it.

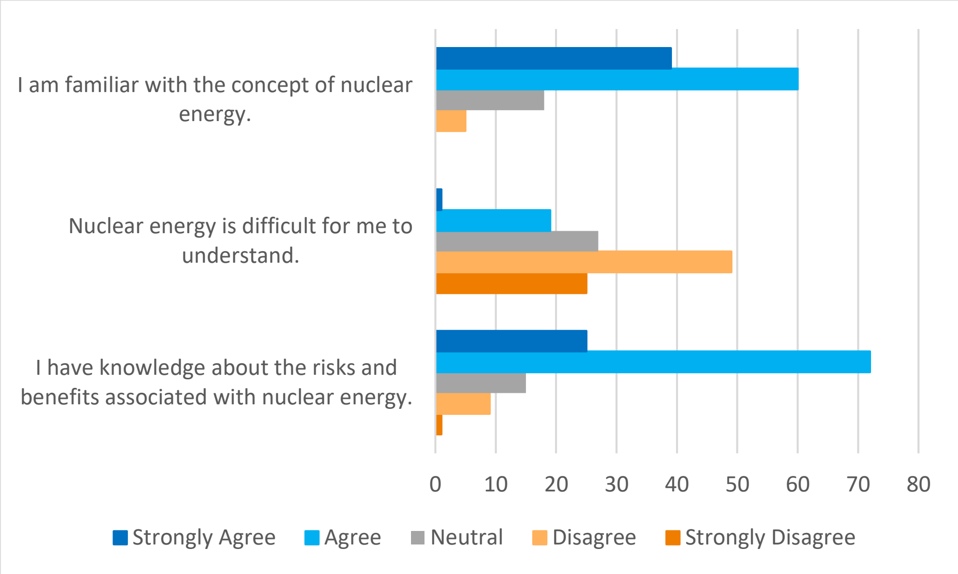

Figure 14 Survey results of knowledge on nuclear power

7.2.2.3. Trust

The trust level of the participants in both the employees working at a nuclear power plant and the government is depicted in Figure 15. Out of the participants, 79% express trust in the employees concerning nuclear energy, at the same time, 61% indicate trust in the government. Nevertheless, 18% of the respondents do not trust the government in governing the power plants. As highlighted in chapter 6.1, it is crucial for people to have trust in both employees and the government to foster the acceptance of a technology.

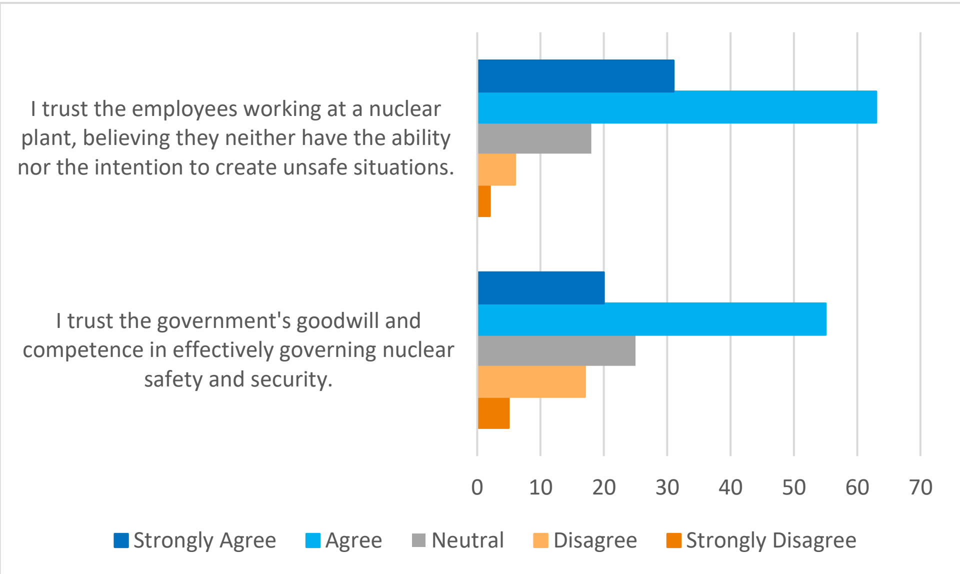

Figure 15 Survey results of governmental trust and trust in NPP employees

7.2.2.4. Context

This section presents the participants' perspectives on the extent of the nuclear power plant and its location relative to their residence, illustrated in Figure 16. Concerning the context of nuclear energy plants, 28% of respondents holds a neutral stance about the debate of whether to construct several small plants or one large plant in Gelderland. However, 42% favours one large plant. Divergence exists in participants' views on residing within the emergency evacuation zone (EZ) of a nuclear power plant, with 41% untroubled by it and 38% expressing concerns.

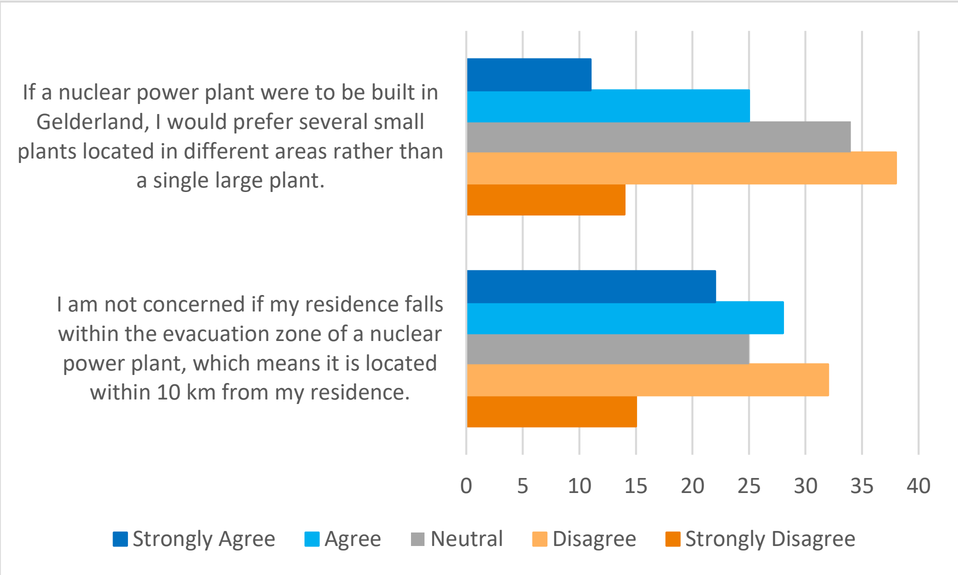

Figure 16 Survey results of NPP extent and resident relative to the plant

Ownership of nuclear power plant	Respondents	Percentage
Owned and controlled by Dutch government	64	52%
Owned and controlled by a private corporation	1	1%
Owned by a private corporation and controlled by the Dutch government	32	26%
Owned by the Dutch government and controlled by a private corporation	25	20%

Table 4 presents the respondents' opinion about the ownership of a nuclear power plant in Gelderland, a slight majority (52%) prefers full government involvement.

Table 4 Survey results of ownership of NPP

Ownership of nuclear power plant	Respondents	Percentage
Owned and controlled by Dutch government	64	52%
Owned and controlled by a private corporation	1	1%
Owned by a private corporation and controlled by the Dutch government	32	26%
Owned by the Dutch government and controlled by a private corporation	25	20%

7.2.2.5. General

In this section, three questions were posed to explore the participants' opinions on climate change and the energy mix, aiming to gain a comprehensive understanding of their perspectives. As depicted in Figure 17, a considerable majority (80%) believes that the acceptance of nuclear energy will be influenced by climate change, while 6% disagree with this, and many respondents (70%) deem this technology necessary to achieve climate goals. However, 17 participants (13%) hold the opinion that nuclear energy is not essential in this context.

In contrast to the Simultaneously, a smaller majority (58%) believes that the energy mix in Gelderland should include more nuclear-generated energy. This discrepancy is intriguing, as one might expect the percentage favouring the technology's necessity for climate goals to align more closely with those advocating for an increased presence of nuclear energy in the energy mix.

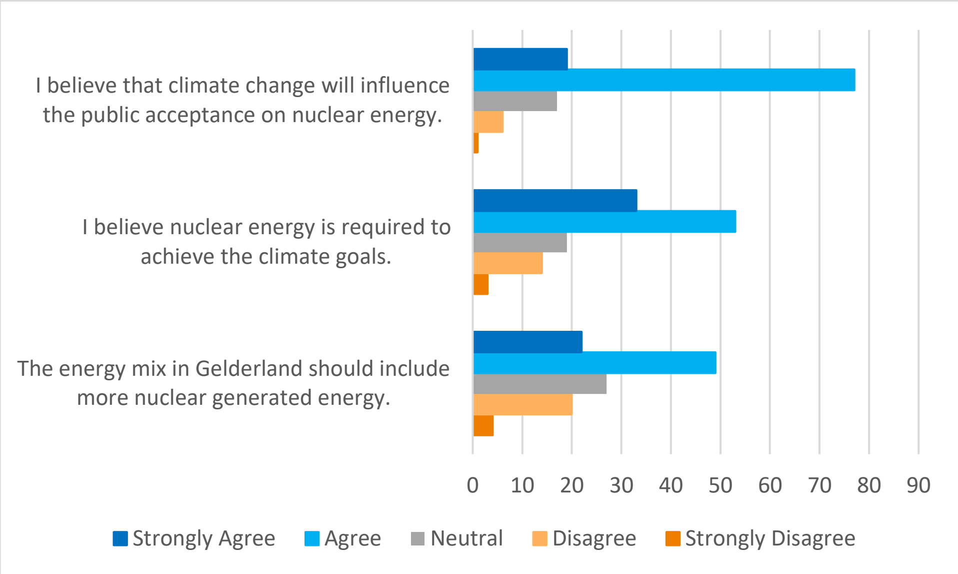

Figure 17 Survey results of the energy mix and public acceptance of nuclear power versus climate change

7.2.2.6. Risks and Benefits

This chapter presents the findings concerning the risk perception of the respondents. The risks were presented in the form of statements, asking participants to indicate their level of agreement by contemplating the question: 'I am concerned about nuclear energy because of,' followed by the provided statements. As previously mentioned, the respondents had five options to choose from, ranging from "strongly agree" to "strongly disagree." The results of this assessment are visually represented in Figure 18. It is important to note that these statements were derived from a combination of insights obtained through a literature study and interviews conducted during the research process.

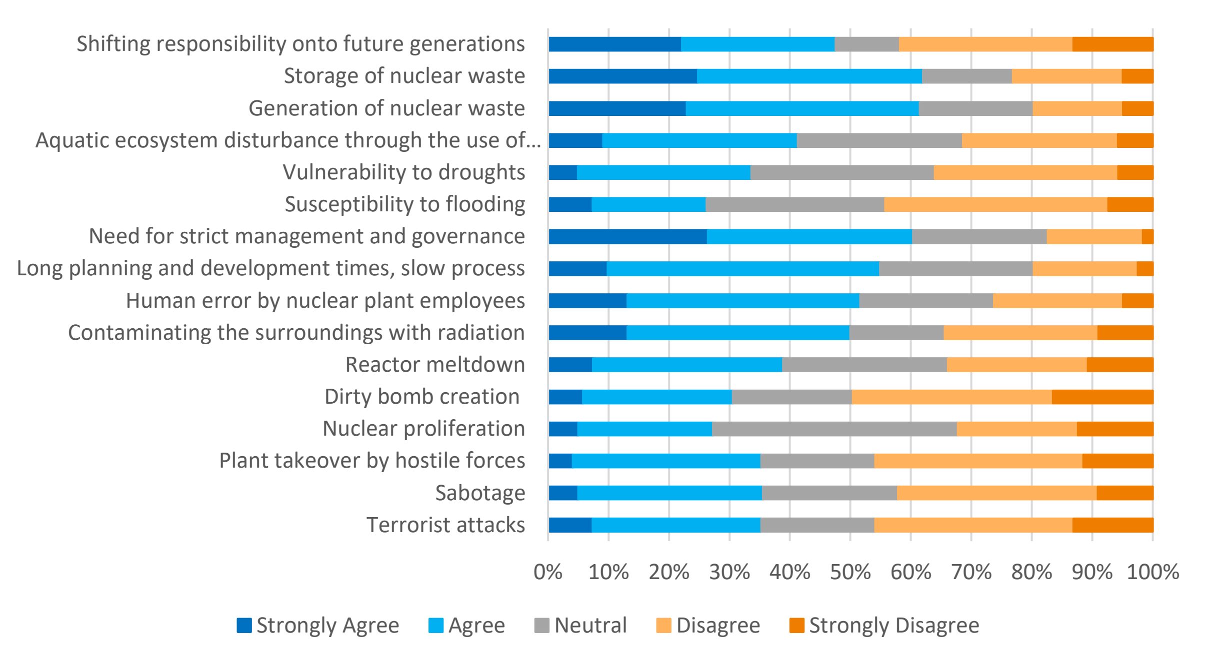

Figure 18 Survey results of risk perception of nuclear power

Similarly to the approach taken for the risks, mentioned earlier, the benefits of nuclear power were assessed in a comparable manner. Participants were presented with statements regarding the advantages of nuclear energy, and they were asked to indicate their level of agreement using a five-option scale, preceded by the prompt 'I appreciate nuclear energy because of'. These statements were formulated based on insights from both a literature study and interviews. The outcomes of this assessment are depicted in Figure 19, providing an overview of the survey results.

