The effect of social identities on the opinion dynamics of nuclear energy

Exploring the emergence of public opinion patterns regarding nuclear energy

Thesis

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TU Delft

Preface

The past months have been quite the rollercoaster; finishing my master thesis, securing a job, moving to Amsterdam. In other words, wrapping up my student life, ending this chapter and moving to a new one. I am looking back proudly on the past years, in which I have learned so much and grown significantly as a person. This growth would not have been possible without the people around me, therefore I would like to show my gratitude. First of all, I want to thank my friends at uni, who have helped me to develop myself as a person. Secondly, my roommates, who I owe a lot of advice and life lessons. Also, my family for always supporting me and being proud of me. Finally, all of these people, my friends, who were part of this journey and who I created a lot of memories with.

Although I have written my thesis alone, there are a lot of people with important indirect contributions. First I would like to thank Geeske for supervising me during her first thesis supervision project in Delft, your views and advice have inspired me to come up with this final product. I also enjoyed our weekly meetings in which I always asked a lot of questions, rather than simply providing solutions you guided me to find answers within myself, which is very helpful. Secondly, I want to thank Martijn for supporting Geeske in the supervision of my thesis project. Next to that, you always had your door open (literally and figuratively) for me to come in and ask for advice and feedback, which you provided enthusiastically and expertly. Finally, a huge shoutout to my friends who worked on their own thesis journeys alongside me: Quincy in the first months of the thesis, Daam in the final weeks before submitting, and Jerry and Anne who were there the whole way. We offered each other support and we had fun in our final days as a student. Stepping into this new chapter, I'm taking all the lessons and good times with me.

Nwankwo Hogervorst
Delft, August 2023

Summary

To be able to reach the climate goals and mitigate the consequences of climate change, ambitious and decisive action must be taken. The divided public opinion on nuclear energy leads to indecisiveness on whether to adopt or discard it as an energy solution. Given the urgent need for effective climate action, consensus on energy solutions is crucial. Therefore, this research aims to understand public attitudes toward nuclear energy. Existing literature primarily examines individual factors without considering the social dynamics that influence the formation of public opinion. By adopting the Social Identity Approach, this study aims to bridge this gap and understand how social groups shape our attitudes toward nuclear energy. Focusing on Germany and France, nations with contrasting nuclear energy stances deeply ingrained in their national identities, this study aims to reveal general patterns and lessons that can guide climate-related decision-making worldwide. This research involves a modeling approach, creating an agent-based model to simulate the interactions between individuals and the social influence they exert on each other. The main research question is formulated as:

"What is the effect of social identities on the opinion dynamics regarding nuclear energy in Germany and France?"

The social identities most strongly associated with attitudes towards nuclear energy are political affiliation, age group (generation), socio-economic status, and gender. In both Germany and France, left-wing supporters, younger individuals, and women tend to oppose nuclear energy more often, while right-wing supporters, older individuals, and men are generally more supportive. These patterns are consistent with the findings of previous research. It is worth noting that in France, the majority across all social identity groups tends to be pro-nuclear, whereas in Germany, the majority is against it. Together with these findings, the social identity approach was used as a framework for creating an opinion dynamics model in which communication only happens in the context of social identities. The theory helps to understand how interactions within social groups shape attitudes and behaviors, emphasizing the significance of group membership and social context.

The outcomes of the model demonstrate that in-group favoritism fosters consensus within social identity groups, while out-group aversion contributes to the polarization between these groups. Furthermore, the results reveal that discussing nuclear energy solely within the context of one social identity, results in polarization of opinions within a population. However, when individuals engage in discussions in the context of multiple social identities, this leads to depolarization of opinions between social identity groups. The possibility of changing contexts allows individuals to find common ground and potentially reach consensus, even if they initially held opposing views. These outcomes do not seem to depend on the initial conditions, as indicated by the similar outcomes between Germany and France.

This research fills a gap in the existing literature by examining how social factors shape attitudes toward nuclear energy. It enhances our understanding of public opinion formation by emphasizing that social identities, and specifically social context, significantly influence general opinion dynamics and can have even more substantial effects in the context of nuclear energy due to limited individual knowledge and the polarized nature of nuclear energy debates. The implications of this research extend beyond its specific focus on nuclear energy and climate governance, encouraging inclusive discussions in multiple different contexts to foster consensus in decision-making processes. Recommendations for future studies are to further explore the effects of social identities and social influence on the opinion dynamics of nuclear energy, both to validate and expand upon the findings of this study. Further research could also delve into the ongoing discussions surrounding nuclear energy and climate action, examining how these conversations are currently unfolding and considering ways to facilitate conversations in the context of multiple social identities, to increase the ability to reach consensus. Additionally, investigating the impact of other factors, such as government campaigns and knowledge levels, would provide a more comprehensive understanding of attitudes toward nuclear energy.

Contents

1 Introduction

1.1. Problem situation

In 2015, world leaders decided to join forces and try to limit global warming. Almost 200 parties signed an agreement to limit global warming below 2 degrees Celsius with respect to pre-industrial levels, this is known as the Paris Agreement. The climate goals are planned to be reached by reducing greenhouse gas (GHG) emissions through collective action [1]. Before the agreement entered into force, doubts were already raised about the sufficiency and attainability of the agreement [2]. In 2022, the United Nations (UN) showed in a report that greenhouse gas emissions are increasing less than before, however, the efforts are still insufficient to reach the climate goals [3]. The IPCC Assessment report of 2021 [4], created by more than 200 scientists worldwide, showed that in the past decade the global average temperature has already increased 1.1°C compared to pre-industrial levels. The report predicts that "the world will reach or exceed 1.5°C of warming within the next two decades even if nations drastically cut emissions immediately" [5]. A 1.5°C increase will already have severe consequences, including extreme weather conditions, droughts, floods, sea-level rise, and loss of species. If the temperature increases more than 2°C, the consequences will be far worse [5]. Given these alarming findings, it is now undeniable that more ambitious approaches must be explored and quick and decisive action must be taken to effectively control and mitigate the impact of climate change.

The energy sector is the largest contributor to greenhouse gas emissions, with more than two-thirds of global emissions [6, 7]. Consequently, implementing technologies that emit fewer greenhouse gases in this sector could offer a huge step towards reaching the climate goals and could have an enormous impact on mitigating climate change [6]. Nuclear energy has been identified as an option due to its low greenhouse gas emissions compared to fossil fuels [8, 9]. "Nuclear power, along with hydropower and wind energy, produces one of the lowest GHG emissions per unit of electricity generated on a life cycle basis" [10]. This characteristic positions nuclear energy as an attractive choice for reducing emissions on a large scale [8]. However, public opinion on nuclear energy remains divided, and the technology is not without its challenges. Safety concerns, particularly surrounding the possibility of accidents and the long-term storage of nuclear waste, have contributed to skepticism and opposition [11, 12]. Public support is a key factor for successful implementation of energy solutions like nuclear energy; the power plants need to be able to operate safely and the public needs to have trust in safe operations [10, 13].

Public opinion on nuclear energy stands out as one of the most divisive and polarized compared to other energy sources [14, 15, 16]. The strong attitudes toward nuclear energy often lead to intense debates; "Those who believe in it, believe in it 100 per cent, and those who oppose it, oppose it 100 per cent. There's very little room for nuanced conversation with regard to nuclear energy" [16]. The lack of consensus in both public opinion and climate strategy negotiations poses a challenge when making decisions about climate action [17] (regardless of whether it involves adopting or discarding nuclear energy). Consensus decision-making is an important part of these negotiations as it creates a shared understanding, bridging differences among stakeholders [17, 18]. Consensus building is desirable, as it will result in climate governance strategies that are widely supported and can be effectively imple-

mented on a global scale, maximizing their potential impact [18, 19]. It ensures that the chosen path, either adopting or rejecting nuclear energy as an energy solution, is supported by a broad spectrum of stakeholders and the general public [18]. Although nuclear energy may not be a preferable solution for addressing climate change, understanding public opinion on nuclear energy can offer valuable insights into reaching a consensus (on adopting or discarding nuclear energy) and can potentially inform decision-making regarding other emerging technologies.

1.2. Research objective

The main interest of this research is therefore the public opinion on nuclear energy[1]. Current literature mainly looks at the relationship between individual factors and the perception of nuclear energy. Researchers have investigated how factors such as perceived risk, perceived benefit, knowledge, and trust, impact individual attitudes toward nuclear energy [21, 22, 23, 24, 25, 26, 27, 28]. Additionally, most studies also examine how socio-demographic attributes, including gender, age, education level, occupation, income, distance to power plant, and political affiliation, relate to a person's attitude [23, 24, 25, 26, 27, 28]. However, what is currently lacking in research is the consideration of social influence and the dynamic nature of public attitudes toward nuclear energy. The existing literature primarily focuses on internal factors shaping individual attitudes, relying on data obtained through surveys and questionnaires, which provide only a snapshot of people's attitudes. However, opinions on nuclear energy and other energy technologies are often based on impressions and are easily influenced, because not many people feel well-informed about the subject [21, 29, 30]. The majority of current research overlooks the social dynamics at play when individuals form opinions about nuclear energy. It is essential to recognize that individuals do not form opinions in isolation, they are continuously influenced by various social and cultural factors, shaping their perceptions and attitudes [31, 32]. A small portion of research recognizes that social influence plays an essential role in shaping public attitudes toward nuclear energy and other emerging technologies [31, 32]. They suggest that future research on energy technology acceptance should consider these factors to develop more accurate models of public attitudes and behavior.

This is where a research gap can be found, little research is performed on the impact of social influence on attitudes toward nuclear energy, as well as the dynamic nature of these attitudes. This thesis will bridge that gap by exploring the effect of social factors on the opinion dynamics of nuclear energy. To accomplish this, the study will adopt the Social Identity Approach. A 'social identity' refers to who we are as part of a group e.g. nationality, religion, or even affiliation with a particular football association. The groups we are part of influence our opinions and actions and form "the pivot between the individual and society" [33]. The attitude toward nuclear energy for example can be influenced by other members of the group, we see people with the same social identity "as more correct, more appropriate, and better than out-groups" [34]. The Social Identity Approach (SIA) has been applied in many social studies as it looks at the behavior of people in a group, the behavior of the group, and the changes in behavior [35]. Multiple studies have already been performed on attitudes toward nuclear energy, however, a study that attempts to understand how social identities might shape the opinion dynamics on nuclear energy has not been performed. Consequently, this research will focus on the effect of social identities on attitudes toward nuclear energy over time, to provide insights that can inform decision-making for climate action regarding nuclear energy and potentially other energy sources.