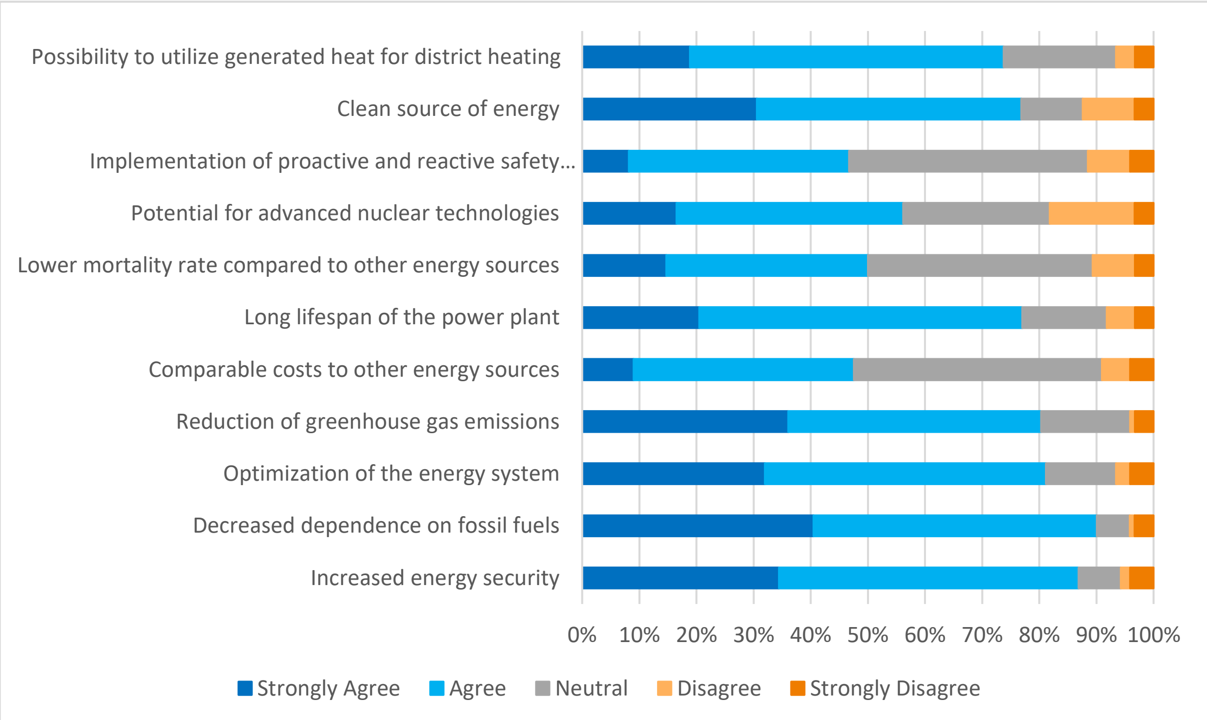

Figure 19 Survey results of benefit perception of nuclear power

Table 5 presents the top 3 risks most acknowledged by respondents and the top 3 risks least acknowledged by them. Additionally, the table displays the participants' most acknowledged benefits alongside the least acknowledged benefits. The corresponding percentages of participants who agreed on each matter are also provided.

Table 5 Top 3 of most and least acknowledged risks and benefits

Top 3	Most acknowledged risk	%	Least acknowledged risk	%	Most acknowledged benefit	%	Least acknowledged benefit	%
1.	Storage of nuclear waste	62	Susceptibility of flooding	26	Decreased dependence on fossil fuels	90	Implementation of proactive and reactive safety measures	47
2.	Generation of nuclear waste	62	Nuclear proliferation	27	Increased energy security	86	Comparable costs to other energy sources	48
3.	Need for strict management and governance	60	Dirty bomb creation	31	Optimization of energy system	81	Lower mortality rate compared to other energy sources	50

Table 5 and Figure 18 and Figure 19 show, that there is already more acceptance of the benefits, compared to the risks. Meaning that the majority of the participants is actually accepting the technology.

7.2.2.7. Additional factors

As the statements regarding the risks and benefits were pre-filled and unchangeable, an open-ended question was incorporated into the survey. This approach allowed participants to share their thoughts on risks and benefits they considered relevant to the public, which had not been addressed in the preceding questions. A thorough analysis of all answers was conducted, leading to the compilation of Table 6, which presents the top three most commonly occurring keywords. It is important to note that the majority of responses were in Dutch, and the translation to English may result in slight deviations from the original answers that were given.

Table 6 Most chosen answer of the open-ended question

Keyword	Number of replies	Percentage
Nuclear waste	7	6%
Sustainable	3	2%
Less pollution	3	2%

Intriguingly, waste emerges again as a significant concern for many respondents, even though it was already highlighted in the risks section of the survey, where it received the highest score of concern. This reiteration underscores its prominence among the participants' worries.

The benefits section does not specifically mention the sustainability of nuclear technology, as its sustainability is a subject of debate. Since uranium, the primary fuel for nuclear energy, is not a renewable source, the notion of sustainability is open to interpretation. If sustainability refers to being renewable for eternity, nuclear energy does not meet this criterion. However, if it implies lasting for a long time, it is still a subjective measure, and therefore difficult to call sustainable. Nevertheless, the benefits section does mention that NPPs have a long lifespan, so it is somehow incorporated in the research.

It is worth noting the irony of mentioning "less pollution" again in the benefits section, considering that nuclear waste itself can be considered a form of pollution if not adequately stored (Burhop, 1971). To address this contradiction, the survey includes the statement that nuclear energy is a "clean source of energy." However, this proposition still conflicts with the potential for nuclear waste to be considered pollution.

7.2.2.8. Policy instruments

Prior to implementing policy instruments within the FCM, the instruments were first presented to the survey participants. This approach aimed to obtain a comprehensive understanding of the participants' opinions on these instruments. By doing so, a clear perspective on the people's views regarding the proposed instruments was gathered, shown in Figure 20. These survey results can subsequently be compared to the outcomes of the scenario modelling conducted within the FCM. Such a comparison enables an assessment of the alignment between the FCM-based scenarios and the real-world perceptions obtained from the survey. The most favourable approach appears to be a knowledge transferable instrument. This instrument should encompass the risks, benefits, and safety measures associated with a specific nuclear energy plant that is potentially planned for construction. This way, people can be fully informed about the technology and develop opinions on whether to support the construction of the plant or not.

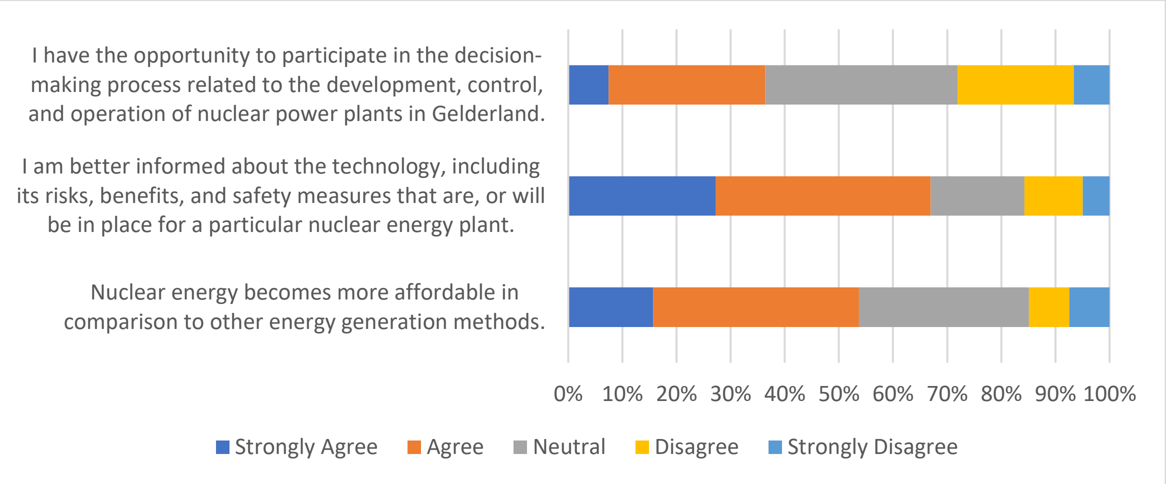

Figure 20 Survey result on most and least favourable policy instrument

7.3 FCM

This chapter integrates the results obtained from the interviews, surveys, and literature study as concepts within the FCM model. The interviews created the risks and benefits aspects related to nuclear energy, in order to test the acknowledgement of these risks and benefits by the public, using the survey. This was added to the FCM as risk perceptions and benefit perceptions. Furthermore, the interviews gave insight in possible effective policy instruments. The three most promising instruments were chosen by additional desk research and integrated as concepts within the FCM. These were then integrated into the survey, revealing the most and least favourable instrument, indicating the weight of the relations between the policy instrument and the targeted concept, which ware the concepts -supported by literature- knowledge, trust and economical aspects. The remaining concepts were the result of the initial performed background research, revealing the components of social acceptance. These were integrated in the survey, which enabled the provision of weights to the relations between the concepts. If the public opinion was not strong enough, or no relations were found between demographical factors and the acceptance of certain aspects of nuclear energy, it was decided to eliminate these from the model, in order to prevent an over complex. The following section will explain the created model first, including the concepts, relations and weights. Secondly, scenarios will be explained, and third, the FCM is assessed on density and complexity. Finally, the scenarios are run in the model, and the results are analysed.

Literature has shown that key elements in public acceptance of nuclear energy consists of trust in authorities and risk and benefit perceptions (Bronfman et al., 2012; Ho et al., 2019; Zhou & Dai, 2020) and that prominent governance aspects are information campaigns, tax incentives and public participation in the decision process (Guo & Wei, 2019b; Kikuchi, 2021; Sherlock, 2019; Sugiawan & Managi, 2019; Zhou & Dai, 2020).On the other hand, applying the social acceptance theory and policy instruments effects theory (Bressers & Klok, 1988; Bronfman et al., 2012),shows that some other less studied aspects may be important for the study's research questions. In particular, the combination of these acceptance aspects with the technology context (Devine-Wright, 2014),together with the effectiveness of the policy instruments, in the current situation, have not been studied in this configuration before. Based on these considerations, and upon the aim of developing a policy simulation tool, it was decided to develop a network of the concepts, elaborated in Table 7 and Table 8, which explains the meaning of the concepts and captures the interrelationships between the different elements that influence social acceptance. Appendix III shows the breakdown of the concepts, their source, and the initial weight that was assigned to them after the survey. The weights of the variables are calculated in the same manner as chapter 7.2.2.1.

Table 7 Concept name, meaning and source

Concept	Name	Meaning	Source
C1	Public Acceptance	Level of agreement on nuclear power by society	Survey, (Bronfman et al., 2012; Devine-Wright, 2014)
C2	Public trust	Level of trust in government and NPP employees	Survey, (Bronfman et al., 2012)
C3	Risk perceptions	Level of agreement with perceived risks of NPP	Survey, (Bronfman et al., 2012)
C4	Benefit perceptions	Level of agreement with perceived benefits of NPP	Survey, (Bronfman et al., 2012)
C5	Public knowledge	Level of knowledge about NPPs	Survey, (Devine-Wright, 2014)
C6	Climate change	Influence of Global warming	Survey, (Ahmad et al., 2023)
C7	Multiple small plants	Having multiple small NPP in Gelderland	Survey, (Devine-Wright, 2014)
C8	One large plant	Having one large NPP in Gelderland	Survey, (Devine-Wright, 2014)
C9	Governmental ownership and control	NPP owned and checked by the government	Survey, (Ho et al., 2019; Y. Kim et al., 2014)
C10	Private ownership and control	NPP owned and checked by private institution	Survey, (Ho et al., 2019; Y. Kim et al., 2014)
C11	Private ownership and governmental control	NPP owned by private institution and checked by government	Survey, (Ho et al., 2019; Y. Kim et al., 2014)
C12	Governmental ownership and private control	NPP owned by government and checked by private institution	Survey, (Ho et al., 2019; Y. Kim et al., 2014)
C13	Resident within EZ	Resident located within emergency zone of NPP	(Devine-Wright, 2014)
C14	Political aspects	Political risks and benefits of NPPs	Survey, UP, EN, (Alexander, 2006; Bragg-Sitton et al., 2020; Burke, 2022; Cravens, 2002; Crowley-Vigneau et al., 2023; Fushiki, 2013; Gyamfi et al., 2020; Jenkins et al., 2018; S. Kim et al., 2020; Y. Kim et al., 2014; Kurniawan et al., 2022; Mourogov, 2000; Pietzcker et al., 2021; Sarkodie & Adams, 2018; Schmiermund, 2023; Sethu et al., 2021; Yu et al., 2022)
C15	Environmental aspects	Environmental risks and benefits of NPPs	Survey, UP, EN, (Ahmad et al., 2023; Park et al., 2022; Samseth et al., 2012; Sarkodie & Adams, 2018; Shrader-Frechette, 2000; Värri & Syri, 2019)
C16	Economical aspects	Economical risks and benefits of NPPs	Survey, UP, EN, (Bersano et al., 2020; Gyamfi et al., 2020; Ho & Kristiansen, 2019; Pietzcker et al., 2021)

C17	Safety aspects	Safety risks and benefits of NPPs	Survey, UP, EN, (Alexander, 2006; Burke, 2022; Fushiki, 2013; S. Kim et al., 2020; Y. Kim et al., 2014; Mourogov, 2000; Ritchie, 2020; Schmiermund, 2023; VIJAYAN et al., 2013)
C18	Technology development aspects	Technological development (Kosowski & Diercks, 2021; Mathew, 2022; L. Wang et al., 2019; Yang et al., 2007)g et al., 2019; Yang et al., 2007)	
C19	Policy process	Process of creating plans and rules for decision-making	(Anderson, 2022; Benson & Jordan, 2015)
C20	Tax incentives	Reducing investment costs of building a NPP	Survey, IL, (Sherlock, 2019)
C21	Public information campaigns	Educate public about nuclear power, through targeted communication strategies	Survey, (Guo & Wei, 2019b; Sugiawan & Managi, 2019; Zhou & Dai, 2020)
C22	Public participation	Involve public in the decision process of NPP implementation	Survey, SS, (Kikuchi, 2021; Sugiawan & Managi, 2019)

Table 8 Concept interrelations and weight

C1, C19	0.5	C5, C4	0.44	C13, C1	-0.04	C18, C4	0.67
C2, C1	0.38	C6, C1	0.41	C14, C3	-0.52	C18, C15	0.67
C2, C3	-0.48	C6, C3	-0.41	C14, C4	0.78	C18, C16	0.67
C2, C4	0.7	C6, C4	0.41	C15, C3	-0.42	C18, C17	0.67
C2, C9	0.52	C7, C1	-0.08	C15, C4	0.74	C19, C20	0.5
C2, C10	0.01	C7, C13	-0.08	C15, C17	-0.42	C19, C21	0.5
C2, C11	0.26	C8, C1	0.08	C16, C3	-0.61	C19, C22	0.5
C2, C12	0.2	C8, C13	-0.08	C16, C4	0.61	C20, C16	0.24
C3, C1	-0.48	C9, C1	0.52	C16, C19	-0.61	C21, C5	0.37
C3, C13	-0.48	C10,C1	0.01	C17, C3	-0.48	C22, C19	0.25
C4, C1	0.7	C11, C1	0.26	C17, C4	0.61	C22, C2	0.05
C5, C1	0.44	C12, C1	0.2	C17, C14	0.61	C22, C5	0.05
C5, C2	0.44						

7.3.1 FCM Assessment

Before moving on to the scenarios, the FCM has to be tested first. The results are shown in Table 9. It shows that the density is 0.1. This indicates a simpler model, with less connections compared the total possible connections. The advantage of a less dense system is its understandability for stakeholders. It is easier to understand when there are less connections involved. Also it shows that it is a simplified representation of the system, with only the most important connections made. Furthermore, the system does not contain any receiver concepts, and a relatively low number of driver concepts. Indicated by a hierarchy index of 0, which means a democratic system. A democratic system means that the concepts have similar influence on each other, which means more collaboration between the concepts and are more adaptable to changes (Nápoles et al., 2018; Özesmi & Özesmi, 2004).

Table 9 FCM characteristics

FCM Properties	Value
Total concepts	22
Total connections	49
Density	0.1
Connections per concept	4.5
Number of driver concepts	4
Number of receiver concepts	0
Number of ordinary concepts	18
Hierarchy index	0.0

Table 10 shows the statistics of the concepts. Initial activation represents the current state of the concepts, which value was gathered through the survey. By calculation the indegree and outdegree of each concept, its centrality was determined. Which says something about the degree of importance of the concept. As visible, the most central concept is C4, which are benefit perceptions. Besides the many connections it has, the average of the benefit perception is influencing the social acceptance, while certain topics of benefit perception is influencing benefit perception at the same time. All of these benefits had a high score in the survey, and therefore leading to a high centrality. After that, risk perceptions have the highest centrality, due to the many connections and again, the high score due to the survey. Because the risks and benefits are calculated in a different way compared to most other concepts, they end up with a higher value, which has to be kept in mind. Finally, the third highest centrality is C1, public acceptance, what the research is all about. It has many connections, but because of the influence of factors with a lower weight, compared to the risks and benefits, it ended up not as first central concept.

Table 10 FCM concept statistics

Concept	Meaning	Initial Activation	Relations	Indegree	Outdegree	Centrality	Type
C1	Public Acceptance	0.00	13	3.60	0.50	4.10	Regular
C2	Public trust	0.38	9	0.49	2.55	3.04	Regular
C3	Risk perceptions	-0.48	8	1.96	0.96	2.92	Regular
C4	Benefit perceptions	0.70	9	4.96	0.70	5.66	Regular
C5	Public knowledge	0.44	5	0.42	1.32	1.74	Regular
C6	Climate change	0.41	3	0.00	1.23	1.23	Driver
C7	Multiple small plants	-0.08	2	0.00	0.16	0.16	Driver
C8	One large plant	0.08	2	0.00	0.16	0.16	Driver
C9	Governmental ownership and control	0.52	2	0.52	0.52	1.04	Regular
C10	Private ownership and control	0.01	2	0.01	0.01	0.02	Regular
C11	Private ownership and governmental control	0.26	2	0.26	0.26	0.52	Regular
C12	Governmental ownership and private control	0.20	2	0.20	0.20	0.40	Regular
C13	Resident within EZ	0.04	4	0.64	0.04	0.68	Regular
C14	Political aspects	0.13	3	0.61	1.30	1.91	Regular
C15	Environmental aspects	0.16	4	0.67	1.58	2.25	Regular
C16	Economical aspects	0.00	5	0.91	1.83	2.74	Regular
C17	Safety aspects	0.07	5	1.09	1.70	2.79	Regular
C18	Technology development aspects	0.67	4	0.00	2.68	2.68	Driver
C19	Policy process	0.00	6	1.36	1.50	2.86	Regular
C20	Tax incentives	0.00	2	0.50	0.24	0.74	Regular
C21	Public information campaigns	0.00	2	0.50	0.37	0.87	Regular
C22	Public participation	0.00	4	0.50	0.35	0.85	Regular

7.3.2 Scenarios, Results and Key Findings

The scenarios are created from the causal model of trust, the policy instrument suggestions from the interviews and the results of the survey. The three most promising instruments, namely, tax incentives, public information campaigns, public participation, were included in the survey (Wang et al., 2020; Zhou & Dai, 2020). According to the survey results, the most favourable to least favourable was as follows: Public information campaigns, tax incentives and public participation. Therefore, four scenarios are created, explained in Table 11. First, tax incentives are implemented in the model via increasing the initial activation to 1 and the relation of policy process to the concept to 1 as well, and inspecting the resulting effect on economic aspects. Thereafter, information campaigns are modelled via increasing the initial activation to 1 and the relation from policy cycle to the concept to 1 as well, and inspecting the result on public knowledge. Then, public participation is simulated via increasing the initial activation to 1 and the relation from policy process to the concept to 1 a well, and inspecting the result on public knowledge and public trust. And finally, all three policy instruments are implemented in parallel, by increasing their initial activation of all three concepts to 1 and their connection from policy process to 1 as well. At the same time, the resulting effect on other concepts are inspected too, if they significantly change. The simulations are further elaborated below, together with their results and key findings, followed by a summary of all four scenarios. In order to provide a concise and focused overview of the course of the scenario simulations, only the most influential and critical concepts are shown, based upon their centrality, together with all policy instruments. Consult Appendix V for the FCM figures for each scenario.

Table 11 Scenarios explanations, relations and goals

Scenario	Concept	Policy Instrument	Relation	Goal
1	C20	Tax incentives for nuclear power projects	Positively influencing C16: economical aspects	Enhance the affordability of nuclear power to bolster public perception of its benefits
2	C21	Public information campaigns using communication strategies	Positively influencing C5: Public knowledge	Educate the public about nuclear energy's risks, benefits, and safety measures for an unbiased perspective
3	C22	Public participation in the decision process of nuclear power in Gelderland	Positively influencing C2, C5 and C19: public trust, public knowledge and policy process	Enable public participation in nuclear power policy decisions, fostering trust and enhancing technology awareness
4	C20, C21, C22	Previous three policy instruments combined	As described above	Enhancing affordability, knowledge, and trust among the public

7.3.1.1. Scenario 1: Tax Incentives

The primary policy measure implemented in the model involves providing tax incentives for investments in nuclear power plants. This initiative was led by the Nuclaer innovation lead, a Canadian citizen who already experienced successful implementation of this policy instrument in Canada.

Notably, nuclear energy has recently become integrated into Canada's low carbon energy framework (Gully, 2023), setting a potential standard for the energy policy of Gelderland. The relatively lower investment costs associated with this technology could allow for more competitive consumer pricing, thereby fostering a positive perception of nuclear energy.

Incorporating this policy instrument into the FCM impacts the policy process positively, as well as influencing economic aspects in a favourable manner. Two other policy instruments, public information campaigns and public participation, are initially given a weight of 0 since they are not being utilized at the moment. Their connection to policy process is minimized to 0.01, acknowledging their potential relevance in future policy considerations. Running the scenario involves setting the connection strength from the policy process concept to the tax incentive at 1, reflecting the complete activation of this policy measure, meaning that the policy measure is being implemented. Additionally, the initial activation of tax incentives is elevated to 1, symbolizing the heightened financial support being offered. It's important to note that this concept isn't a static one, contrary to expectations, as the tax incentive is a one-time offer limited to the investment phase of the nuclear power plant project.

In Figure 21, the simulation's progression is illustrated. Only the central concepts and those directly targeted by the policy instrument are retained in the graph, with all other concepts removed to maintain focus.

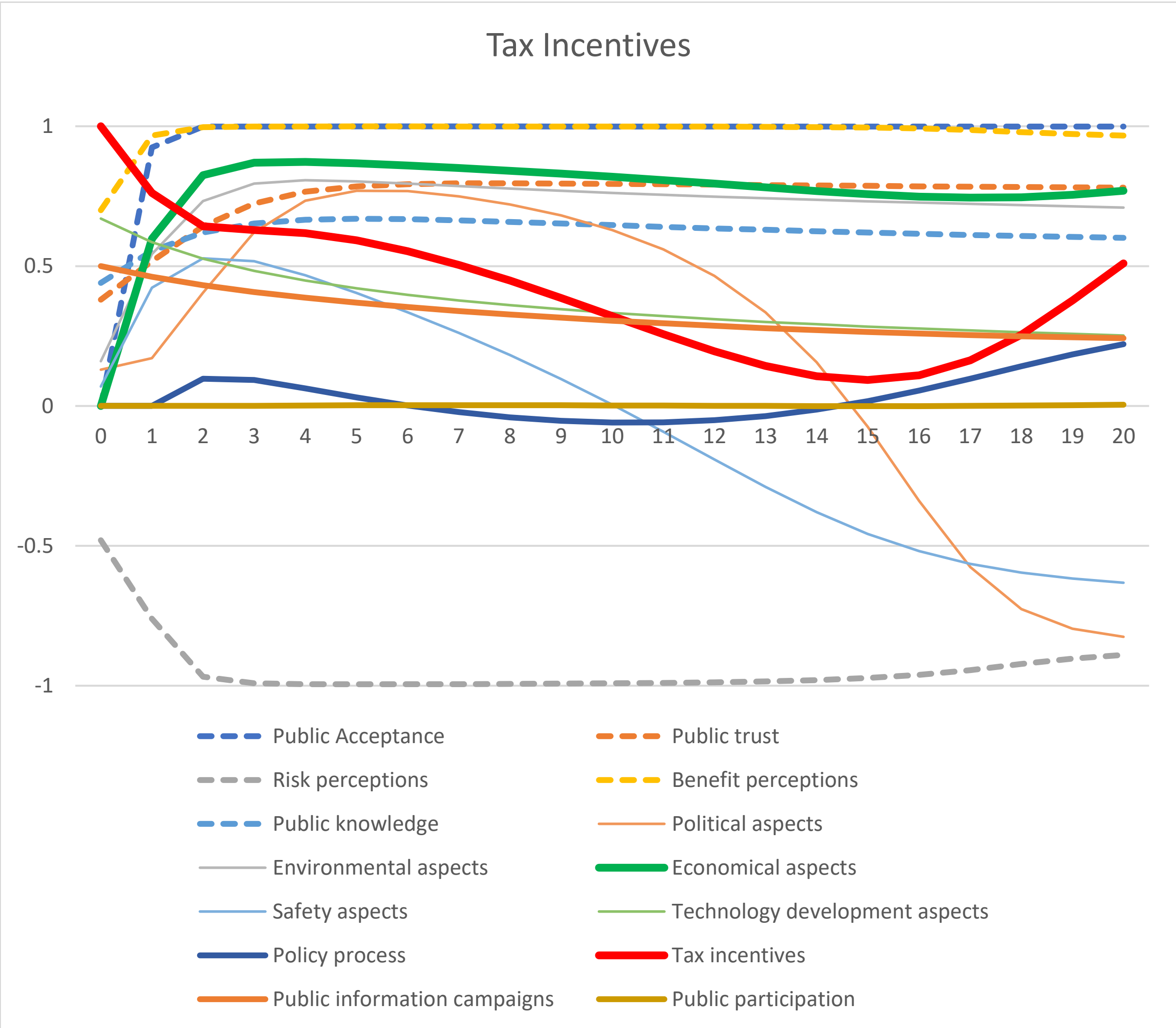

Figure 21 Simulation results of scenario 1, tax incentives

The objective behind implementing tax incentives was to enhance the affordability of nuclear power. As depicted in Figure 21, this objective was effectively accomplished as evidenced by the substantial rise in economic aspects, climbing from 0 to 0.87. This score stands out significantly when compared to other concepts within the FCM. Nonetheless, the impact of this incentive diminishes gradually over time, with a slight recovery towards the end. A plausible explanation lies in the timing of the tax incentive, which is granted only at the project's beginning. Consequently, the positive economic effects fade during the construction phase but resurge upon the plant's operationalization, attributing to improved consumer pricing.

Benefit perceptions rise remarkably, followed by a minor decline towards the simulation's end. This can be rationalized by the increase of public knowledge, which has a documented positive correlation with benefit perceptions (Wang et al., 2019). Conversely, risk perceptions and its trajectory mirror this pattern, although negatively. The underlying cause remains unexplained. Safety aspects experience a rapid climb followed by a decline, and eventually stabilizing. Subsequently, political aspects follow this path. The graph illustrates that as safety aspects decrease, political aspects adopt a more unfavourable stance (Cravens, 2002; S. Kim et al., 2020; Y. Kim et al., 2014). Despite optimizing the energy system and bolstering the province's energy independence, negative sides come up once the NPP becomes integrated into the energy mix, with a decrease of safety aspects, making it susceptible to power disruptions upon which households and industries rely (Burke, 2022). besides, tax incentives initially decline, likely due to expenses that are made, yet they show an eventual rise. This could be attributed to the renewed effectiveness of incentives as more NPP projects are potentially planned. Policy process witnesses a rise followed by a slight descent into the negative, gradually transitioning back to positive values. This trend might indicate that subsequent policy options become limited due to budgetary constraints. However, over time, this trend reverses, possibly indicating a recovery of financial resources for additional policy instruments as already mentioned, thereby sustaining the positive association with nuclear energy.

All in all, the simulation leads to higher public acceptance, which experiences a rapid surge and subsequently maintains stability throughout the simulation. Pertaining to policy instrument options, the necessity for public information campaigns diminishes, potentially owing to public contentment with improved energy pricing. According to the simulation, public participation becomes even less significant in this context.

7.3.1.2. Scenario 2: Implementation of Public Information Campaigns

The second scenario modelled involves the implementation of public information campaigns. In this approach, targeted communication methods are utilized to educate the public about the potential risks, benefits, and safety measures associated with the proposed nuclear power plant(s) in Gelderland. The communication strategies employed encompass a range of options, including public events such as seminars and conferences, leveraging social media platforms like LinkedIn and Instagram for document sharing, as well as traditional media outlets such as newspapers, television, and radio. Although numerous other opportunities for public engagement exist, these examples serve to illustrate the point. The overarching aim is to enhance public awareness, striving to offer an honest and comprehensive perspective on nuclear energy in a neutral manner. The intention is to empower the public to form a fair opinion about the technology.

Given the short-term nature of this policy instrument, it remains dynamic rather than static. This is because this is a one-time targeted campaign, which is not lasting for multiple years. Its initial activation is set to 1, and the weight linking policy process to this instrument is adjusted to 1 as well. Correspondingly, the connections from policy process to the other two instruments are reduced to 0.01, mirroring the reasoning applied in scenario 1. The results are illustrated in Figure 22.