1.3. Geographical area of interest

Considering the potential variation in results across different geographical locations, it was decided to select a specific geographical area of interest for this research. The composition of social identities and their potential effects can differ significantly from one location to another. By focusing on a particular geographical area, this research can gain a deeper understanding of how various social identities interact and influence outcomes within that specific context. Moreover, attitudes toward nuclear energy and the ways in which attitudes change can also vary among countries. Research by Talarico et al. [36] highlights the influence of national identity on the formation of public opinion regarding nuclear

[1] Note that in literature 'nuclear power' and 'nuclear energy' are used interchangeably [20]. In this thesis 'nuclear energy' will be preferred.

energy. For instance, they state that the Fukushima disaster was congruent with German beliefs about the danger of nuclear energy, and therefore influenced their opinion more than those of other countries.

Given the German history of anti-nuclear attitude, it was decided to dive deeper into the country's relationship toward nuclear energy. Blackmore [37] found that Germany's anti-nuclear movement played a crucial role in shaping anti-nuclear norms in the country since the 1970s. Their framing of nuclear energy had a significant impact on shaping public perceptions regarding nuclear energy risks. Additionally, the anti-nuclear movement was further strengthened by nuclear accidents such as the Three Mile Island accident and Chernobyl. Their powerful message resulted in widespread acceptance of their views and the emergence of anti-nuclear norms in Germany (domestic norms play a significant role in the formation of identity). These norms were formally recognized by the 2002 left-wing government and implemented into legislation that would phase out nuclear energy. "Germany's anti-nuclear norms were, therefore, a significant aspect of Germany's identity prior to Fukushima" [37]. Despite efforts of the 2009 right-wing government to keep the nuclear plants running, the Fukushima accident in 2011 led to strengthening of the anti-nuclear norms and escalation of the nuclear phase-out. Blackmore [37] concludes that the anti-nuclear movement in combination with Germany's political opportunity structure[2], and the occurrence of major nuclear accidents has led to the embeddedness of anti-nuclear norms in the national identity of Germany.

On the other side, the French have a more positive relationship with nuclear energy. Hecht [39] explains that after World War II, France found itself in a position of relative weakness in the global order. The country had been occupied by Nazi Germany, and its economy was struggling to recover. In order to assert its power and prestige on the world stage, the French government decided to invest heavily in nuclear energy. The government saw nuclear energy as a way to achieve two important goals: first, to reduce France's dependence on imported oil and gas, which the government saw as a threat to the country's energy security; and second, to establish France as a major player in the global nuclear industry. The French government started an ambitious program of nuclear expansion, building dozens of nuclear reactors and creating a large nuclear energy sector that employed tens of thousands of people. As Hecht [39] explains, the French government used nuclear energy as a way to assert its political and cultural identity. French nuclear engineers were portrayed as heroes, and their work was celebrated nationally. Nuclear energy became a symbol of French technological excellence and self-sufficiency, and the country's nuclear industry was widely seen as a source of national pride.

As the attitudes of France and Germany towards nuclear energy are deeply ingrained in their respective national identities, it is worth comparing the clear differences between them. While France is predominantly pro-nuclear and Germany is predominantly anti-nuclear, it is important to note that significant opposition exists within both countries across various social identity groups [40, 41]. In Germany, despite the shutdown of all nuclear plants in April 2023, opposition to the shutdown persists among social identity groups. This opposition primarily comes from right-wing voters, men, older individuals, and those with low incomes[3] [40, 42]. Similarly, in France, despite the passing of a new law in May 2023 to accelerate the construction process of new nuclear plants, there is significant opposition to this law and nuclear energy in general among social identity groups. Notably, left-wing voters, women, young people, and those with low incomes tend to hold more negative views toward nuclear energy in France[3] [41, 43]. To analyze the impact of social identities on the opinion dynamics of nuclear energy, this research will cover both a country where the majority supports nuclear energy and a country where the majority opposes it, covering both sides of the opinion spectrum. By focusing on these two countries with contrasting attitudes, this research aims to uncover patterns and lessons that can be applied to other countries facing similar debates and dilemmas regarding nuclear energy.

[2] The term 'political opportunity structure' refers to the political conditions and contexts within which social movements operate. This concept is often used in social movement literature to understand the enabling or limiting conditions for collective action [37, 38].

[3] See section 3.2 for a more detailed analysis on the relation between social identities and attitudes toward nuclear energy in Germany and France.

1.4. Thesis structure

In chapter 2, the research design is explained. It is discussed how answering the main research question is tackled, leading to multiple research sub-questions. Subsequently, the methods for answering the sub-questions are presented. In chapter 3, relevant literature is reviewed to understand social identity research and its concepts. Additionally, the relationship between social identities and nuclear energy attitudes in Germany and France is explored. Finally, the concepts for modeling nuclear energy opinion dynamics are outlined and two hypotheses are presented. Subsequently, chapter 4 delves into model development. It begins by conceptualizing the model and its components. This conceptual framework is then formalized using pseudo code. Ultimately, the model is constructed, outlining its main assumptions and simplifications, and undergoing verification. The contents of chapter 5 present the experimental setup and the results of the experiments conducted with the model. Furthermore, a sensitivity analysis is performed and the model is validated. In chapter 6, the results of the experiments are discussed, linking them back to the hypotheses and the broader research picture. Also, the limitations of the research and the effect of the assumptions and simplifications are presented, alongside some possibilities for future research. Finally, in chapter 7, conclusions are drawn on the research questions. Revealing the scientific and societal contributions, as well as the recommendations for future research.

2

Research design

2.1. Research question

This research investigates the influence of social identities on the attitudes regarding nuclear energy within the German and French populations. The goal is to understand how social identities might shape the behavior and public opinion within these countries. By examining the interplay between social identities and public opinion, the research aims to provide insights into the formation and evolution of attitudes toward nuclear energy in these specific contexts, which could inform decision-making for climate action regarding nuclear energy and potentially other energy sources. The main research question can be formulated as:

"What is the effect of social identities on the opinion dynamics regarding nuclear energy in Germany and France?"

2.2. Approach

The goal of this research is to provide insights into the role of social identities in shaping the public opinion on nuclear energy. A modelling approach lends itself well to the exploration of these social identity effects. An agent-based model can be created to simulate the dynamics of opinion formation and interactions among individuals. The main advantage of the modelling approach is that interactions can be simulated, meaning that one will see if patterns emerge in the modelled behaviour [44]. Modelling helps to simulate what would happen in complex situations, which are challenging to analyze manually (e.g. when dealing with a large number of interacting agents) [44]. Agent-based models can also be transparent and easy to understand, which helps to explain the model and its outcomes [44]. The agent-based model will help uncover patterns and dynamics that may not be immediately apparent, enhancing our understanding of how social identities influence the formation of public attitudes. A limitation of the modelling approach is that the real world will be simplified, and assumptions will be made [44]. Thus, the simplifications and assumptions should be evaluated to assess the usefulness of the conclusions.

First, the current state of research on social identities is reviewed to find out how it can be used to model the opinion dynamics of nuclear energy (leading to research sub-question one, S1). Next to that, it is researched what the relation is between different social identities and the attitude toward nuclear energy in Germany and France, e.g. what percentage of men has a positive attitude toward nuclear energy (leading to S2). Subsequently, these findings are used to create a model and simulate the social interactions and opinion dynamics of nuclear energy. The model aims to capture the interplay between social identities, individual attitudes, and social influence, revealing the mechanisms through which social identities affect the formation of public opinion on nuclear energy (leading to S3). With these outcomes, conclusions are drawn on the main research question to give insight into the workings of attitude formation toward nuclear energy in the social identity context.

The research sub-questions are formulated as:

- "How can social identity research be used to model the opinion dynamics of nuclear energy?" (S1)
- "How are social identities related to attitudes on nuclear energy in Germany and France?" (S2)
- "What patterns will emerge in the public opinion on nuclear energy in Germany and France if communication is only influenced by social identities?" (S3)

2.3. Methods

The research sub-questions help in the steps to be taken to draw conclusions on the main research question. The answers to S1 are gathered through literature research, the theories and research on social identities are reviewed. This review helps to identify key concepts for modelling the opinion dynamics of nuclear energy. For this literature review, only academic literature was used to ensure credibility, find original work, and enable snowballing (tracking relevant references and citations) [45]. Based on the concepts of existing research, two hypotheses are created to be able to link the modelling results back to the theory. For the literature review, Google Scholar[1] is used as it covers a wide range of journal articles and has extensive search options compared to similar databases [46]. Furthermore, ResearchRabbit[2] is used to allow for extra and efficient snowballing. The answers to S2 are gathered through similar literature research and pre-existing survey data, to establish the relationship between social identities and attitudes towards nuclear energy. Survey data is obtained from reputable market research and polling firms (IFOP[3] and IfD Allensbach[4]). Surveys in the French and German languages were explored because more data was available for the countries in their respective languages.

The answers to S3 are gathered through a representation in an agent-based model. With the knowledge of the social identity interactions and the connections to the attitudes toward nuclear energy, a model is created to see what patterns emerge. The model incorporates the findings from S1 and S2 to help answer the final sub-question. The modelling environment of NetLogo[5] is used due to familiarity with the environment and the programming language, and because it offers extensive online documentation and support [44]. To create and use the agent-based model, the model development steps of Van Dam et al. are used [44]: Initially, a conceptual model is designed, followed by formalization in pseudo code. These steps are taken to specify the use of the concepts and to ensure that the model's core logic is well-defined [44]. Subsequently, the model is implemented in NetLogo. After the model is created, it undergoes verification to confirm that the conceptual model is correctly translated into model code (i.e. it behaves as intended) [44]. This is followed by the execution of experiments within the model. For the analysis of the data of the NetLogo experiments, Python[6] is used because it allows for the efficient handling of large datasets and the automation of repetitive data analysis. A sensitivity analysis was performed, to explore how variations in model parameters impact the results. Subsequently, the model was validated, ensuring its credibility and applicability to real-world scenarios [44]. The implications drawn from the model's outcomes are discussed and linked to the initially formulated hypotheses and the broader research picture. Also, the limitations and the effect of the assumptions and simplifications on the results are discussed. Finally, the results of the research are synthesized, conclusions are drawn, and some recommendations are done on possibilities for future research.

[1] https://scholar.google.nl/
[2] https://www.researchrabbit.ai/
[3] https://www.ifop.com/
[4] https://www.ifd-allensbach.de/
[5] https://ccl.northwestern.edu/netlogo/
[6] https://www.python.org/

3

Literature review: Social identities and nuclear energy

This chapter will address research sub-question 1 and 2. First, literature will be reviewed to find the state of the art of social identity research and to explain relevant topics and concepts to the reader. Secondly, more literature will be reviewed to find how social identities relate to attitudes toward nuclear energy, specifically in Germany and France. Some numerical evidence will be provided to support these findings. Finally, it will be summarized what concepts will be used in modelling the opinion dynamics of nuclear energy and some hypotheses will be given.