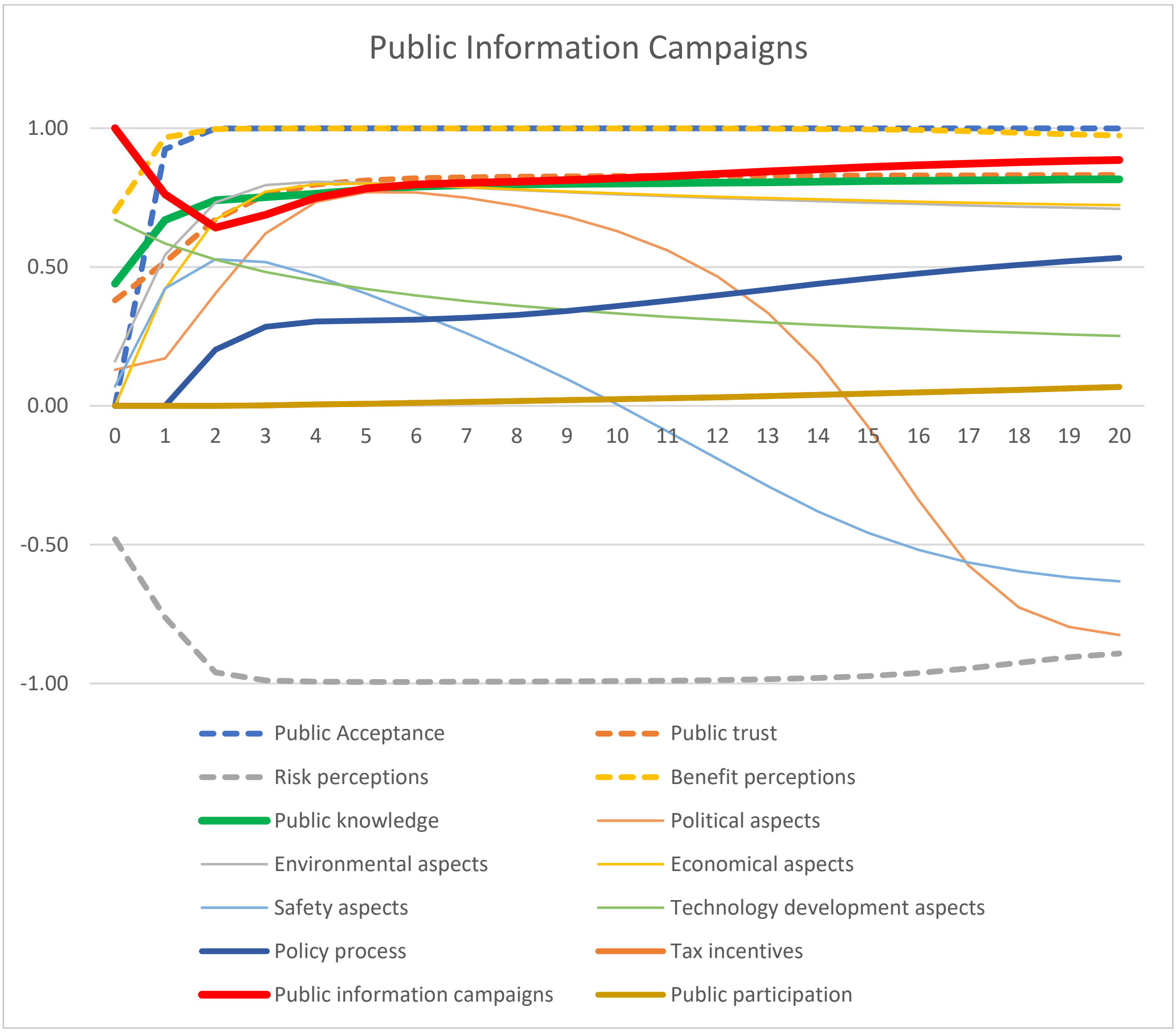

Figure 22 Simulation results of scenario 2, public information campaigns

Incorporating public information campaigns produces strikingly similar outcomes to the tax incentives policy. This is exactly in line with past findings on environmental-related risks, where it says that providing information about flood risks publicly, addresses the imbalance within the housing market related to flood risks (Votsis & Perrels, 2016). Hence, enhancing public knowledge about nuclear energy could potentially yield equal, or even greater benefits than tax incentives. The similar outcomes compared to scenario 1, holds true for metrics such as public acceptance, risk perceptions, benefit perceptions, economical aspects, however, this one does not increase at the end of the simulation, political aspects, environmental aspects, safety aspects, and technology development aspects. This suggests that these factors might be more influenced by the presence of a NPP itself, without the implementation of any specific policy instrument. Introducing an NPP might naturally evoke safety concerns, subsequently translating into political instability, as indicated by the simulation. Furthermore, the introduction of public information campaigns triggers a rapid rise in public knowledge, which eventually stabilizes after a brief period. Consequently, the effectiveness diminishes, likely due to the majority of individuals already being informed. Attaining further public engagement becomes challenging, as the initial campaign surge captures the widest audience, followed by diminishing impact as newer campaigns take over (Aaker, 2011).

Lower costs compared to tax incentives result in the gradual increase of policy process throughout the simulation. This could arise from having resources available for additional policy instruments or due to the perception that information campaigns alone are insufficient, prompting exploration of alternative policies and thus fostering policy process. Nonetheless, tax incentives, which closely follows the trajectory of public participation, shows only marginal growth. This suggests a potential lack of popularity for tax incentives in this context.

7.3.1.3. Scenario 3: Public Participation

Public participation serves as the final implemented policy instrument, advocated for by the energy ethics professor who strongly support its application. This approach holds global popularity as a policy instrument, and when pursued to the fullest extent, contributes to nuclear energy and its generation as common good (He et al., 2013; O'Connor & van den Hove, 2001). The intention behind public participation is to ensure that the general public becomes intricately involved in the decision-making process regarding nuclear energy in Gelderland. Its primary objectives encompass fostering greater trust in both the government, the technology and the employees. Simultaneously, it aims to enhance public knowledge about the technology, thereby enabling individuals to develop unbiased perspectives.

To simulate this scenario, the presence of the factors represented in the two previous scenarios is diminished in the same manner as in the former simulations. The initial weight of public participation is heightened to 1, and the impact of policy process on this concept is also set to 1. Given the continuous nature of public participation, this concept remains static. The public's involvement in the decision-making process becomes an ongoing engagement rather than a one-time occurrence.

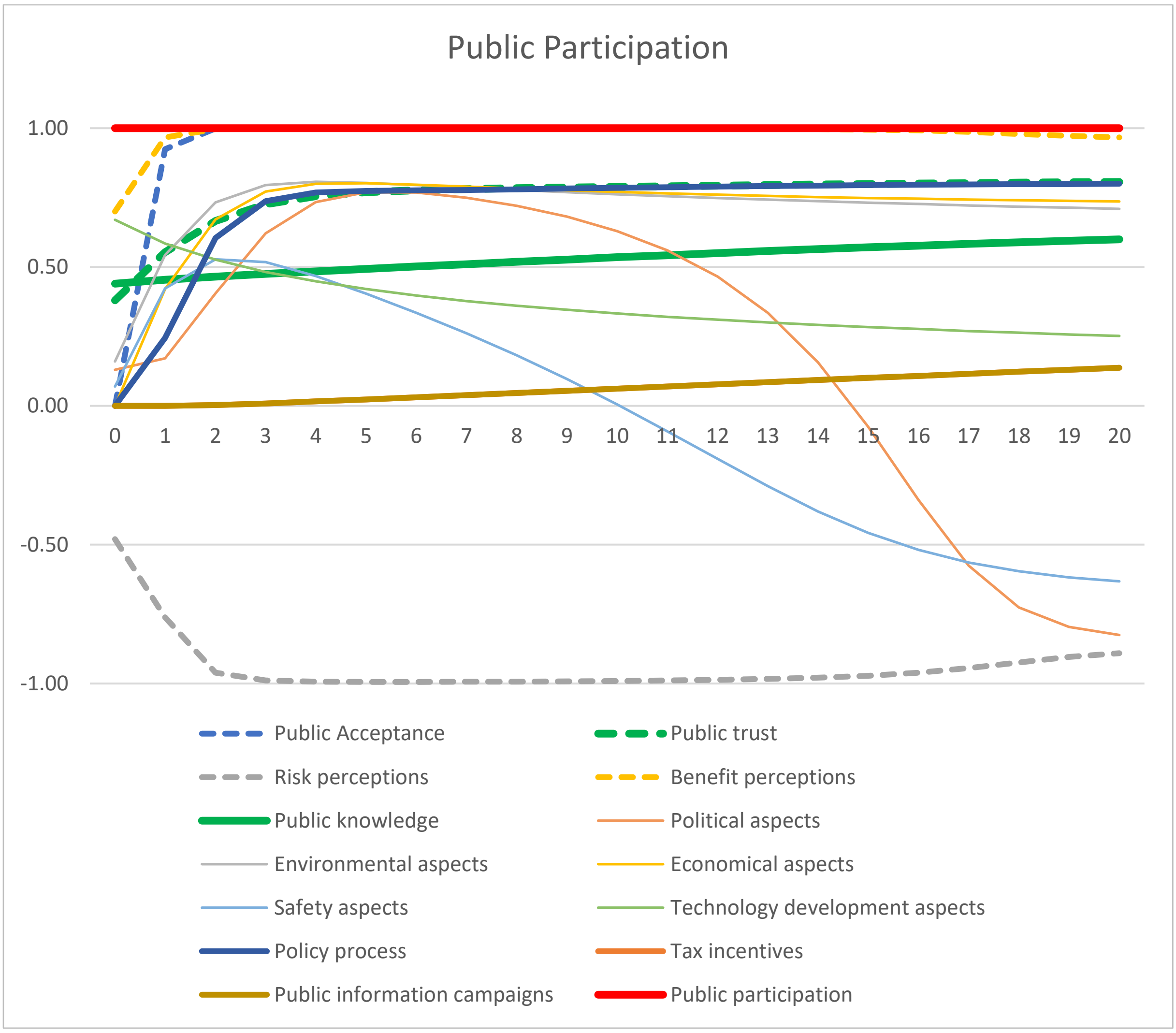

Figure 23 Simulation results of scenario 3, public participation

Once again, the same outcomes as observed in the first two scenarios happen for public acceptance, benefit perceptions, political aspects, environmental aspects, safety aspects and technology development aspects, as visible in Figure 23. Namely, that public acceptance rises fast and remains stable throughout the rest of the simulation, an increase of benefit perceptions and a decrease of risk perceptions, and a concerning decrease of safety and political aspects. However, a slight variation arises in risk perception, which scores 0.02 lower compared to the previous two scenarios. This divergence might be attributed to the heightened participation element, which potentially brings forth additional risk considerations due to the public's engagement, possibly exposing previously unexplored topics (O'Connor & van den Hove, 2001). The demand for public information campaigns experiences a gradual increase, although at a slow pace. This can be attributed to the fact that those who do not participate remain uninformed, necessitating the continuation of these campaigns. Tax incentives follow a similar trajectory, advancing at a consistent rate, as the appeal of lower-cost energy probably persists among the public. While public trust exhibits a steady rise, it lags behind the rapid progress observed in the case of public information campaigns. This phenomenon might be explained by the fact that individuals not joining in the participation process remain less informed, resulting in a slower trust-building process.

Remarkably, policy process attains notably high scores in this scenario. This could be attributed to the direct engagement with the public, thereby enhancing the coordination of policy process attempts and facilitating decision-making processes (O'Connor & van den Hove, 2001).

7.3.1.4. Scenario 4: Combined Policy Instruments

This final simulation represents a combination of scenario 1, 2 and 3, encompassing the implementation of all proposed policy instruments. As stated by Johnstone et al. (2017), employing diverse policy instruments is vital for achieving multifaceted objectives. Theoretically, the incorporation of all three scenarios should result in an increase of public knowledge, enhancement of public trust, and an increase in affordability. The outcomes are depicted in Figure 24.

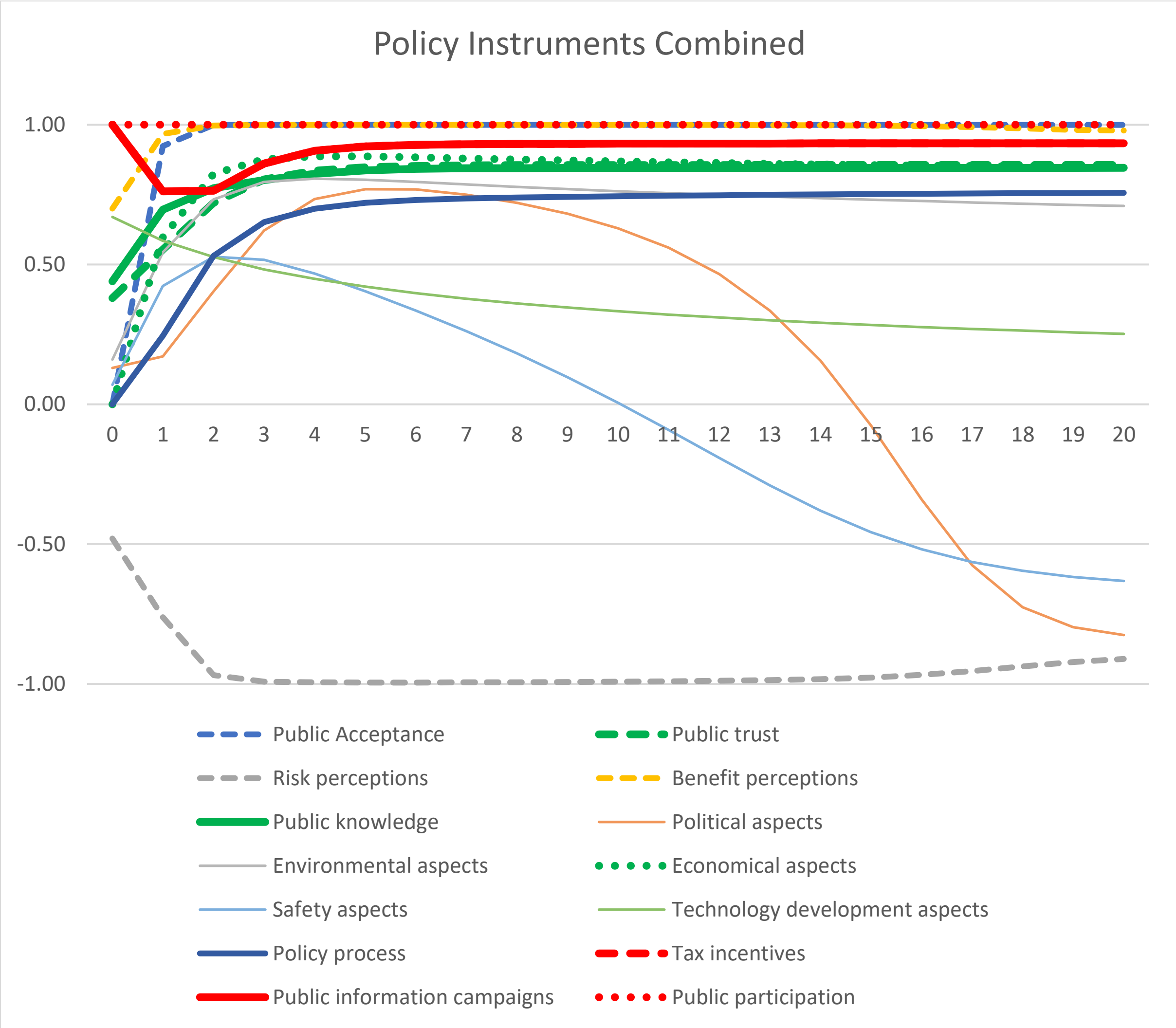

Figure 24 Simulation results of scenario 4, policy instruments combined

The trajectories of public acceptance, risk perceptions, benefit perceptions, political aspects, safety aspects and technology development aspects mirror those observed in scenario 3. Conversely, the three specifically targeted concepts, namely public trust, public knowledge and economical aspects, reveal rapid climbs followed by stabilization around a score of 0.85. This outcome is exceptionally favourable. Similarly, policy process experiences an upward trend without encountering significant challenges over the simulation period.

The behaviour of public information campaigns aligns with that observed in scenario 2, where it was introduced as a standalone policy instrument. In contrast, tax incentives exhibit distinct behaviour compared to scenario 1. This parameter copies the curve of public information campaigns, potentially due to the combined influence of public participation. It's plausible that the public might exhibit resistance to ongoing tax incentives, but they might favour alternative implementations such as a continuous reduction in production-related taxes rather than just investment-based incentives.

7.3.1.5. Simulation summary

A comprehensive summary of the outcomes for each scenario is presented in Figure 25, offering an overview of the initial state (state 0) and the final values reached after 20 iterations when a fixed point attractor was achieved. This refers to the point of balance that is reached within the system, meaning that interconnected concept values do not fluctuate anymore, and influences and feedback loops stabilised.

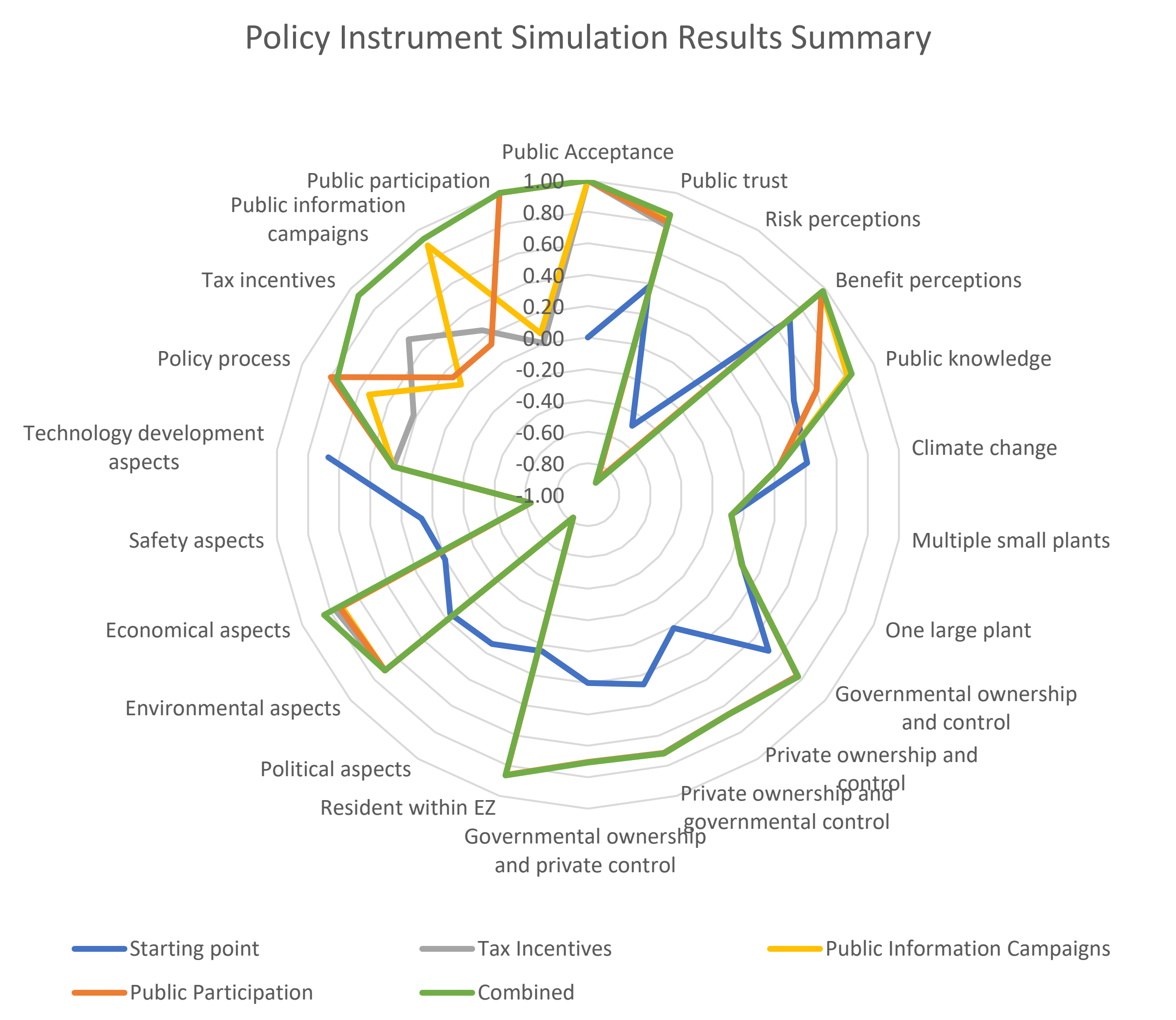

Figure 25 Simulation results summary

In accordance with all previous simulations, safety aspects exhibit an initial decline, where increasing safety concerns outweigh the perceived benefits and safety measures. This can potentially lead to the emergence of a political crisis, possibly caused by the safety concerns. Despite this estimated chain, the expected negative influence on social acceptance does not materialize in any of the simulations, which could indicate fundamental flaws in the model's logic (Hatwágner et al., 2019). Another noteworthy trend is observed in technology development aspects, which remain positive but experience a gradual decline over time. This may be attributed to a lack of research and development funding in the model, as it is not connected with economic aspects. However, no scientific literature was identified to verify these findings. Furthermore, given the recurring nature of these outcomes across all simulations, it appears that this effect accompanies the implementation of an NPP, regardless of the introduction of policy instruments. This contradicts the research objectives.

The overarching objective of augmenting trust, knowledge, and affordability is achieved across all scenarios. Graphs illustrating these concepts for each scenario are illustrated in Figure 26, Figure 27 and Figure 28. Public trust witnesses improvement in all cases, with the most substantial enhancement achieved when all three policy instruments are included. A similar trend is observed for public knowledge. Tax incentives, however, can lead to diminishing public knowledge and trust over time. Solely relying on public participation results in the slowest knowledge growth according to the simulation, rendering it the least effective of the three to implement. Economical aspects are most positively impacted when all three policies are combined. Nonetheless, in the long term, tax incentives could exert the most positive influence on affordability.

In summary, the combination of all policy instruments produces the most favourable outcomes. However, it requires further future research to assess the economic feasibility of this approach and explore potential additional effects beyond trust, knowledge, and affordability. Despite the models limited capacity to represent the absolute truth, the study successfully revealed unexpected outcomes. Given the difficulties of predicting the behaviour of the complex system of public acceptance, these results could prove valuable when considering the implementation of an NPP alongside associated policy instruments.

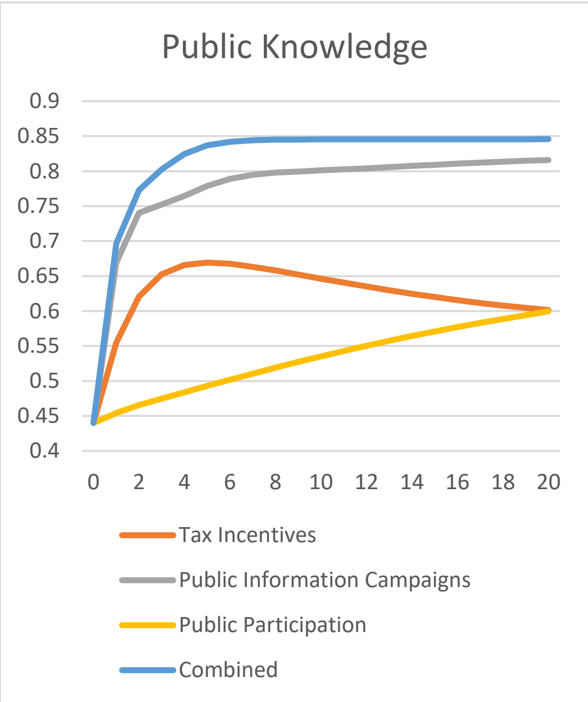

Figure 26 Simulation results summary of public knowledge

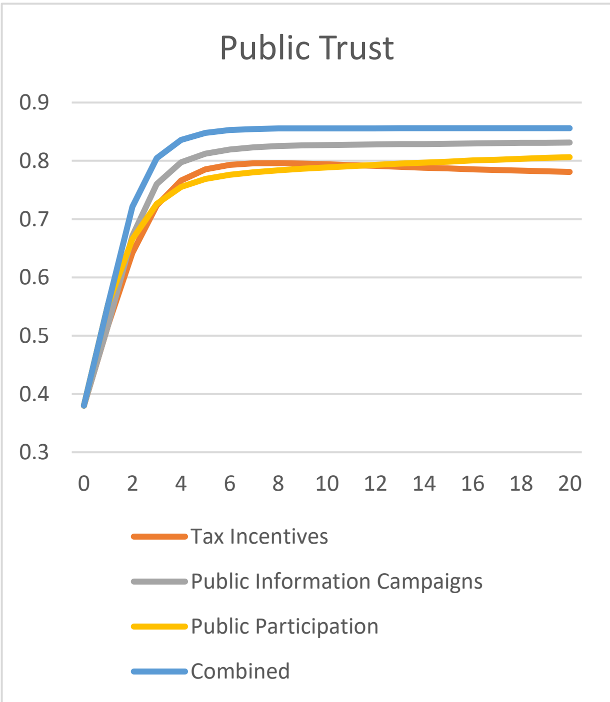

Figure 27 Simulation results summary of public trust

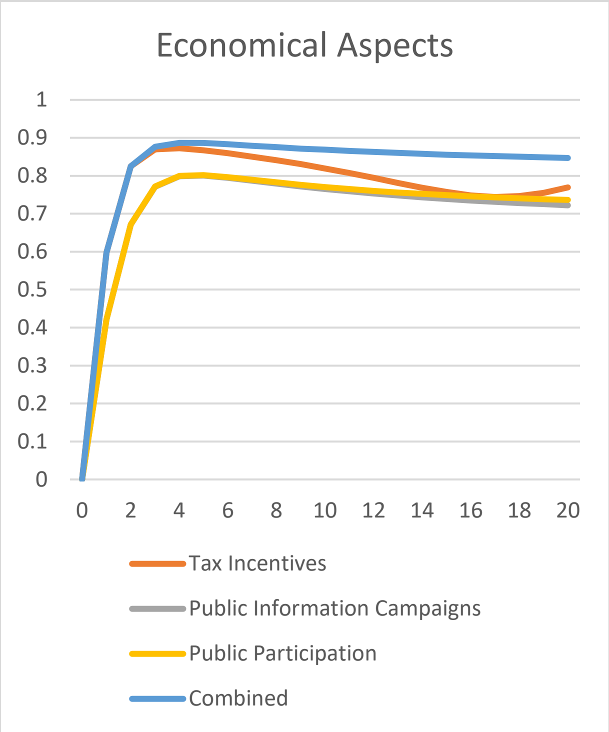

Figure 28 Simulation results summary of economic aspects

8. DISCUSSION

This chapter discusses the key findings highlighted in sections 7.1.2, 7.2.2, and 7.3.2. It establishes connections between the most important results obtained from interviews, surveys, and scenario simulations, and the earlier conducted desk research.

In the pursuit of a comprehensive understanding of public acceptance, this research adopted a synthesized approach (Bronfman et al., 2012; Devine-Wright, 2014; Y. Kim et al., 2014). The relations between the concepts and their weights were obtained from the literature study and survey. However, literature itself gave conflicting signals, and therefore, the model is subject to discussion (Huang et al., 2010; S. Wang et al., 2019). Moreover, nuclear energy is a sensitive subject, which makes it important to line out again, that the modelling results only offer additional insights on top of existing desk research and experiences from similar situations. As such, these results should be regarded as insights for policy making rather than a definitive guide (Guo & Wei, 2019b; Keramitsoglou & Tsagarakis, 2013).

The research unveiled public acceptance as a pivotal component within the policy cycle, capable of influencing the effectiveness of policy decisions. Therefore it can be useful apply the policy process on public acceptance itself, the research explored ethically sound policy instruments to impact it. To do that, public acceptance and the policy cycle had to be investigated thoroughly. Leading to the identification of socio-psychological, context and personal factors, acquired from the research from Devine-Wright (2014). However, survey results showed that contextual factors were less related to public acceptance compared to socio-psychological and personal factors, since 27% on average remained neutral on these stances. Therefore, future research could reconsider incorporating context factors. Gender and age played substantial roles, and trust in the government and NPP personnel and knowledge received strong emphasis from participants, aligning with studies by Bronfman et al, (2012) and Winkleby et al, (1990). This resulted in the need for policy instruments targeting trust and knowledge. Literature and the interviews with the nuclear energy professor and nuclear innovation lead showed that a better affordability could also increase the acceptance (Sherlock, 2019). This led to the formulation of three policy instruments: tax incentives, public information campaigns, and public participation. However, survey results indicated less enthusiasm for participation in the decision making process (36%) and greater interest in enhancing knowledge about the technology's aspects (67%). The simulation of these instruments assessed their effectiveness on knowledge, trust, and economic dimensions. Trust and economic aspects experienced positive influence across all instruments, albeit with slight variations. Tax incentives and public participation showed the least effect on knowledge improvement, with tax incentives even causing a decrease in positive influence. In contrast, public participation exhibited a slower increase in positive influence. Remarkably, the model's reaction to safety and political aspects deviated from anticipated patterns, manifesting a political crisis, yet this phenomenon is lacking any scientific explanation. However, this difference was within the intended scope of the FCM's purpose: to unveil unforeseen scenarios (A. J. Jetter & Kok, 2014). Nevertheless, this result is not taken into account as result of the policy instruments, since it seems to be a consequence of the implementation of a NPP itself. All three policy instruments showed positive relationships on the targeted concepts: trust, knowledge and economical aspects increased. Among the scenarios, Scenario 4, encompassing a blend of all three policy instruments, emerged as the most effective strategy in terms of public knowledge, trust, and economics (Sherlock, 2019; S. Wang et al., 2019). To implement these policies, the research findings must be shared with the Province of Gelderland. Nonetheless, a feasibility study must be performed to establish costs, which could potentially limit its implementation.

Despite the efforts to employ optimal methods for yielding robust outcomes, it's important to acknowledge that the research does have its limitations. The next chapter will explore the limitations of this study in more detail.