3.1. Social identities in literature

In this section, first, the theory of the social identity approach will be delineated and its key concepts will be discussed. Furthermore, it will be discussed how social identities relate to opinion dynamics and how they are used in opinion dynamics modelling. Also, it will be explored why and how social identities are used in agent-based models in general. Finally, it will be explained why social identities should be used in the opinion dynamics of nuclear energy and how this could be accomplished.

3.1.1. The theories of social identities: understanding the influence on opinion dynamics

The Social Identity Approach is a theoretical framework within social psychology that seeks to understand how individuals perceive and relate to themselves and others in the social world [33]. The social identity approach is a combination of Social Identity Theory and Self-Categorization Theory. Social identity theory emphasizes the importance of group membership in shaping behavior and attitudes, while self-categorization theory focuses on how individuals categorize themselves and others to determine appropriate behavior in different social contexts [33, 47, 48]. These theories will be explained in more detail below.

The core concept of these theories is the 'social identity', which refers to the part of an individual's self-concept that is derived from their membership in various social groups [35]. A social group can be any category that people identify with, such as their nationality, gender, occupation, religion, or even sports teams. When people identify with a particular group, they tend to adopt the characteristics, values, and norms associated with that group, and this group membership becomes an important part of their sense of self [33, 35, 47].

The Social Identity Theory is developed by Henri Tajfel and John Turner, it explains that identifying with a group influences an individual's behavior and attitudes [47]. People identify as part of a group to give them a sense of belonging, this will shape their behavior [33]. In this context, in-group refers to the social group with which an individual identifies and feels a sense of belonging, while out-group refers to the groups an individual does not belong to and does not identify with [49]. In-group favoritism, also known as in-group bias, is the phenomenon where individuals display preferential treatment and

positive attitudes toward members of their own group. This preference for the in-group comes from the desire to maintain a positive social identity, leading individuals to conform to the norms and opinions of their fellow in-group members. On the other side, out-group aversion is the tendency for individuals to show negative attitudes and discrimination towards those who belong to different social groups [33, 35, 49]. Furthermore, when we identify ourselves as a member of a group, our self-esteem becomes tied to the well-being of the group. For example, when someone from our own nationality takes part in a sports event, there is a natural inclination for us to root for them and derive happiness and excitement from their success. This illustrates our feeling of connection to others who we share an identity with, even if there is no personal relation or interest. To see how well our group is doing, we automatically compare ourselves to other groups (e.g. all other nationalities participating in the sports event), as our sense of identity is partly defined by distinguishing ourselves from those who are not part of our group [33, 35].

Self-Categorization Theory, proposed by John Turner, builds upon social identity theory and explains how social context influences how people categorize themselves and behave [48]. Self-categorization theory emphasizes the role of salience in shaping social identity. How people act in a certain situation will depend on which social identity is salient[1]. "Salience is the extent to which a social identity is cognitively focal at a particular time" [50]. Imagine a group of students from different universities meeting up for drinks at a bar. Initially, as they engage in conversation, they focus on sharing their experiences and pride related to their respective universities. In this context, their university membership becomes the salient identity, creating a sense of connection and belonging within each university group. However, as the evening progresses, they are asked to put on the jersey of their favorite football team. Suddenly, the salient identity transforms from their university affiliation to their football team affiliation. As a result, the students reposition themselves, students from different universities who were initially seen as out-group members, may now be viewed as fellow supporters of the same team. Together they may enthusiastically sing specific chants associated with their team. They will now feel less connected to a student from their own university who supports a different football team. The students will position themselves and behave depending on the salient identity. Thus, individuals may identify with different groups depending on the social context, and this identification can influence their behavior, attitudes, and beliefs [33].

To further explain how this works, the self-categorization theory explains how people group others into social categories based on their similarities and how well they fit in with the group's norms. When determining which group someone belongs to, we use two criteria: comparative fit and normative fit. Comparative fit means that we group people together based on how similar they are to each other compared to how different they are from people in another group (this is called the meta-contrast principle). If the differences between people within a group are smaller than the differences between that group and another group, then we will categorize them as belonging to the same group [50, 51]. Normative fit refers to how closely someone's behavior or opinion aligns with the group's perceived norms. "If someone acts in line with a group's social norms, they are likely to be categorized as a group member" [50]. In the example given in the previous paragraph, the students put on the jerseys of their favorite football teams. This will accentuate the support for their respective teams and their associated differences, which leads the students to categorize each other based on comparative fit. If the students in the bar were not wearing their jerseys, but they spontaneously started singing chants associated with their football teams, they would be acting in line with the group norms and categorizing each other based on normative fit.

Self-categorization theory builds on Social Comparison Theory, which was developed by Leon Festinger. Social comparison theory suggests that individuals evaluate their own abilities and opinions by comparing themselves to others, with the aim of gaining accurate self-evaluations and enhancing their self-esteem [35, 52]. Building upon this, self-categorization theory explains that social identities are based on the differentiation between social groups. People engage in social comparison to categorize themselves and create a feeling of belonging and self-worth, this shapes their behavior and opinions [35]. "To reach positive evaluations of one's own in-group, people engage in processes of social comparison. They derogate the out-group with the aim of increasing their own self-esteem" [53]. Social comparison theory explains that individuals may adjust their opinions to be more similar to those of

[1] Salient means: most noticeable, important, or prominent

others who are seen as similar or superior in a particular domain (upward comparison). On the other hand, when individuals perceive themselves as superior or hold a higher status in a particular group, they may be more likely to maintain or even reinforce their own opinions (downward comparison) [52, 54, 55].

Superiority or higher group status can also be related to the notion of a prototype. ”A group prototype is a fuzzy set of attributes that capture those perceptions, attitudes, and behaviors that define the group and differentiate it from relevant other groups” [56]. In other words, a prototype is an idealized representation of the typical member of a particular group. It is like a mental picture that people have of what someone from that group should look, act, and behave like. When a social identity is salient, the most prototypical members are seen as the embodiment of the typical behaviors and attitudes of the group. This means that the most prototypical members are perceived as having more influence within the group than those who are less prototypical. In other words, people tend to follow the lead of the most typical members of the group more than those who are less typical [57].

Finally, the Optimal Distinctiveness Theory, originally proposed by Marilynn Brewer, builds upon and extends the theories of social identities [58]. This theory proposes that ”individuals have two fundamental and competing human needs — the need for inclusion and the need for differentiation” [59]. This means that people naturally desire to be both part of a group and at the same time distinct from other groups, they tend to seek a balance between these two needs. On one hand, individuals look for inclusion by adapting their behavior and opinions to align with their in-group. On the other hand, they aim to distinguish themselves from out-groups by adapting their behavior and opinions to be different [59].

Overall, the theories on social identities offer a framework for understanding how individuals perceive themselves and others based on social identities, and how this perception can influence their behavior and social interactions.

3.1.2. Social identities in opinion dynamics models and other research

Research into social identities and their influence on opinion dynamics helps to understand how people form and spread their opinions within social groups. Key findings from this line of research emphasize the significant role of social influence in shaping individual opinions and the spread of opinions within social networks [31, 32, 60, 61, 62]. Social identities are found to mainly affect who individuals interact with and how they perceive the opinions of others in the process of social influence [62], which is explained in more detail in the previous section. Current research on the use and effect of social identities and social influence in opinion dynamics provides insights into the mechanisms driving opinion formation and the evolution of public opinion [60, 61]. To better understand the role of social influence, researchers have developed various agent-based models [61, 50].

The Social Identity Approach (SIA) has been applied in Agent-Based Models (ABMs) to understand and simulate aspects of human behavior in social contexts [50]. The SIA provides a framework for understanding human behavior in social contexts, particularly how individuals identify with social groups and how this identification influences their attitudes and actions (see subsection 3.1.1). The SIA allows researchers to investigate how group-based social influence affects individual decisions, leading to the emergence of complex social behaviors and patterns [50]. Agent-based models are specifically used because they are well-suited for studying complex social systems and emergent behaviors. The SIA deals with the dynamic interactions between individuals and groups, and ABMs allow for the representation of these interactions between individuals (agents). Agent-based models, as computational simulations, offer the opportunity to operationalize and test the concepts and dynamics proposed by the SIA in a controlled and flexible environment [44, 50]. The SIA has been applied in various kinds of ABMs, covering diverse research domains. The most prevalent application of the SIA in ABMs is in the domain of opinion dynamics, where it has been used to specify group-based social influence. However, it has also been applied in other models to represent collective behavior, group dynamics, and social influence (for example in conflict research and crowd behavior) [50].

The Voter model and the Bounded Confidence model are two of the most fundamental and widely studied opinion dynamics models. Many other agent-based models are inspired by or built upon these two basic concepts [61]. The next paragraphs will dive deeper into these models to understand the basics of opinion dynamics modelling.

The Voter model, introduced by Holley and Liggett [63], is a model where individuals interact with their neighbors in a social network. The model aims to understand how the opinions of individuals in a population evolve over time through interactions with each other. In this model, individuals are represented as nodes in a network, and the opinions they hold are represented by discrete variables (typically binary, such as ”for” or ”against” a specific idea like nuclear energy) [61, 63, 64]. In the basic version of the model, the network is often assumed to be fully connected, meaning that every agent can interact with any other agent in the population. At each time step, the model randomly selects one agent from the population. This chosen agent interacts with one of its neighbors, which is also randomly selected from the set of connected individuals, and adopts their opinion. As the process repeats over multiple time steps, the model captures the spread and evolution of opinions within the population [61, 63, 64, 65, 60]. The basic version of the voter model is often adapted to explore more complex scenarios and to create more realistic representations [61]. Instead of a fully connected network, agents could be connected to only a certain set of other individuals (to simulate social groups). Next to that, probabilities could be assigned to both the selection of a neighbor and the adoption of their opinion (for example, to simulate a higher chance of interacting with like-minded people) [61, 65, 60]. These adaptations allow researchers to investigate how different factors influence opinion dynamics.