8.1 LIMITATIONS

To begin with, the number of survey participants was insufficient. Ideally, a larger and more precisely targeted group of participants would be preferable to accurately reflect the population of Gelderland. The sensitive nature of the topic posed challenges during data collection, with potential biases due to non-cooperation of the people with very opposing viewpoints.

Additionally, this study is primarily focused on nuclear energy. Although the survey touched on the broader energy mix, the FCM analysis exclusively considers nuclear energy as the sole energy source. This approach falls short of capturing the complete reality. Therefore, to better understand the dynamics of nuclear energy, a comprehensive approach might require zooming out to consider the broader energy system, acknowledging its interconnections beyond nuclear energy by including the wider energy context within the FCM, since nuclear energy will certainly be a component of the energy mix.

Furthermore, the model offers a simplified representation of reality, disregarding certain unmentioned factors that might also influence social acceptance. Similar limitations apply to the incorporation of policy instruments, with existing literature predominantly highlighting positive influences and establishing solely positive connections to public acceptance. In addition, this research solely delved into social effects. However, effective policy implementation hinges on more than just public acceptance; factors like stakeholder engagement, planning, capacity, and resources play vital roles (Mthethwa, 2012). Similar concerns apply to the present situation: Ukraine's conflict with Russia has created uncertainties about its nuclear plants, while Europe's electricity shortage highlights the importance of energy independence. As a result, the benefits of nuclear energy in this situation are greater than its drawbacks in Gelderland, as shown by the survey. While Ukrainian citizens will probably be more focused on the risks. Additionally, constructing the FCM was notably challenging, with multiple iterations needed to achieve a compact but representative model.

It's important to note that the simulation did not encompass the entire policy process, as outlined in the methods. Instead, only policy effects were integrated, overlooking the significance of the policy process itself. Another limitation is the exclusion of alternative scientific studies questioning the value of social acceptance studies. Despite suggestions from the energy ethics professor to look into literature criticising this method due to its outdated nature, sufficient other investigations have demonstrated its effectiveness.

Additionally, the phrasing of questions in interviews and surveys can influence outcomes. Variations in question formulation can give diverse responses, potentially affecting results. Additionally, this study discusses one large plant and several smaller plants without specifying the quantity of nuclear-generated energy. This absence may impact the replies, as the prominence of nuclear energy witin the energy mix – whether a minor or major contributor – could yield contrasting perceptions.

Lastly, the concept of plant takeover by hostile forces includes cyber-attacks as well, though this may not have been fully comprehensible to all participants. Furthermore, certain questions were improperly constructed; those lacking a strongly agree to strongly disagree scale proved challenging to assign weights to. This discrepancy led to varying weight scales and consequently reduced the model's reliability.

9. CONCLUSIONS

Given the current Russia-Ukraine conflict, the urgency for energy independence has highlighted nuclear energy as a viable addition to the clean energy mix. However, empirical studies on public acceptance and its drivers of this technology in Gelderland are lacking, crucial for informed decision-making on plant implementation and suitable policy instruments. This research aims to provide Gelderland with insights into how the current public acceptance of nuclear energy influences the functioning of tax incentives, public participation campaigns and public participation.

The simulations revealed that the interplay of concepts influencing public acceptance of nuclear energy led to an increase in acceptance, which may not necessarily be attributed solely to the three policy instruments. This effect could potentially be caused by the already high baseline acceptance among Gelderland residents. However, significant differences were observed in the behaviour of the influential concepts—trust in the government and NPP personnel, public knowledge, and economic aspects—across the simulations. Among the three policy instruments—tax incentives, public information campaigns, and public participation—all led to a rapid rise in public acceptance. Their combined implementation yielded the most promising outcomes across public knowledge, trust, and economic aspects. Subsequently, public information campaigns exhibited the strongest results when implemented individually, followed by public participation which had the slowest increase in public knowledge but was the only instrument which continued to increase public trust over time. Tax incentives demonstrated comparatively weaker results, especially in terms of trust, but showcased a notable impact on economic aspects and, as the only instrument, an increase at the end.

These findings offer practical insights for the Province of Gelderland when selecting suitable instruments to enhance public acceptance components. Additionally, they shed light on the current public acceptance landscape of nuclear energy in Gelderland, highlighting the existing majority of accepting the technology, alongside notable opposition. This requires further investigation into the reasons for opposition and addressing issues related to trust, knowledge, and economic concerns. With this clear understanding of the policy instruments' effectiveness, the Province of Gelderland can use these results as guidance for policy decisions related to this subject. Recommendations for moving forward are provided below.

9.1 RECOMMENDATIONS

This study's conclusions and identified limitations provide a basis for the recommendations that can further enhance the understanding of public acceptance of nuclear energy. They are elaborated in the chapters below.

9.1.1 Extend concepts, interrelations and research policy instrument effects

To advance the understanding of how public acceptance of nuclear energy influences the impact of policy instruments, further analysis of the interconnections among FCM concepts is required. The current concepts are created by use of literature, interviews, and survey results. However, to gain practical results, real-world policy application is needed, potentially in a related case or region. The analysis of these results align with the evaluation phase of the policy process. Upon examining the outcomes, the Province of Gelderland gains the ability to accurately assess the effectiveness of the policy instruments. This assessment includes determining the validity of existing concepts and interrelationships and identifying opportunities for policy enhancement, if needed. Of particular importance is the examination of citizens who express disapproval or fear towards nuclear technology. Understanding the cause of their fear or disapproval, and the influence of policy instruments on these opinions is a crucial aspect of this investigation.

9.1.2 Evaluate Feasibility and Trade-Offs

Assess the feasibility of applying all three policy instruments at the same time, in terms of costs, effectiveness, and potential risks. Moreover, an essential decision needs to be made: is the implementation of all three instruments truly essential, or could comparable outcomes be achieved through the application of one or two? While this theoretical research indicates the latter's viability, the exploration of practical cases is essential to validate this perspective. Which could be done in the same way as stated above, in similar cases or starting off by implementing it in smaller regions.

9.1.3 Enhance the FCM Model and Expand the Simulation

The complex nature of public acceptance of nuclear energy, demands a more comprehensive exploration. The existing FCM model should be enhanced by breaking down the FCM into more specific concepts. This extension could be achieved through a more comprehensive desk research, enabling an examination of similar cases in other countries or regions, and how this can be incorporated into the model. The utilization of FCM as an approach to discover the functionalities of particular policies could increase its success if relationships between concepts were more precise, by studying the related cases. Consequently, additional desk research is essential to precisely define the environmental, economic, political, and technical dimensions of the technology within the model, which creates a wider perspective on the acceptance of nuclear energy. This exploration should reveal how these dimensions interconnect, a detail that wasn't thoroughly explored in the current study. Additionally, it could clarify the interplay of each of these dimensions with public acceptance. This broader perspective will contribute to a more holistic and accurate representation. Moreover, conducting a larger-scale research effort can provide a more reliable study.

9.1.4 Examine Public Participation Effectiveness

Explore the effectiveness of public participation within decision-making processes. Address the lack of interest which was identified in the survey and delve into potential challenges coming from limited participant involvement. This can be achieved by conducting interviews with individuals who do not prefer to engage in the decision-making process, which identifies participation barriers. These insights can be used in the policy process concerning public participation. It's important to note that a survey might not be the most suitable approach, as those reluctant to participate in decision-making may similarly show reluctance to participate in a survey. This examination can shed light on strategies to enhance the engagement of a wider range of stakeholders.

9.1.5 Quantify Nuclear Energy's Role in the Energy Mix

While the current study touched on nuclear energy within the energy mix, future research could quantitatively define its role more precisely. Investigate the implications of nuclear energy as a dominant energy source and explore how such a scenario might influence public acceptance. Incorporating these recommendations into future research efforts will contribute to a more nuanced, comprehensive, and accurate understanding of public acceptance of nuclear energy, and the possible policy instrument effects, ultimately supporting policymakers and stakeholders in making informed decisions.

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APPENDIX I – SEMI-STRUCTURED INTERVIEW QUESTIONS

I am doing research about the current public opinion of nuclear energy, and how this is affected by policy instrument implementation. The objectives of my research are to find out the current status of public acceptance in Gelderland, and to give recommendations to the Province of Gelderland for policy process, when they are planning to implement nuclear energy plants.

Contact information:

Name: Nadine Hendrikse

Email: n.n.hendrikse@student.utwente.nl

Mobile number: +31627488851

The information gathered by this interview will not be shared, and will be stored securely. Furthermore, it will only be used for the purposes of the master study. On top of that, the input will be stored, analysed and presented in a way that does not identify the individual or organisation, without consent.

The interviewee is able to stop the interview at any time, for any reason, if they feel compelled to do so. Furthermore, the consent of the interviewee will be asked to use their input in the ways stated above. At the end of the research, the interviewee will receive the thesis report when finished.

The following questions are asked to gather more information about the influences of social acceptance on nuclear energy, and to investigate possible policy instruments that are applicable for policy process when implementing nuclear power plants:

1. What do you think of the recent development, that nuclear energy counts as a sustainable investment, and might therefore be regarded as green energy? (although Uranium is required for the process)
2. What are, according to your knowledge, risks and benefits of nuclear energy, using fission technology?
3. What is the most common accident (and most likely to happen nowadays)? How does this affect the areas around the plant? Can you say something about the extent of the accident? How far can it reach, in km?
4. How, do you think, are these influencing public acceptance of nuclear energy?
5. How are contextual factors of nuclear energy influencing public acceptance? See below for examples. Are there any contextual factors to add?
    - Scale: large scale level, power station (not household level etc.)
    - Ownership: State owned or privately owned
    - Type of nuclear technology: Nuclear fission
6. Will these factors positively or negatively affect public acceptance?
7. In what way does the government has influence on social acceptance of nuclear energy?
8. Could public acceptance be influenced by use of policy instruments? If so, what kind of policy instruments might be good to implement before implementing a nuclear energy plant?
9. Do you have anything to add, or suggestions for this research?

APPENDIX II – SEMI STRUCTURED INTERVIEW RESULTS

Risks
Nuclear energy professor:

- Risks during wartime: the presence of a nuclear power plant during a war can pose risks if it is taken over by hostile forces, or the possibility of terroristic attacks on the powerplant, potentially leading to catastrophic consequences. Furthermore, it can be a target of sabotage, which makes the country more vulnerable.
- Location of nuclear power plants: the location of nuclear power plants, particularly in low-lying areas, can pose risks related to potential flooding. At the same time, when the plant is located next to a river which desiccates in periods of draughts, can obstruct energy generation, and therefore threatens energy security.
- Potential for reactor meltdown: the potential for a reactor meltdown due to failure in regulating the burning of enriched uranium fuel rods, which could release a large amount of energy in a short period of time.
- Challenges of long-term waste storage: the difficulty of storing nuclear waste for long periods of time, particularly in countries with geological limitations, such as the Netherlands.
- Slow process of energy transition: the slow process of developing policy strategy, and building nuclear power plants can delay the progress of energy transition efforts.
- Challenges of high-level nuclear waste: the long lifespan of high-level nuclear waste, which can remain hazardous for thousands of years and pose (unwanted) responsibilities to future generations.
- Risks of nuclear proliferation: the potential for nuclear materials from nuclear power plants to be used for nuclear weapons, leading to proliferation risks.
- Human error: the possibility of an employee or reactor operator to make a mistake, which can have consequences for her/himself and/or people around him/her.
- Risk of dirty-bomb: by stealing radioactive waste, and creating a bomb from it. Possibility to threaten countries or areas with the release of this weapon. Even though there is only a probably a small amount of radioactivity, it can cause a lot of panic.
- Continuous mismatch of demand and supply: Nuclear power plants produce continuous energy, but the demand for electricity fluctuates. This can result in a continuous mismatch between the amount of electricity being produced and the amount of electricity being consumed. They cannot continuously switch on and off to match the fluctuating demand, like gas power plants can, as they operate at maximum capacity for extended periods of time.
- Reliance on other sources for peak demand: Nuclear power plants provide a base load of electricity, but they may not be suitable for meeting peak demand due to their steady output. Other sources, such as gas power plants, need to be used to meet the peaks in demand, which can pose challenges in terms of reliability and availability.
- Need for long term-planning and large investments: Building a nuclear power plant requires significant upfront investment, and the time from planning to actual operation can take many years. The breakeven point, or the point at which the investment is fully recovered, may also take a long time, which requires long-term planning and financial commitment. This might be a no-go for big investors.

Engineer in the nuclear industry

- Waste disposal: The risk of nuclear waste is relatively low in terms of volume, but there is a need for proper long-term storage solutions. Some isotopes in nuclear waste can remain

radioactive for thousands of years, posing a certain risk. Furthermore, European legislation obliges to store the waste in the country where the waste is generated. However, Dutch geographical features may be less suitable for waste storage, while other countries (e.g. Finland) already possess proper storage locations.
- Nuclear power plants are designed to contain radioactive isotopes. Multiple barriers are in place to ensure the radioactivity is contained. For example, before leaving the facility, personnel has to pass multiple radiation monitors.
- Conflict: geopolitical tensions or conflict can disrupt the operation of the nuclear power plants leading to potential energy supply disruptions. However, this is not unique to NPP's.
- Environmental and climate risks: Nuclear power plants require a large amount of water cooling, and changes in water availability due to climate change can impact their operation. Sea level rise, storm surges, and extreme weather events can also pose risks to coastal nuclear power plants. However, NPP's have to adapt their design to the location, and the design undergoes a "periodic safety review" every 10 years.
- Governance and management: Effective governance and management of nuclear power plants are crucial to ensuring safety. Independent oversight (IAEA) is in place to ensure a culture where safety is the overriding priority, at all times.

Nuclaer innovation lead:

- Too technical to understand: Nuclear energy is a complex technology, which makes it hard to understand for a large group of people. Also, it takes effort to for most of the people to understand nuclear energy properly.

Benefits

Nuclear energy professor:

- Energy security and energy independence: Improving energy security and energy independence, because less dependent on fuel supply from other countries. Also creates less dependency on fossil fuels.
- Continuous energy production: Nuclear power plants can generate electricity consistently without being affected by weather conditions or fluctuating energy demand. The load factor or duty factor of nuclear power plants is typically over 90%, meaning they are almost always operating at maximum capacity. They are suitable for providing a baseload power, which is necessary to meet the constant demand for electricity.
- Energy system optimization: Nuclear energy can complement renewable energy sources by providing a consistent source of electricity that can help balance out the intermittent nature of renewable energy. This can result in more efficient and cost-effective energy systems by reducing the need for energy storage or curtailment of excess electricity from renewable sources.
- Low greenhouse gas emissions: Nuclear energy is considered a low-carbon source of electricity as it does not produce greenhouse gas emissions during the generation of electricity. This can help reduce the overall carbon footprint of a country or region and contribute to efforts to combat climate change.
- Comparable costs to other energy sources: The overnight costs of building a nuclear power plant, which is the initial investment required, may be high (around 10 billion euros), but the levelized cost of electricity (LCOE), which takes into account the total cost of electricity

production over the lifespan of the reactor, can be competitive with other sources of electricity generation, such as solar or wind power.