In the Bounded Confidence model, introduced by Deffuant et al. [66], individuals are also represented as nodes in a network, each having an opinion on a particular topic. However, unlike the voter model, their opinions are represented on a continuous scale rather than binary. For example, opinions can be represented on a scale from 0 to 1, where 0 is completely against an idea, and 1 is completely in favor of it. Furthermore, individuals interact only with those neighbors whose opinions fall within a certain confidence range or threshold, this range reflects their openness to diverse opinions. The main idea behind the bounded confidence model is that individuals are more likely to interact and be influenced by others who hold similar opinions (homophily), but they are less likely to be influenced by those with significantly different opinions [66, 61, 60, 67]. In the model, at each time step, an agent is randomly selected from the population to update its opinion. This agent checks the opinions of its neighbors and will only interact with those neighbors whose opinions fall within its confidence range. If the agent finds neighbors within its confidence range, it computes an average of their opinions and updates its opinion to be more aligned with this average [66, 60, 67]. Common adaptations to the bounded confidence model are changes in the confidence range. For example, individualized confidence ranges for agents, representing varying levels of tolerance to differing views. This addition allows for a more realistic portrayal of opinion formation in diverse populations [61, 68].

The voter model and the bounded confidence model provide insights into how social influence drives opinion dynamics. These models have shown that states of consensus, polarization, or fragmentation of opinion can emerge [61]. Consensus occurs when individuals in a social network converge to a shared opinion. Polarization, on the other hand, happens when individuals split into distinct and often opposing opinion clusters, with limited interaction and agreement between different clusters. Fragmentation occurs when the network divides into multiple smaller disconnected opinion groups, each holding different views [68]. The model outcomes are closely related to the underlying network topology and the strength of social influence [61]. In the voter model, consensus is more likely to be achieved in well-connected networks (most agents can interact with each other) with strong social influence (the chance of adopting the opinion of another agent is high). Polarization arises when individuals tend to interact primarily with like-minded agents. Fragmentation occurs in networks with limited connections between different opinion clusters [61, 68, 69, 65]. In the bounded confidence model, consensus occurs when individuals have a relatively low confidence threshold, meaning they are willing to interact and be influenced by others with a wide range of opinions. Polarization arises when individuals have a high confidence threshold, meaning they are only willing to interact and be influenced by others with opinions that are very similar to their own. Fragmentation occurs when there is a mix of both low and high confidence thresholds within the population [61, 68, 69, 67]. In both models, the chance of con-

sensus is higher when the initial differences in opinions are not too extreme. If the initial differences in opinions are too extreme, polarization or fragmentation becomes more likely [68, 69]. Note that the conditions under which certain outcomes may arise differ per model and initialization (they are path-dependent). Therefore, researchers often show critical transition points (tipping points) to understand when and how different states occur. For instance, they might show when the majority of the population shifts from favoring a certain idea to opposing it, or when specific conditions lead to the emergence of distinct opinion clusters [60, 70].

While there has been a significant amount of research and development of opinion dynamics models, the empirical validation of these models remains a challenging task due to the ambiguity and multifaceted nature of opinions, and the scarcity of accessible data on opinions. Some validation approaches that are used include comparing model predictions with real-world data from elections and polls, as well as conducting controlled sociological experiments with human subjects. Despite these efforts, empirical validation efforts are still relatively limited [61, 67].

Overall, the current state of research on social identities and social influence in opinion dynamics highlights the interplay between individual beliefs, social networks, and social influence [61, 60, 68]. Peralta et al. [61] conclude that by further investigating these mechanisms, researchers can gain a deeper understanding of opinion formation processes and contribute to addressing complex societal challenges. This understanding can help address pressing challenges that require consensus among large groups of people, such as the impact of social divisions, economic inequality, and climate change. They conclude that by refining models and incorporating empirical validation, researchers can contribute to more effective decision-making processes in our increasingly interconnected yet fragmented world [61].

3.1.3. Social identities in relation to nuclear energy opinion dynamics

The research on social identities and opinion dynamics makes clear that identification with a group can significantly affect our behavior and opinions (see subsection 3.1.1 and subsection 3.1.2). Worley mentions in his research that, ”the more intense the conflict, the stronger the identification and the greater likelihood that an individual will behave more as a group member and less as an individual” [49]. Since the debate on nuclear energy is one of the most heated and divisive debates [14, 15, 16], research on social identities in this context could give a better understanding of these debates. Steiglechner et al., who explore the role of social identities on opinion dynamics in the context of the climate problem, explain in their research that gaining a better understanding of the impact of social identities on opinion dynamics could help to address disagreement in climate debates [62].

While no specific work conducts research on the effect of social identities on the opinion dynamics of nuclear energy. Plenty of research exists on the effect of social identities on opinion dynamics in general (see subsection 3.1.1 and subsection 3.1.2) and plenty of research exists on the attitude of specific social identity groups towards nuclear energy (which will be further researched in section 3.2). Combined this will help to create a nuclear energy opinion dynamics model, which can provide insights that can inform decision-making for climate action. How the research on social identities will be used to model the opinion dynamics of nuclear energy is further explained in section 3.3.

3.2. Perspectives on nuclear energy within social identity groups

In literature, political affiliation is the social identity mentioned most often to have an effect on a person's attitude toward nuclear energy. According to Wang and Kim [26], the majority of liberals are usually opposed to nuclear energy, while conservatives are generally in favor of nuclear energy. Furthermore, they mention that political orientation is also closely related to environmentalism, environmentalism is a strong social identity in Germany and affects their attitude toward nuclear energy significantly [26].

Post-material values also seem to have an effect on people's opinions. Post-materialism is a theory developed by Ronald Inglehart [71] which describes a value change over generations, where the older generation put more value on economic and physical security, and the younger generation put more value on self-expression [72]. "Postmaterialist values tend to emerge among younger generations in an environment of economic prosperity and material security where people have met basic survival needs and can attend to higher order needs of self-expression and quality of life" [73]. With the basic survival needs met, the younger generation no longer needs to primarily concern themselves with ensuring sufficient energy generation or dealing with scarcity. Instead, they place greater importance on issues like the environment and the sustainability of energy generation methods. This is a possible explanation for the finding that younger individuals tend to be less in favor of nuclear energy compared to older generations who have grown up in different times and prioritize different values.

Furthermore, according to Wang and Kim [26], higher income seems to reduce the approval of nuclear energy, since it allows people to invest in more expensive but safer energy sources. However, Pampel [73] notes that there are differing theories on the relationship between socio-economic status (SES) and levels of support for nuclear energy. One theory suggests that higher socio-economic status and national income will lead to lower support for nuclear energy (this is the case for Germany, see subsection 3.2.1). While there is another theory that "focuses on knowledge and familiarity with nuclear technology as central and suggests that high SES and national reliance on nuclear energy will increase support" [73] (this is the case for France, see subsection 3.2.1).

Finally, gender is another important factor to consider. One of the most widely recognized patterns in the literature of attitudes toward nuclear energy is that women are less supportive of nuclear energy than men [74]. Research has shown that women tend to be more safety-conscious than men and often express greater concern for the well-being of others. This has been the predominant explanation for the gender divide in attitudes towards nuclear energy in the general public. Although moderate, the correlation between gender and acceptance of nuclear is still significant [75].

So the main social identities affecting the attitude toward nuclear energy are found to be: political affiliation, age group (generation), socio-economic status, and gender. These are therefore the identities that will be considered in this research. Further data on attitudes towards nuclear energy in Germany and France can be found in the next section.

3.2.1. Opinion distribution in Germany and France

In 2021, the IfD Allensbach (Institut für Demoskopie) conducted a survey on the population of Germany [40], 1027 people of age 16 and up were interviewed. In the survey it was asked if the person agrees with the decision of the government to phase out nuclear energy, the results will be assumed to answer the question if the person is in favor of or against the use of nuclear energy in Germany. Overall, 56% of the population is anti-nuclear, and 25% is pro-nuclear, 19% is unsure (In 2012, 73% was anti, 16% was pro, and 11% was unsure). A summary of the survey data can be found in Table 3.1, and details of the calculation of the percentages in the table can be found in Appendix A. Note that in the survey there is a percentage of people that is unsure about their opinion, the assumption will be made that this percentage can be evenly divided between anti and pro, to be able to compare the data to the French survey data and for later modelling purposes.

A 2022 survey by the French institute of public opinion (IFOP, Institut français d'opinion publique) provides information on the attitude of the French towards nuclear energy [41]. The survey was on 1000 people, age 18 and up. In total 75% of the French population is in favor of the use of nuclear energy

in France, 25% is against. A summary of the survey data can be found in Table 3.2, and details of the calculation of the percentages in the table can be found in Appendix A.

Table 3.1: Opinion distribution on nuclear energy in Germany (anti-nuclear vs pro-nuclear)

Social Identity	Anti	Pro
Political affiliation		
Left wing	75.2%	24.8%
Right wing	58.6%	41.4%
Age group		
Young	71.7%	28.3%
Old	62.7%	37.3%
Socio-economic status		
Low	64.3%	35.7%
High	67.7%	32.3%
Gender		
Male	62.1%	37.9%
Female	69.6%	30.4%

Table 3.2: Opinion distribution on nuclear energy in France (anti-nuclear vs pro-nuclear)

Social Identity	Anti	Pro
Political affiliation		
Left wing	42.8%	57.2%
Right wing	13.9%	86.1%
Age group		
Young	30.2%	69.8%
Old	19.8%	80.2%
Socio-economic status		
Low	28%	72%
High	13%	87%
Gender		
Male	17%	83%
Female	32%	68%

The studies on both countries confirm the findings of general research that women, left-wing supporters, and younger people are more opposed to nuclear than men, right-wing supporters, and older people. The difference between Germany and France is that the majority of all these groups in France is pro-nuclear, while in Germany the majority is against it. For socio-economic status, in Germany the people with a high status are more opposed to nuclear. In France, the people with a high status are highly in favor of nuclear energy. This also reflects the uncertainty of research about this relation (as explained in section 3.2).

3.3. Concepts for modelling & hypotheses

Social identity theory suggests that individuals develop a sense of belonging to certain social groups, and that this sense of belonging influences their attitudes and behaviors [47]. This theory proposes that people strive to maintain a positive social identity, and that this identity is shaped by the groups they belong to [33, 35, 49], such as the identities that were identified to be related to the attitude toward nuclear energy in section 3.2 (political affiliation, age group, socio-economic status, and gender).

Self-categorization theory suggests that individuals categorize themselves into different social groups based on their current context [48]. Comparative fit or normative fit might cause a social identity to become salient. When for example age group becomes the salient social identity, then young people will identify more strongly with each other and old people will identify more strongly with each other [50, 33, 51]. If then the subject of nuclear energy becomes part of the group discussion, the groups might position themselves in terms of their respective social identity, as they usually have different views on nuclear energy (see section 3.2). Incorporating multiple identities, salience, and fit is essential to enable agents to exhibit contextual behavior within a model. The inclusion of salience and fit, two core elements of the self-categorization theory, is not prevalent in most social identity models [50]. This research will formalize these aspects in the model, ensuring that these fundamental principles of the social identity approach are included.

Finally, there are multiple theories that explain how people might adapt their behavior and opinions in the context of social identities. People tend to conform to the norms and opinions of their in-group (in-group favoritism) while showing aversion towards the out-group (out-group aversion) [33, 35, 49]. Based on the principle of prototypes, people tend to conform to the opinions of other group members and might converge on the opinion of the most prototypical member [57, 56]. Social comparison theory adds that the most prototypical members will not feel the need to adapt their position compared to the in-group, however, they may strengthen their opinion (become more extreme) compared to the out-group [52, 54, 55]. Finally, according to the optimal distinctiveness theory, people tend to find a balance between adapting their opinion to be similar to their in-group and adapting their opinion to be different from the out-group [58, 59]. Based on the concepts presented above, two hypotheses will be tested in this research.

Hypothesis 1: In-group favoritism leads to consensus within social identity groups
This hypothesis seeks to explore the role of in-group favoritism in shaping public opinion on nuclear energy. When social identities become salient, individuals tend to identify more strongly with their in-group and conform to its norms and opinions [33, 35, 49, 57, 56] (explained in more detail above). As a result, it is hypothesized that this in-group favoritism will lead to intra-group consensus, meaning that individuals within the same social identity group will converge on similar attitudes toward nuclear energy.

Hypothesis 2: Out-group aversion leads to polarization between social identity groups
This hypothesis aims to investigate the impact of out-group aversion on public opinion regarding nuclear energy. When social identities become salient, individuals may show aversion towards the opinions and attitudes of the out-group [33, 35, 49, 52, 54, 55, 58, 59] (explained in more detail above). As a consequence, this out-group aversion is expected to contribute to inter-group polarization, meaning that different social identity groups will exhibit contrasting attitudes toward nuclear energy, driven by their need to differentiate from out-groups.

It is important to consider these concepts of social identities because they might have a significant impact on shaping public opinion on nuclear energy over time [31, 32, 60, 61, 62]. Understanding these factors and testing these hypotheses will give insight into how people can form their attitudes towards nuclear energy and how those attitudes can change within a larger social context. Ultimately, this can help to better understand the complex and dynamic public opinion on nuclear energy and inform efforts to reach consensus on climate action, considering the adoption or rejection of nuclear energy as part of the broader climate governance strategies.

4

Model development

In this chapter, the conceptual model will be created, explaining the components of the model. Then, the model will be formalized by means of pseudo code. Finally, the complete model is presented, inlcuding its assumptions and simplifications, and verification.

4.1. Conceptualization

The conceptual model consists of four main components: objectives, inputs, outputs, and model content [76]. The objectives determine the purpose, nature, and time-frame of the model. Inputs are the elements of the model that can be altered to improve or better understand the problem situation. Outputs or responses report the simulation model results and determine if the modelling objectives are met or why they are not. Finally, model content consists of all the components and interconnections and is determined by the level of detail required for the model's scope and the required level of accuracy [76].

4.1.1. Objectives

The objectives should be kept in mind at all times during the modelling phase and are therefore an essential part of the conceptual model. The goal is to find out what patterns will emerge if opinions on nuclear energy only spread through social identities. The model aims to investigate the influence of social identities on public attitudes towards nuclear energy in Germany and France (S3). The main modelling objectives are:

- Understand the mechanisms behind the spread of opinions through social identities
- Study the impact of initial conditions in Germany and France
- Find the drivers in the opinion spreading process
- Describe the differences between Germany and France

It was decided to adhere to the KISS principle (keep it simple, stupid) when creating the model. This principle emphasizes the importance of simplicity, which helps to create a model that is comprehensible to other researchers and whose results are reproducible. By keeping a model simple, it is easier to interpret the results and create meaningful explanations [77]. However, it should be kept in mind that this approach may lead to oversimplification of the complexity of social identities and the opinion dynamics of nuclear energy. By finding a balance between simplicity and capturing the essentials, it will be made sure that important details that could significantly impact the accuracy and validity of the model are not left out. Additionally, the model's limitations will be discussed thoroughly in section 6.2.

4.1.2. Inputs

The inputs of the model will determine the characteristics and behavior of the agents. This is shown in Figure 4.1, which provides a visualization of an agent's states and behavior. This section will explain how the agents in the model are initialized, the components in the figure will be further explained in subsection 4.1.4. The inputs that will be needed to create the model are the following:

- Distribution of social identities
- Initial opinions on nuclear energy

Distribution of social identities

When the agents in the model are created they first need to be assigned their social identities. To simplify the distribution of social identities for both Germany and France, they are considered to be binary (for a full list of assumptions and simplifications, see Appendix C). There are two options for each of the four social identities:

- Political affiliation: left wing or right wing
- Age group: young or old
- Socio-economic status: low or high
- Gender: male or female

This means that individuals will be assigned one of the two options for each of these identities. The probability of being assigned a particular social identity is determined by the percentages in Table 4.1 and Table 4.2. The data was obtained from the participant distributions of the surveys, which are assumed to reflect the population distribution for both countries (see Appendix A for the explanation of the calculation of the percentages in the tables below).

Table 4.1: Population distribution in Germany

Social Identity	Percentage
Political affiliation	
Left wing	47.4%
Right wing	52.6%
Age group	
Young (16-44)	34.5%
Old (45+)	65.5%
Socio-economic status	
Low	49.2%
High	50.8%
Gender	
Male	48.2%
Female	51.8%

Table 4.2: Population distribution in France

Social Identity	Percentage
Political affiliation	
Left wing	31.1%
Right wing	68.9%
Age group	
Young (18-49)	48.7%
Old (50+)	51.3%
Socio-economic status	
Low	50.0%
High	50.0%
Gender	
Male	47.5%
Female	52.5%

The divide between most social identities is approximately 50/50, there are two exceptions. The first is age group in Germany with approximately one in three individuals falling into the young category (16-44 years old), while two in three individuals belong to the older age group (45+ years old). In France, the exception is political affiliation, which is close to one-third left-wing and two-thirds right-wing.

Initial opinions on nuclear energy

The initial opinion distribution per social identity and per country can be found in subsection 3.2.1. The percentages are used to give the agents in the model their initial opinion. First, the country should be selected, Germany or France, this will determine the distribution of initial opinions the agents will receive. Once the country is selected, each individual agent will be assigned a dominant identity randomly from one of the four social identities. This dominant identity represents the identity that an individual identifies with most strongly. Finally, based on the assigned dominant identity, the individual will be given an initial opinion. The percentages in Table 3.1 and Table 3.2 determine whether the individual is pro or anti-nuclear. For instance, if a woman in Germany is assigned 'gender' as her dominant identity, she will have a 30.4% chance of being pro-nuclear and a 69.6% chance of being anti-nuclear.

4.1.3. Outputs

The outputs that will be generated by the model are the following:

- Initial opinion distribution
- Final opinion distribution
- Distinct opinions

The initial and final opinion distribution will show what happens to the public opinion of a country in one simulation run. The distinct opinions will help to identify clusters on the opinion spectrum. In combination with the parameter settings, these outputs will help to discover the mechanisms and drivers of the spread of opinion through social identities, the impact of initial conditions, and the differences between Germany and France.

4.1.4. Model content

The model content can be visualized in two figures: Figure 4.2 provides an overview of the entire model, while Figure 4.1 zooms in specifically on an individual agent. This section provides detailed explanations of the model components and how they are interconnected, supporting the visual representations.

Way of communication

It was decided that agents will discuss nuclear energy in a group (2 individuals or more). This allows for the concepts of prototypicality and group influence to be modelled, and provides the ability to capture group dynamics. Each tick, the agents will divide into new random social groups in which they will discuss the topic of nuclear energy.

Way of opinion spread (model versions)

In Figure 4.2 the main model content can be found, it shows the opinion spread process, the components will be explained in more detail here. After the agents come together in their social group, they will position themselves based on the self-categorization theory. First, given the context, one of the four social identities will become the salient identity in the group. An identity could become salient through comparative fit (the meta-contrast principle), the observed differences between the members of the group. Or through normative fit, the behavior of the agents will make one of the identities more visible and will make them categorize themselves based on that identity. The categorization will therefore be based on the most common dominant identity in the group. Given the salient identity, the agents will position themselves based on that identity and this will shape their behavior based on the social identity theory. When they then discuss nuclear energy, they have three possible ways to adapt their opinion (these will be the three model versions).

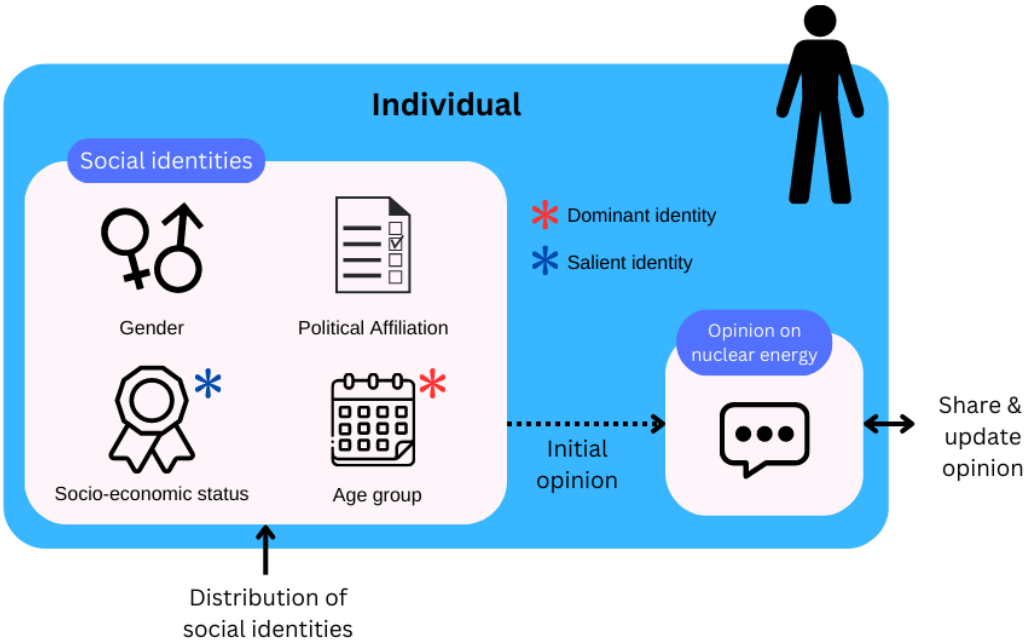

Figure 4.1: Conceptual representation of an agent

The first model version (mv1) is the most simple version, based on the principle of prototypes. One individual of the in-group with the most prototypical behavior or opinion (prototypical for the identity of the group) will have more influence on the other group members and will be seen as more correct (disregarding knowledge on the topic), this is based on the principle of prototypes. This will be implemented in the model by making someone the group's 'prototype', this is one of the members whose dominant identity is the same as the groups salient identity. By discussing the subject of nuclear energy the in-group members will converge on the opinion of the prototype. In this model version, individuals compare themselves only to the in-group, meaning that the prototype does not have the need to adapt their opinion (as they are seen as the most prototypical).