- Long lifespan: nuclear energy can provide electricity for several decades, with a typical lifespan of 40-60 years. This allows for long-term planning and stability in the energy supply.
- Safety measures in nuclear reactor design: Nuclear reactors are designed with active and passive safety measures, such as regulation of fuel burning rate, expansion coefficients, and containment structures, to prevent meltdowns and ensure safe operation. This has resulted in a low number of accidents despite the existence of older technologies in some of the 430 nuclear power plants worldwide.
- Reduction of Deaths Compared to Other Industries: occurrence of a nuclear disaster is relatively rare (e.g., one in a thousand years) compared to daily casualties in other industries, such as automobile accidents.
- Potential for Advanced Nuclear Technologies: Newer nuclear technologies, such as advanced fuel burning and thorium reactors, have the potential to reduce the amount and longevity of nuclear waste, making nuclear energy a more sustainable option in the long term.
- Indestructible Containment Structures: Nuclear reactors are designed with containment structures that are highly durable and can withstand extreme conditions, including during wartime or if the facility is overtaken by unauthorized personnel. This adds an additional layer of safety to prevent catastrophes.
- Potential for Waste Reduction: Advanced nuclear technologies have the potential to significantly reduce the longevity of nuclear waste from 100,000 years to 1,000 to 500 years, addressing concerns about long-term waste management.

Engineer in the nuclear industry:

- Dispatchable: nuclear power plants can react on the electricity demand. Which makes it able to complement weather dependent energy sources. Nevertheless, it is better to operate at a constant rate for fuel efficiency and equipment load.
- Low emissions: nuclear energy has very low emissions, with very low CO_2 emissions, i.e. grams of CO_2/MWh, similar to wind energy. The process itself does not emit any greenhouse gases. Making it a clean source of energy, in terms of green house gas emissions.
- Stable prices: nuclear energy production is batch-driven, allowing for consistent energy supply for about a year without being dependent on market prices. This makes operation expenses less volatile to the market compared to gas-based energy.
- Potential for heat utilization: nuclear power plants generate significant amounts of heat as a by-product, which can be utilized for district heating or for industries nearby, increasing the overall efficiency of the plant.

Possible policy instruments

Nuclear energy professor: Note: effectiveness is dependent on the public trust in the government and in other actors involved in the implementation or running of nuclear energy plants.

- Subsidies: Providing financial support to incentivize investment in nuclear energy, such as direct subsidies to nuclear energy projects or subsidies for research and development of nuclear technologies.
- financial incentives: Setting financial conditions, such as tax breaks or other incentives, to reduce risks for investors and make nuclear energy more attractive for investment. This can

include de-risking measures where the government takes on a portion of the financial risk as insurance or guarantee.

- Performance standards: Setting requirements for the results to be achieved, without mentioning the technology to achieve that result, allowing the industry to determine how to meet those targets. This can encourage investment in research and development for improving the technology. (regulation policy)
- Public persuasion: engaging in communication efforts to persuade the public about the benefits and safety of nuclear energy. This can involve relying on trusted sources, such as credible politicians or expert, to convey information and build public trust.

Energy ethics professor:

- Ensuring participation: policy instruments can be used to ensure participation of citizens, for example, by involving them in decision-making processes, such as stakeholder workshops, and ensuring that everyone has the opportunity to participate. Therefore, the public can be co-responsible for the choices and discussions surrounding a nuclear energy.

Nuclaer innovation lead:

- Tax incentives: the government can create tax incentives on the investment of building a nuclear power plant. Which makes electricity generation cheaper, and more affordable for the public. This was already successful in Canada.

APPENDIX III – FCM CONCEPTS SUBSTANTIATION

Class	Type	Concept	Variables	Weight	Source
General	Acceptance	C1	Public acceptance		Survey, (Lehtonen et al., 2020; Weinberg, 1972)
	Trust	C2	Trust in authorities	0,28	Survey, (Bronfman et al. 2012)
		C2	Trust in employees	0,48	Survey, (Bronfman et al. 2012)
	Familiarity	C5	Knowledge	0,44	Survey, (Wang & Kim, 2018)
Contextual	Scale	C7	Multiple small plants	-0.08	Survey, (Devine-Wright, 2014)
		C8	One large plant	0.08	Survey, (Devine-Wright, 2014)
	Location	C13	Residence within emergency planning zone	0,04	Survey, (Devine-Wright, 2014)
	Ownership	C9	Government ownership and control	0.52	Survey, (Ho et al., 2019; Y. Kim et al., 2014)
		C10	Private ownership and control	0.01	Survey, (Ho et al., 2019; Y. Kim et al., 2014)
		C11	Private ownership and government control	0.26	Survey, (Ho et al., 2019; Y. Kim et al., 2014)
		C12	Government ownership and private control	0.20	Survey, (Ho et al., 2019; Y. Kim et al., 2014)
Risks	Political	C3, C14	Political conflict		NEP, EN, (Cravens, 2002)
		C3, C14, C17	Terroristic attack	-0,46	Survey, NEP, (Kim et al., 2014)
		C3, C14, C17	Target of sabotage	-0,47	Survey, NEP, (Kim et al., 2020)
		C3, C14, C17	Plant takeover by hostile forces	-0,45	Survey, NEP, (Kim et al., 2020)
		C3, C14, C17	Nuclear proliferation	-0,47	Survey, NEP, NE, (Mourogov, 2000)
		C3, C14, C17	Dirty bomb	-0,43	Survey, NEP, (Schmiermund, 2023)
		C3, C14, C17	Reactor meltdown	-0,50	Survey, NEP, (Fushiki, 2013)
		C3, C14, C17	Contaminate surrounding	-0,55	Survey, (Alexander, 2006)
		C3, C14, C17	Electricity supply disruption		NE, (Burke, 2022)
		C3, C14	Human error	-0,58	Survey, (Sethu et al., 2021)

		C3, C14	Slow process of energy transition	-0,61	Survey, NEP, (Pietzcker et al., 2021)
		C3, C14	Strict management and governance	-0,67	Survey, NE, (Kurniawan et al., 2022; Yu et al., 2022)
	Environmental	C3, C15, C17	Flooding	-0,45	Survey, NEP, (Ahmad et al., 2023)
		C3, C15, C17	Drought	-0,49	Survey, NEP, (Ahmad et al., 2023)
		C6	Climate Change	0,41	Survey, (Ahmad et al., 2023)
	Waste	C3, C15	Nuclear waste	-0,65	Survey, NEP, NE, (Park et al., 2022), (Samseth et al., 2012)
		C3, C15	Nuclear waste storage	-0,65	Survey, NEP, NE, (Park et al., 2022), (Samseth et al., 2012)
		C3, C15	Future generation responsibility	-0,54	Survey, NEP, (Shrader-Frechette, 2000)
	Economic	C3, C16	Large investment		NEP, (Pietzcker et al., 2021)
		C3, C16	Long time of planning and building	-0,61	Survey, NEP, (Pietzcker et al., 2021)
Benefits	Political	C4, C14	Energy security and energy independence	0,78	Survey, NEP, (Jenkins et al., 2018), (Sarkodie & Adams, 2018)
		C4, C14	Independent of fossil fuels	0,81	Survey, (Crowley-Vigneau et al., 2023)
		C4, C14	Continuous energy production		NEP, (Gyamfi et al., 2020)
		C4, C14	Energy system optimization	0,76	Survey, NEP, (Bragg-Sitton et al., 2020)
	Economic	C4, C16	Competitive costs compared to other sources	0,61	Survey, NEP, (Bersano et al., 2020)
		C4, C16	Stable prices		NE, (Gyamfi et al., 2020; Ho & Kristiansen, 2019)
	Safety	C4, C17	Proactive and reactive safety measures	0,60	Survey, NEP, NE, (Vijayan et al., 2013)
		C4, C17	Low number of deaths compared to other industries	0,63	Survey, NEP, (Ritchie, 2020)
	Technology	C4, C18	Potential for advanced nuclear technologies	0,63	Survey, NEP, (Mathew, 2022)
		C4, C18	Long lifespan	0,72	Survey, NEP, (Mathew, 2022; L. Wang et al., 2019; Yang et al., 2007)
		C4, C18	Dispatchable		NE, (Kosowski & Diercks, 2021)
	Environmental	C4, C15	Low greenhouse gas emissions	0,77	Survey, NEP, NE, (Sarkodie & Adams, 2018)

		C4, C15	Potential for heat utilization	0,71	Survey, NE, (Värri & Syri, 2019)
Policy	Formation	C19	Policy process		(Anderson, 2022; Benson & Jordan, 2015)
	Instruments	C20	Tax incentives	0,24	Survey, NIL, (Sherlock, 2019)
		C21	Public Information campaigns	0,37	Survey, (Guo & Wei, 2019b; Sugiawan & Managi, 2019; Zhou & Dai, 2020)
		C22	Public participation	0,05	Survey, EEP, (Kikuchi, 2021; Sugiawan & Managi, 2019)

APPENDIX IV – SURVEY QUESTIONS

The survey was available in Dutch and English. Below, the introductory text, questions, and closing text are shown.

Dear participant,

Zie knop rechtsboven voor Nederlands.

I'm Nadine Hendrikse, a master's student at the University of Twente, and I welcome you to take part in this research study for my master's thesis focused on energy management. The purpose of this survey is to investigate the present state of public views on nuclear energy in Gelderland, with the final goal to improve nuclear energy governance. To accomplish this, I will be creating a tool that simulates the potential impact of various policy instruments on social acceptance.

If you are a resident of Gelderland who is 15 years or older, I highly appreciate your participation in this study. For participants under the age of 16, informed consent from both the minor and their parent(s) or legal representative(s) is required.

Your involvement in this survey will contribute significantly to enhance the understanding of the current public acceptance of nuclear energy in Gelderland. Nuclear energy is a powerful source of electricity generation, with the potential to enhance energy security and reduce reliance on fossil fuels. While it offers optimized energy systems, reduced greenhouse gas emissions, and long operational lifespans, it also poses risks such as security threats, environmental vulnerabilities, and challenges related to waste management. It is crucial to weigh both the benefits and drawbacks when considering the role of nuclear energy in the broader energy landscape.

The estimated time to complete this survey is approximately 10 minutes. The survey is best completed on a computer, and not recommended on a mobile phone.

Please note that your participation is entirely voluntary, and you can withdraw from the study at any time. Rest assured that your anonymity will be preserved, and the principles of the GDPR will be strictly followed. The gathered information will be used solely for research purposes and will not be utilized beyond the scope of my master's thesis.

If there are any questions or comments about this survey, please reach out to me via email: n.n.hendrikse@student.utwente.nl.

Thank you for taking part in this survey! Your opinion is very appreciated.

By participating in this study, I confirm that I live in Gelderland and that I am either above the age of 16 or have obtained consent from my parent(s) or legal representative(s) to participate in this survey. Furthermore, I approve the terms stated in the introduction of this survey and I commit to providing honest responses throughout the survey.

Do you consent to these terms? Yes/No

In which province do you live?

What is your postal code?

What is your birth year?

How do you identify your gender?

What is your highest level of completed education?

In the following section, you will find statements. Please indicate your level of agreement with each statement by selecting one of the following options: "Strongly agree," "Agree," "Neutral," "Disagree," or "Strongly disagree."

- I am familiar with the concept of nuclear energy.
- Nuclear energy is difficult for me to understand.
- I have knowledge about the risks and benefits associated with nuclear energy.
- The energy mix in Gelderland should include more nuclear generated energy.
- I believe nuclear energy is required to achieve the climate goals.
- I believe that climate change will influence the public acceptance on nuclear energy.
- I am not concerned if my residence falls within the evacuation zone of a nuclear power plant, which means it is located within 10 km from my residence.
- I trust the government's goodwill and competence in effectively governing nuclear safety and security.
- I trust the employees working at a nuclear plant, believing they neither have the ability nor the intention to create unsafe situations.
- If a nuclear power plant were to be built in Gelderland, I would prefer several small plants located in different areas rather than a single large plant.

Choose your most favourable option from the following:

- Nuclear power plants should be owned and controlled by the Dutch government.
- Nuclear power plants should be owned and controlled by a private corporation.
- Nuclear power plants should be owned by a private corporation and controlled by the Dutch government.
- Nuclear power plants should be owned by the Dutch government and controlled by a private corporation.

In the following section, you will find a statement followed by multiple risks associated with nuclear power plants. Please indicate your level of agreement by selecting one of the following options: "Strongly agree," "Agree," "Neutral," "Disagree," or "Strongly disagree."

I am concerned about nuclear energy because of:

- Terrorist attacks
- Possibility of sabotage
- Risk of plant takeover by hostile forces

- Nuclear proliferation
- Potential for creating a dirty bomb
- Risks of reactor meltdowns
- Possibility of contaminating the surroundings with radiation
- Risk of human error by nuclear plant employees
- Slow process of energy transition due to long planning and development times
- Need for strict management and governance
- Its susceptibility to flooding
- Its vulnerability to droughts
- Disturbance to the aquatic ecosystem through the use of surface water
- Generation of nuclear waste
- Storage of nuclear waste
- Shifting responsibility onto future generations

In the following section, you will find a statement followed by multiple benefits associated with nuclear power plants. Please indicate your level of agreement by selecting one of the following options: "Strongly agree," "Agree," "Neutral," "Disagree," or "Strongly disagree."

I appreciate nuclear energy plants because of:

- Increased energy security
- Decreased dependence on fossil fuels
- Optimization of the energy system
- Reduction of greenhouse gas emissions
- Comparable costs to other energy sources
- Long lifespan of the power plant
- Lower mortality rate compared to other energy sources
- Potential for advanced nuclear technologies
- Implementation of proactive and reactive safety measures
- Clean source of energy
- Possibility to utilize generated heat for district heating

Besides the mentioned risks and benefits, what other factors shape your opinion on nuclear energy? Please provide your response using keywords.

This last part of this survey will contain three statements. Please indicate your level of agreement with each statement by selecting one of the following options: "Strongly agree," "Agree," "Neutral," "Disagree," or "Strongly disagree."

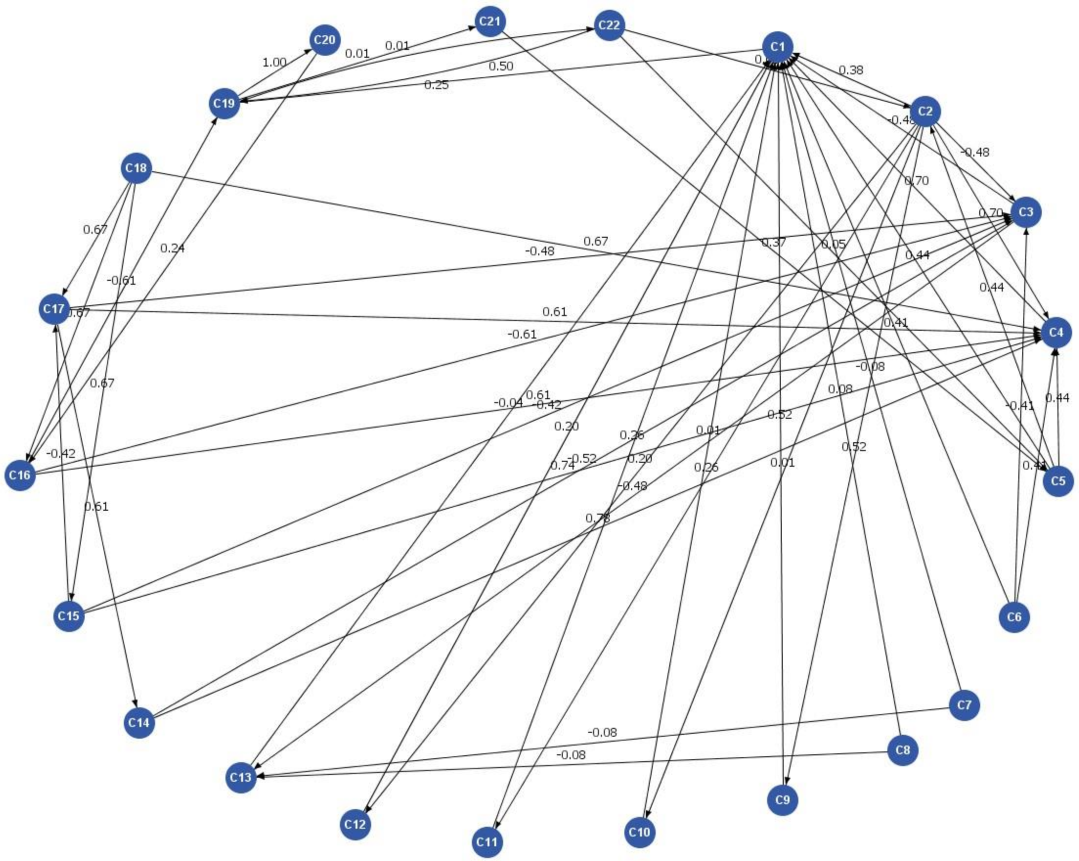
My approval of nuclear energy would increase if:

- Nuclear energy becomes more affordable in comparison to other energy generation methods.
- I am better informed about the technology, including its risks, benefits, and safety measures that are, or will be in place for a particular nuclear energy plant.
- I have the opportunity to participate in the decision-making process related to the development, control, and operation of nuclear power plants in Gelderland.

Thank you for taking the time to complete this survey! Your feedback is valuable and will contribute to the understanding of the current public opinion on nuclear energy in Gelderland.

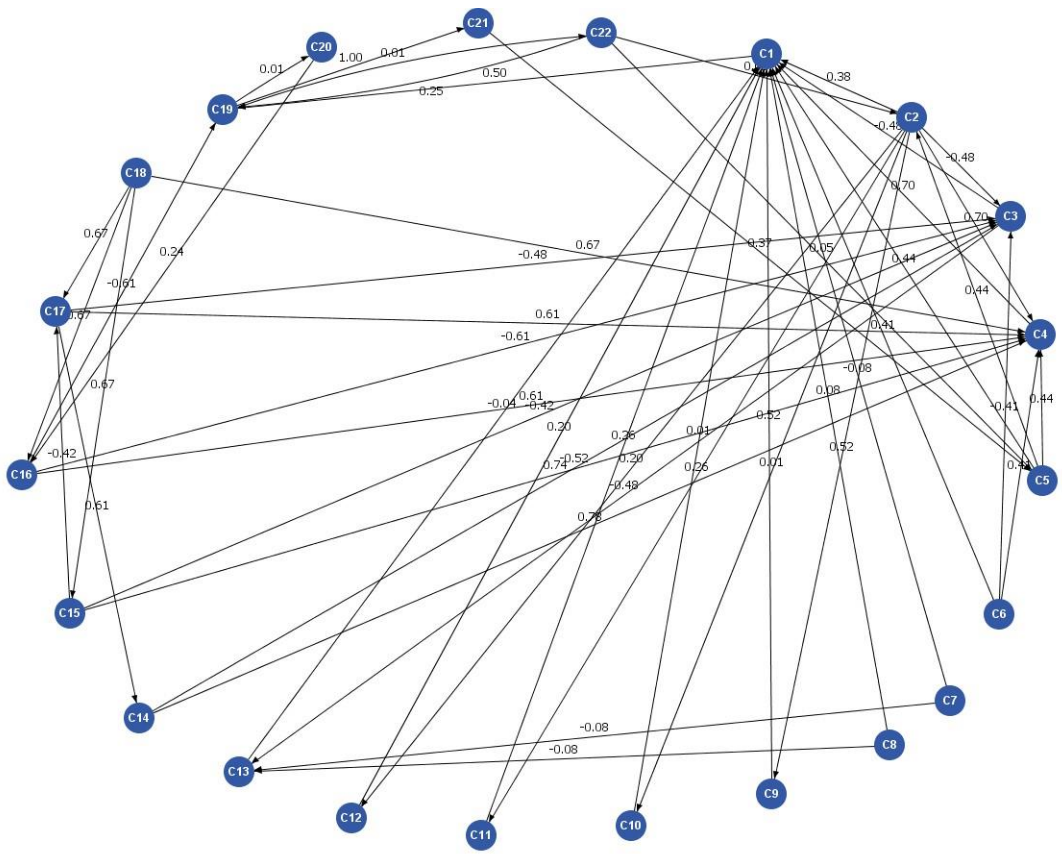
I would like to keep you NEPdated about the outcomes of this study. If you are interested in receiving this data, please feel free to contact me at n.n.hendrikse@student.utwente.nl.

APPENDIX V - FCM REPRESENTATION



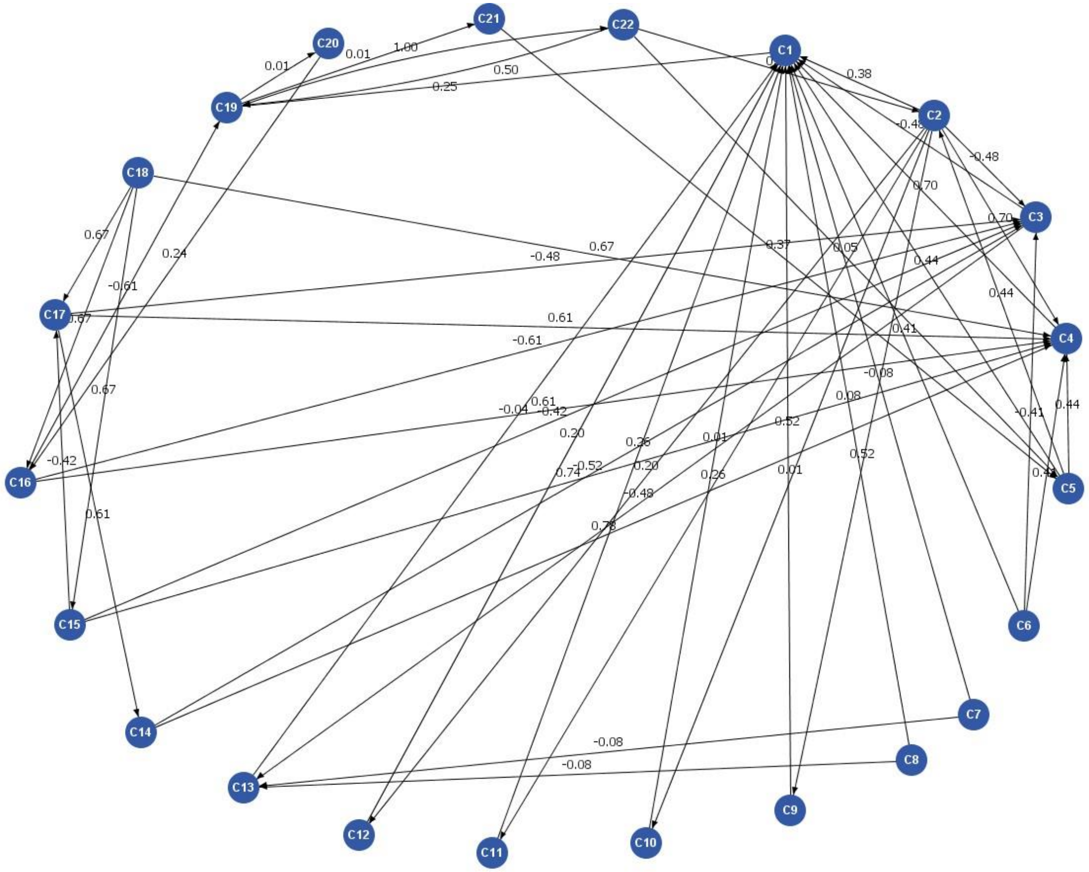
C1	Public Acceptance
C2	Public trust
C3	Risk perceptions
C4	Benefit perceptions
C5	Public knowledge
C6	Climate change
C7	Multiple small plants
C8	One large plant
C9	Governmental ownership and control
C10	Private ownership and control
C11	Private ownership and governmental control
C12	Governmental ownership and private control
C13	Resident within EZ
C14	Political aspects
C15	Environmental aspects
C16	Economical aspects
C17	Safety aspects
C18	Technology development aspects
C19	Policy process
C20	Tax incentives
C21	Public information campaigns
C22	Public participation

Figure 29 FCM representation of scenario 1, tax incentives



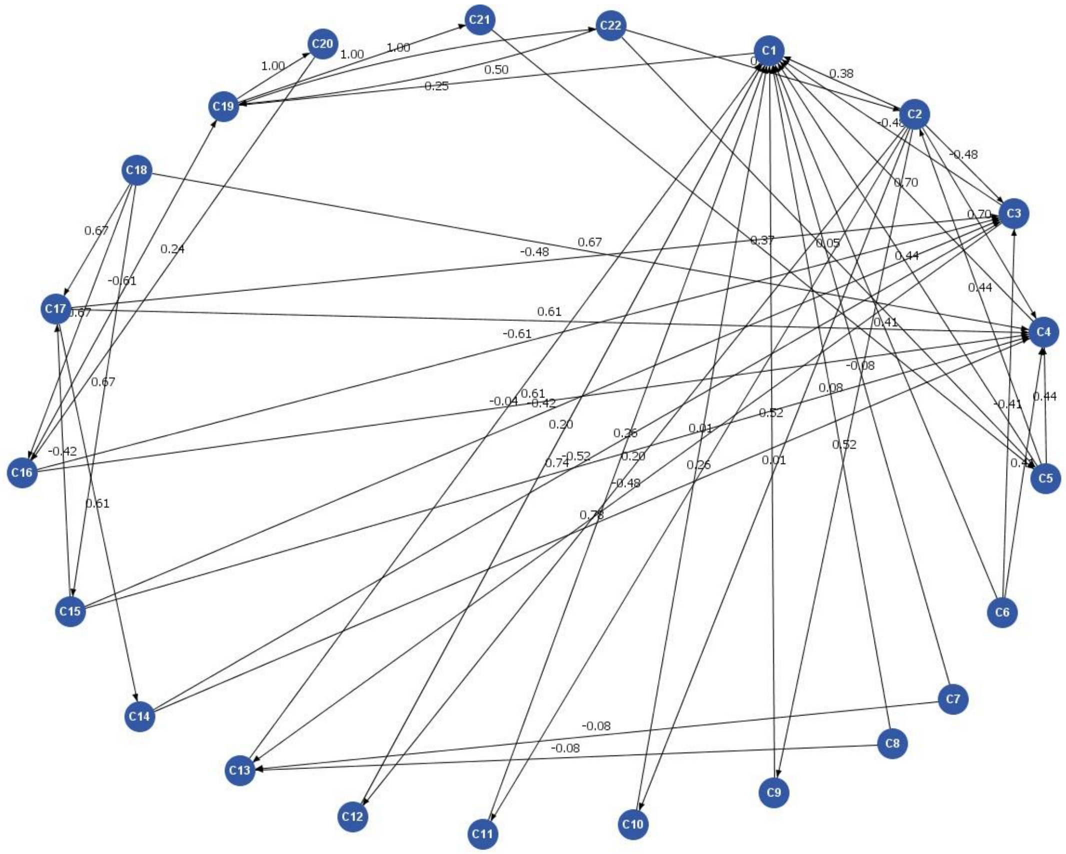
C1	Public Acceptance
C2	Public trust
C3	Risk perceptions
C4	Benefit perceptions
C5	Public knowledge
C6	Climate change
C7	Multiple small plants
C8	One large plant
C9	Governmental ownership and control
C10	Private ownership and control
C11	Private ownership and governmental control
C12	Governmental ownership and private control
C13	Resident within EZ
C14	Political aspects
C15	Environmental aspects
C16	Economical aspects
C17	Safety aspects
C18	Technology development aspects
C19	Policy process
C20	Tax incentives
C21	Public information campaigns
C22	Public participation

Figure 30 FCM representation of scenario 2, public information campaigns



C1	Public Acceptance
C2	Public trust
C3	Risk perceptions
C4	Benefit perceptions
C5	Public knowledge
C6	Climate change
C7	Multiple small plants
C8	One large plant
C9	Governmental ownership and control
C10	Private ownership and control
C11	Private ownership and governmental control
C12	Governmental ownership and private control
C13	Resident within EZ
C14	Political aspects
C15	Environmental aspects
C16	Economical aspects
C17	Safety aspects
C18	Technology development aspects
C19	Policy process
C20	Tax incentives
C21	Public information campaigns
C22	Public participation

Figure 31 FCM representation of scenario 3, public participation



C1	Public Acceptance
C2	Public trust
C3	Risk perceptions
C4	Benefit perceptions
C5	Public knowledge
C6	Climate change
C7	Multiple small plants
C8	One large plant
C9	Governmental ownership and control
C10	Private ownership and control
C11	Private ownership and governmental control
C12	Governmental ownership and private control
C13	Resident within EZ
C14	Political aspects
C15	Environmental aspects
C16	Economical aspects
C17	Safety aspects
C18	Technology development aspects
C19	Policy process
C20	Tax incentives
C21	Public information campaigns
C22	Public participation

Figure 32 FCM representation of scenario 4, policy instruments combined

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