Model version two (mv2) builds on mv1 and will introduce a repulsive force (where mv1 only works with an attractive force). As explained, the prototypes do not feel the need to adapt their opinion compared to the in-group, however, they might adapt their opinion compared to the out-group. They see the out-group as inferior and will move their opinion away from theirs, based on social comparison theory. This will be modelled by making the opinion of the in-group prototype diverge from the opinion of the out-group prototype. The other group members will still converge on the opinion of their prototype (after the prototype has adapted their opinion).

The final model version (mv3) will be based on the optimal distinctiveness theory. This theory suggests that individuals will try to find a balance between their need for inclusion and their need for differentiation. This will be implemented in the model by making the in-group members converge on the opinion of the prototype whenever there are multiple in-group members (they will feel more need for inclusion). When a person is the only in-group member, their need for differentiation increases and they will move their opinion away from the prototype of the out-group (e.g. when political affiliation is the salient identity in a social group of four members. When there are three left-wingers and one right-winger, the left-wingers will converge on the opinion of their prototype and the right-winger will diverge from the opinion of the left-wing prototype).

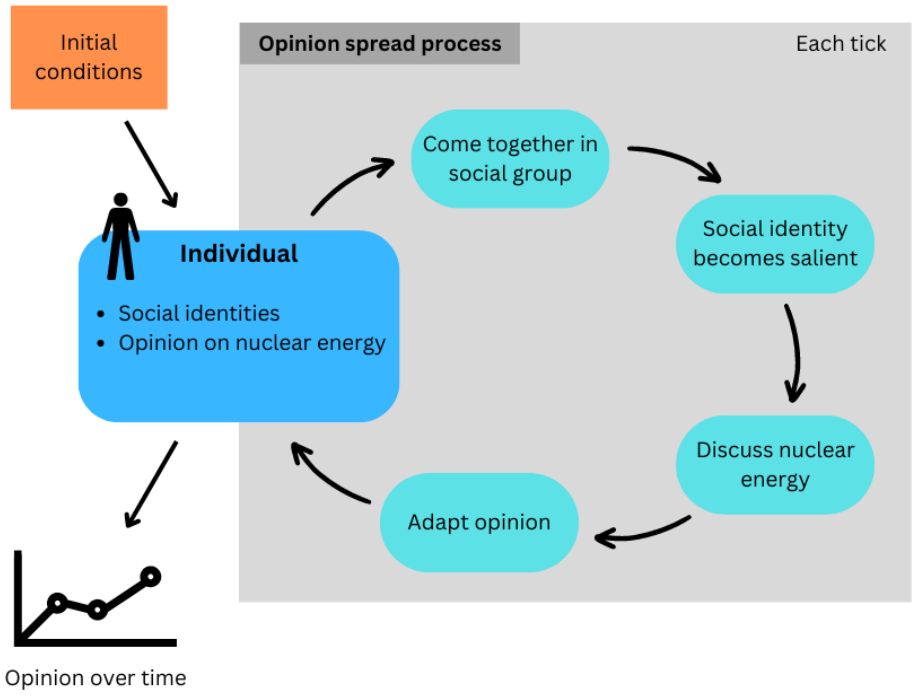

Figure 4.2: Conceptual representation of the model

Active identities

In order to see the effect of social identities, the model will include the possibility to turn on/off each identity. This will help to identify the impact of individual identities as well as the combined effect of multiple identities. In the model, each agent will be assigned only the identities that are turned on, meaning that they will also only have a dominant identity (and salient identity) chosen from the identities that are turned on. Only the activated identities can therefore affect the behavior of the agents.

Group size

Furthermore, it was decided to put some restrictions on the group size. The experiments of Fay et al. show that ”in small, 5-person groups, the communication is like dialogue and members are influenced most by those with whom they interact in the discussion. However, in large, 10-person groups, the communication is like monologue and members are influenced most by the dominant speaker” [78]. Note that dominant speaker is not the same as dominant identity. A dominant speaker is the biggest contributor to the conversation [78], while the dominant identity is the social identity a person identifies with the most. In this model, the prototype of the group is based on the dominant identities of the group members. Although a member of the group is the most prototypical, they might not be a dominant speaker. It could be the case that the prototype is a non-dominant speaker and is mostly silent during the discussion. Fay et al. mention that ”an ideal small interactive group should have about 5 members and that groups change in terms of their interaction and communication patterns as they approach a size of 10” [78]. It is decided that the communication in the groups in the model happens in interactive groups where members are assumed to contribute equally and are able to identify the most prototypical member. Therefore, the average group size is set to 5 and a maximum group size is created and set to 9.

Opinion adaptation

The extent to which an agent can adapt their opinion in one discussion is determined by the opinion-changerate (scale 0-1). When an agent converges on the opinion of their prototype, the opinion-changerate says how much an agent’s opinion can move closer to the opinion of the prototype. Where 0 means that the agents do not change their opinion, 0.5 would mean that the agents move half the distance closer, and 1 means that they completely adopt the opinion of the prototype. When agents diverge in opinion, the opinion-changerate says how much an agent’s opinion can move away from the opinion of the other agent. Since the agents will diverge their opinion to differentiate from other agents, it is assumed that they move away more when their opinion is closer to the opinion of the other agent. To model this, the complement of the opinion difference (1 - opinion difference) will be taken and then multiplied with the opinion-changerate to determine the opinion adaptation. For example, there are two agents who will diverge and their opinion difference is 0.3 and the opinion-changerate is 0.3, then the absolute opinion adaptation will be (1 - 0.3) * 0.3 = 0.21. Note that both agents can then move 0.21 away from the initial opinion of the other, because the opinion-changerate indicates how much a single individual can adapt their opinion in one discussion.

4.2. Formalization

Here the conceptual model will be formalized. This is done by means of pseudo code.

```
Setup:
- Set country (Germany or France)
    - If country is Germany:
        - Set population distribution as Germany distribution
        - Set opinion distribution as Germany distribution
    - If country is France:
        - Set population distribution as France distribution
        - Set opinion distribution as France distribution
- Create individuals:
    - Assign (active) social identities:
        - Political affiliation: left or right
          Age group: young or old
          Socio-economic status: high or low
          Gender: male or female
        - Set dominant identity as one of the active identities
    - Give Initial opinion (continuous on scale 0 to 1):
        - Percentage of people that is pro-nuclear (of the agent's dominant identity) is the
            chance that the agent is pro-nuclear
        - If pro-nuclear:
            - Set opinion > 0.5
        - If anti-nuclear:
            - Set opinion < 0.5

Go:
- Divide the agents in random groups (average group size = 5, maximum group size = 9)
- If there are 2 or more people in the group:
    - For each group, set 'salient identity' as the most common dominant identity in the
        group
    - In each subgroup within the salient identity (e.g. when 'gender' is the salient
        identity then 'male' and 'female' are the subgroups), make one person the prototype
        of the group:
        - One of the agents whose dominant identity is the salient identity
        - If none of the agents have their dominant identity the same as the salient identity
            , then select a random agent of that subgroup to be the prototype
    - Update opinion:
        - If model version is 1:
            - The opinion of the agents moves closer to the opinion of the prototype of their
                subgroup
        - If model version is 2:
            - The two prototypes move their opinion away from each other
            - The opinion of the other agents moves closer to the opinion of the prototype of
                their subgroup
        - If model version is 3:
            - If number of agents in subgroup > 1:
                - The opinion of the agents moves closer to the opinion of the prototype of
                    their subgroup
            - If number of agents in subgroup = 1:
                - The agent moves their opinion away from the opinion of the prototype of the
                    other subgroup

Tick
```

4.3. The model

The model code was built on the conceptualization and formalization created above. The source code can be found in Appendix B and the full NetLogo model is available online.

4.3.1. Assumptions and simplifications

The creation of the model involved making certain assumptions and simplifications. The difference between the two is explained by Robinson [76]: ”Assumptions are made either when there are uncertainties or beliefs about the real world being modelled”. ”Simplifications are incorporated in the model to enable more rapid model development and use, and to improve transparency”. The main assumptions and simplifications are:

- **Population and opinion distribution:** The assignment of identities and opinions to the agents does not take into account that certain combinations of identities and opinions are more common in real life.
- **Complexity of social identities:** There are only 4 social identities and each identity is divided in 2 groups. Simplifying the complexity of real-life identities.
- **Behaviour of the agents:** The agents in the population are fully connected (everyone can form a social group with anyone) and everyone follows the same rules for opinion adaptation. Also, the chance that an identity becomes salient in the model is roughly equal for all four identities.

In Appendix C, the full list of assumptions and simplifications can be found. The effect of these will be discussed in section 6.2.

4.3.2. Verification

To check whether the model does what it is expected to do, the model has to be verified. The aim of verification is to confirm that the conceptual model is correctly translated into model code [44]. According to Van Dam et al. [44], there are four parts in the verification of an ABM:

- *Recording and tracking agent behavior* - This step involves tracking the inputs, states and outputs of agents and internal processes. It helps to ensure that the model functions correctly at the agent level.
- *Single-agent testing* - Here, the behavior of a single agent is examined. By defining the expected behavior and comparing it with the actual outcomes, it can be determined whether the agent behaves as intended.
- *Interaction testing* - This step introduces a second agent (the minimum number of agents required for all the processes in the current model to be able to run). This helps to ensure that the interactions in the model happen as expected.
- *Multi-agent testing* - The final step of verification involves evaluating the behavior of the entire model. This ensures that all agents interact correctly and the model functions as intended.

Next to these verification steps, some additional measures are taken to verify the model, the complete model verification can be found in Appendix D. If any unintended behavior is discovered during any of the tests, it is addressed and adaptations are made to the model if necessary.

5 Results

This chapter will explain the experimental setup and present the results of the experiments. Furthermore, a sensitivity analysis is performed, and the model is validated.

5.1. Experimental setup

Below, the experimental design is described and Table 5.1 shows the possible combinations of parameters and the number of runs. For both countries, all 3 model versions will be used, and each model version will be tested with all possible combinations of identities. There are 15 identity combinations, not including the possibility where all identities are turned off. Each combination will be run 100 times, resulting in a total of 4500 runs per country.

General setup

- *Ticks [until convergence]*: At the end of every run, the opinions of all agents are duplicated and put in a list. The opinions in this list are rounded to 2 decimals and duplicates are removed, this creates a list of distinct opinions. A stop condition is implemented which stops the run if there are 2 or less distinct opinions. In this way, the model will stop whenever the opinions converge to one or two clusters (consensus or polarization).
- *Tick limit [1000]*
- *Repetitions [100]*: To obtain a representative set of outcomes, feasible with the computing power available.

Parameter settings

- *num-agents [1000]*: See sensitivity analysis in section 5.3.
- *avg-group-size [5]*: As explained in the conceptual model.
- *opinion-changerate [0.3]*: See sensitivity analysis in section 5.3. It is not deemed realistic that a person fully adopts the opinion of another person in one discussion, and an opinion-changerate above 0.5 leads to more chaotic behavior. Below 0.5 seems realistic, set to 0.3 (no big changes in opinion).

Output at each tick

- *The opinion of all agents*
- *The distinct opinions*

Table 5.1: Experiment design

Country	Model-versions	Identity combinations	Runs
Germany	3	15	4500
France	3	15	4500
Total			**9000**

5.2. Results

In this section, the results of the experiments in the model are presented. The main results are accompanied by plots, additional extra results are visualized in Appendix E and are referred to in text, e.g. Figure E.1.

5.2.1. Model-version 1

In model-version 1, the agents move their opinion closer to the opinion of the prototype of the group. The opinions converge before 100 ticks, well before the limit of 1000 ticks (see Figure E.1). When there is only one identity, the run could take 80 ticks before convergence. When adding more identities, the convergence happens earlier.

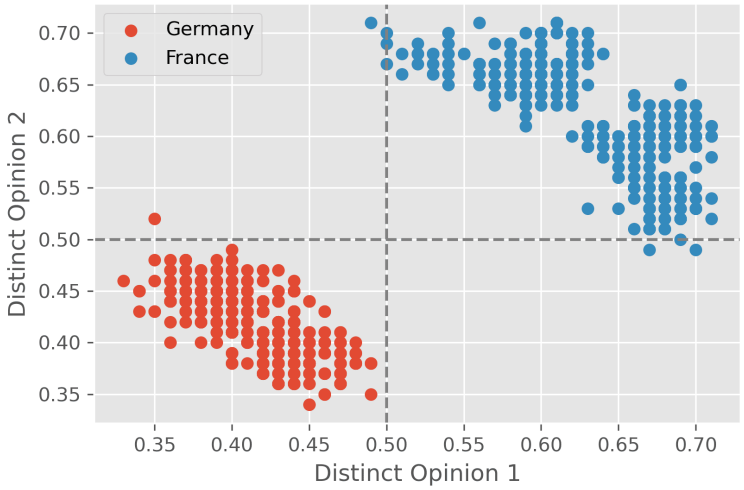

Figure 5.1: The distinct opinions after convergence (model-version 1, all runs with 1 identity only)

For the runs in model-version 1 with only one identity active, public opinion consistently converges into two clusters. In Germany, the clusters are almost always (moderately) anti-nuclear, while in France, they are predominantly (moderately) pro-nuclear (see Figure 5.1). This can be explained by the fact that the agents in the model only adapt their opinion with respect to their in-group. When there is only one identity active, all agents will have that identity as their dominant identity, meaning that they can all become the prototype in a social group. This results in convergence on approximately the average opinion of their social identity, for example, left-wingers converge to their average initial opinion, and right-wingers converge to their average initial opinion. The chance that the opinions of both social identities end up fairly similar is smaller in France (see Figure 5.1 and Figure E.2), this might be explained by the bigger differences between social identities in France.

Now analyzing what happens when multiple identities are active. For all runs with two or more identities active, the opinions converge to a single cluster. Germany always converges to anti-nuclear, and France always converges to pro-nuclear (see Figure 5.2). This convergence can be explained by the fact that multiple social identities are active and the formation of social groups in the model is random (meaning that everyone can end up in a social group with anyone, a fully connected network). In different social groups, different identities will become salient, meaning that the agents will adapt their opinion with respect to a different prototype each tick. Because the agents have multiple identities to consider in social groups with all possible combinations of identities, salient identities, prototypes etc., this ultimately leads to convergence to a single cluster. The final opinion in France is more extreme than in Germany. This is because the opinions approximately converge to the average of the initial opinion distribution, which is more extreme in France.

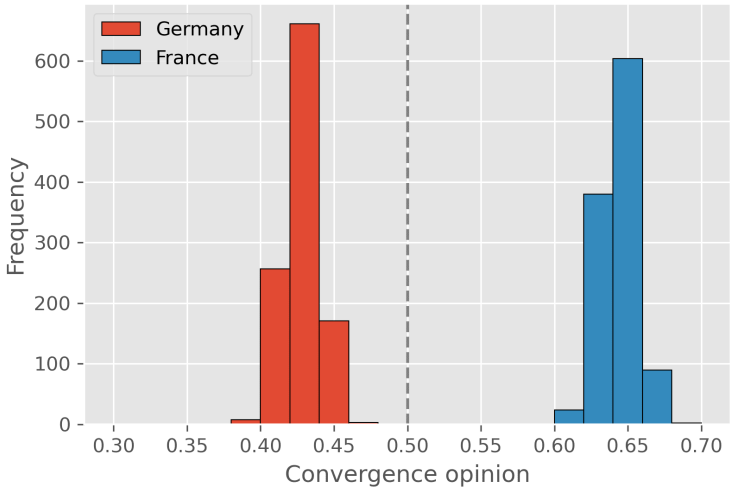

Figure 5.2: Opinion after convergence (model-version 1, all runs with 2-4 identities)

5.2.2. Model-version 2

In model-version 2, a repulsive force was introduced. The prototypes in the group move their opinion away from each other, and afterwards the other agents move their opinion closer to the opinion of their respective prototype. This model-version converges rather quickly when only one identity is turned on (see Figure E.3). The convergence speed for the runs in Germany is a bit more spread compared to France. The model does not converge when there is more than one identity turned on in model-version 2 (the tick limit of 1000 is reached every single time).

When only one identity is active, the opinions in the model converge to two extreme clusters (see Figure 5.3). Both countries show polarization in their opinions, for example, the women converge to completely anti-nuclear and the men end up completely pro-nuclear. It is not always the case that the social identity with the highest initial number of pro-nuclear agents ends up completely pro-nuclear, in some runs the opposite happens (which depends on the initial opinions and sequence of ticks, in other words, it is path-dependent). Extreme polarization occurs in all runs in model-version 2 with only one identity active. This happens because the agents always diverge from their out-group and converge on their in-group.

As explained, no convergence happens when more than one identity is active in the model. The model keeps running until it is stopped by the tick limit. In these runs, the full spectrum of opinions is used, with some light clustering at the extremes. Although the model does not converge, there are still some emerging patterns which can be seen in Figure 5.3. When there is one identity active, the opinions polarize to the extremes. When a second identity is added, there is still a significant number of extreme opinions created (indicated by the peaks at the edges). However, more than half of the agents now has an opinion in the middle region of the spectrum (0.1-0.9). Adding more identities leads to more agents in the middle of the spectrum and less agents with an extreme opinion. Furthermore, in France there are usually more agents with an extreme pro-nuclear opinion than with an extreme anti-nuclear opinion. In Germany, the opposite does not necessarily happen, as can be seen in the plot for the runs with one and two identities active in Germany in Figure 5.3, where there are more agents with an extreme pro-nuclear opinion than with an extreme anti-nuclear opinion.

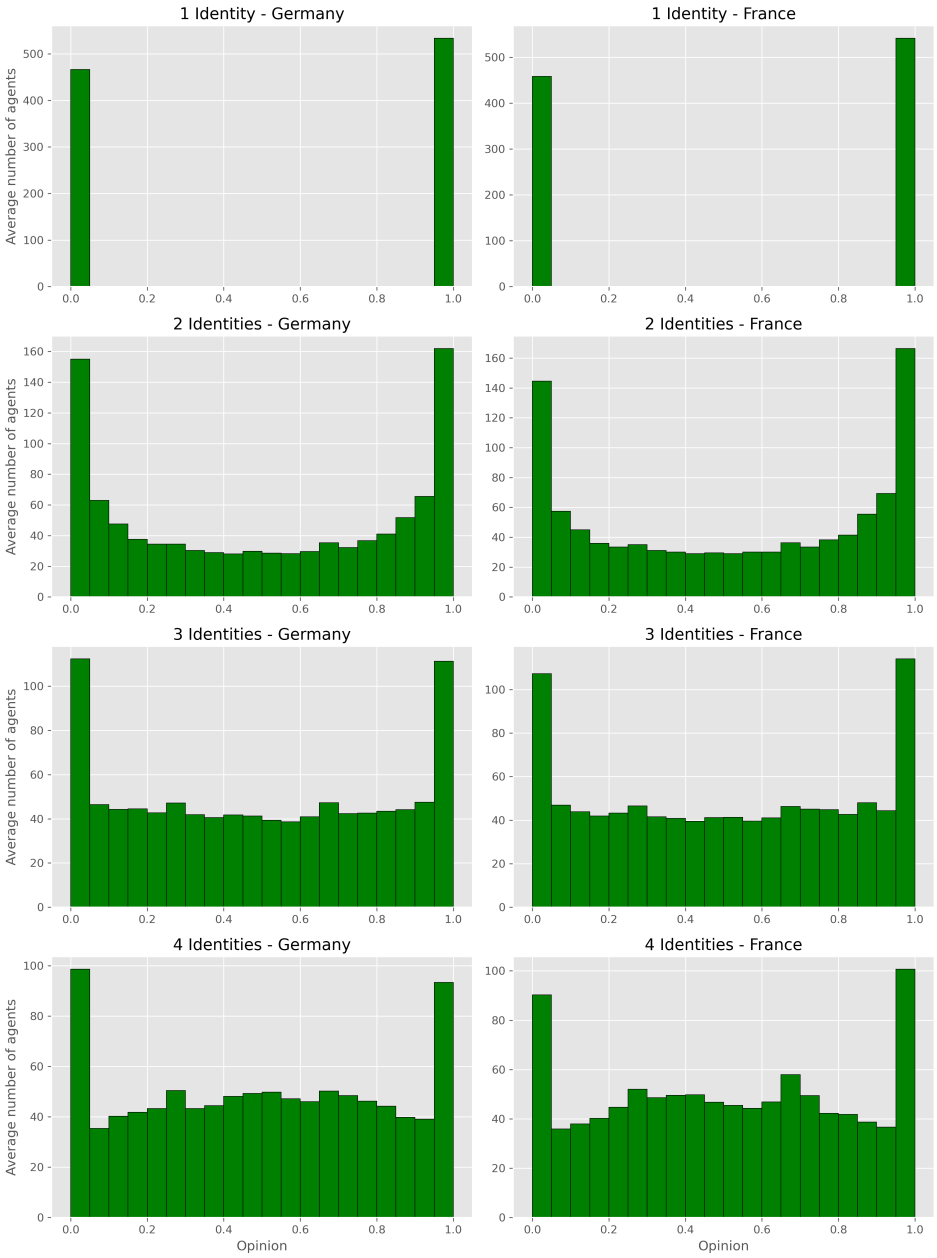

Figure 5.3: Average final opinion distribution in model-version 2

5.2.3. Model-version 3

In model-version 3, the agents converge on the opinion of their prototype, unless they are the only member of the in-group, then they will diverge from the opinion of the prototype of the out-group. The model converges for the runs with one active identity and the model does not converge for any run with more than one identity (same as in the second model version). It should be noted that runs with one active identity in model-version 3 take significantly longer to converge than the runs with one active identity in the second model version. It takes at least 100 ticks with a maximum around 500 ticks in both countries (see Figure E.4).

When only one identity is active, the opinions in the model converge to two extremes, just like in model-version 2. In every single run of model-version 3 with one identity active, polarization happens (see Figure 5.4). For the runs with more than one active identity, the final opinion distribution shapes similar to a normal (Gaussian) distribution, the majority of the opinions is in the middle of the spectrum (mod-

erate opinion) and the number of opinions decreases toward the extremes. Note that these runs were always stopped by the tick limit, and not because they converged.

Adding more identities has a depolarizing effect, leading to less extreme opinions. With one active identity the opinions polarize, this happens because the agents converge on their only in-group and diverge from their only out-group. Adding one other identity leads to depolarization, however, the opinions are still significantly spread out. Adding a third and fourth identity leads to narrowing of the public opinion. Again note that the runs with multiple identities never converge and the opinions stay dynamic. The bottom three plots in Figure 5.4 do not show the averages of static distributions, merely a snapshot of the averages of dynamic distributions. The opinions are still moving around as a cluster in the middle of the spectrum, not much can therefore be said about the majority being anti or pro.

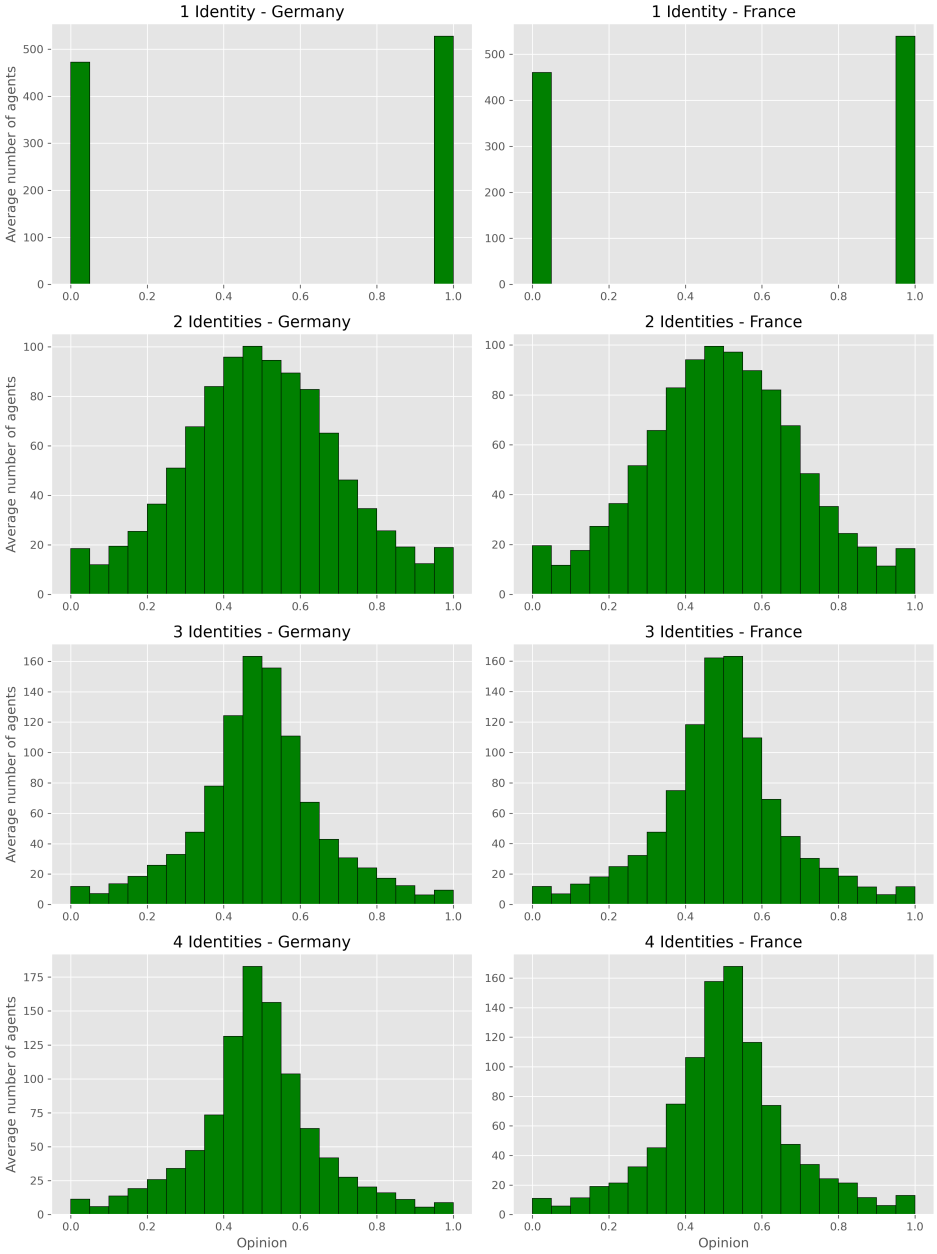

Figure 5.4: Average final opinion distribution in model-version 3

5.3. Sensitivity analysis

A sensitivity analysis was conducted to understand how different input parameters might change the output of the model. This will help to identify which parameters have the most significant impact on the model's results and can provide insights into the robustness and reliability of the model [79]. The values that are tested can be found in Table 5.2.

Table 5.2: Parameter test values for the sensitivity analysis

Parameter	Values				
num-agents	100	1000			
avg-group-size	2	5	8		
opinion-changerate	0.1	0.3	0.5	0.8	1.0

During the sensitivity analysis, it was found that using 1000 agents in the simulation led to population distributions and initial opinion distributions that closely matched the intended values, showing less variation across multiple runs. When only 100 agents were used, the distributions were more likely to deviate from the intended numbers. Furthermore, the emerging patterns became more clearly visible with 1000 agents and there was enough computing power available to run the model with 1000 agents. Therefore, it was decided to run the experiments with 1000 agents.

Model-version 1

In general, the first model version does not show different behavior compared to the behavior found before. The model only behaves differently with an opinion-changerate of 1.0, in this scenario, agents fully adopt the opinion of their prototype after each discussion. With an opinion-changerate of 1.0, the model either fails to converge within the tick limit (see Figure E.5 and Figure E.6) or converges with considerable variance in outcomes (see Figure E.7 and Figure E.8). This happens because the agents completely adopt each other's opinions, resulting in more chaotic movement on the opinion spectrum.

Model-version 2

Overall, the sensitivity analysis on model-version 2 does not show high deviance from the general pattern. Extreme polarization happens when only one identity is turned on, and adding more identities has a depolarizing effect. Only the pattern of depolarization is different with different parameter settings. The amount of depolarization seems to depend on the avg-group-size, bigger groups lead to more depolarization when an identity is added (see Figure E.9 and Figure E.10), this is because the agents come in contact with more people and more contexts. Also, an opinion-changerate above 0.5 leads to less depolarization (see Figure E.11 and Figure E.12), this is because agents can then adapt their opinion significantly after a discussion, meaning that when diverging from an opinion close to them, they will move from one side of the spectrum to the other (leading to less opinions in the middle of the spectrum). This means that with an opinion-changerate of 1.0, the model converges quickly with opinion clusters at the extremes.

Model-version 3

The sensitivity analysis on model-version 3 gave similar results compared to model-version 2. Adding more identities leads to more depolarization. Also, a bigger group size leads to more depolarization (see Figure E.13 and Figure E.14). In contrast to model-version 2, an opinion-changerate above 0.5 does not lead to less depolarization (see Figure E.15 and Figure E.16). This is because in model-version 3, agents diverge in opinion less often. However, similar to model-version 2, with an opinion-changerate of 1.0 only extreme opinions exist.

General

It can be said with relative certainty that adding more identities has a depolarizing effect, however the pattern of depolarization depends on the model-version, the avg-group-size and the opinion-changerate (i.e. the way of opinion adaptation, the size of the social groups, and how quick people adapt their opinion). An opinion-changerate of 1.0 (agents either fully adopt the opinion of another agent, or move their opinion the maximum distance away from others) leads to very different behavior compared to all other

parameter settings, and should therefore be avoided when using the model. In general, an opinion-changerate above 0.5 might not be realistic and leads to more chaotic behavior, it might therefore not be preferable.

5.4. Validation

At last, to check whether the model is useful and convincing, the model should be validated. Traditional validation focuses on checking whether the model accurately represents the real-world system of interest [44], however, since in real life, social identities are not the only influence on people's attitudes toward nuclear energy, there is no real-world situation to compare the model to. Therefore, suitable methods for validating this model are expert validation (domain experts are interviewed to validate the system behavior and the models fit for purpose), literature validation (patterns and outcomes of other research are compared to the current research), or model replication (a second ABM is created with a different technique, preferably by a separate research team) [44]. Because of time constraints, the model will be validated by comparison to literature and other models.

Comparable research was found in the work of Laurent Salzarulo [70]. Salzarulo created a general opinion dynamics model based on social identities and more specifically the meta-contrast principle (from the self-categorization theory). The model simulates how individuals categorize and update their opinions in social groups. The agents in the model adapt their opinion by adopting the opinion of the most prototypical member of their in-group. An opinion becomes more prototypical of a social group if it minimizes its mean distance from in-group opinions and maximizes its mean distance from out-group opinions. The model calculates the prototypicality of an individual's opinion, identifies the most prototypical opinion within the in-group, and updates an individual's opinion based on the opinion of the most prototypical member. The model is run with a population of fully connected agents, and includes both an attractive force (convergence on the prototype) and a repulsive force (determined by the out-group aversion). Both models are based on similar prinicples and include similar features. A key difference between the models is that in Salzarulo's model group membership is determined by how similar individuals' opinions are to each other, while in the thesis model it is determined by a pre-defined set of identities. Furthermore, the most prototypical member is based on the most prototypical opinion of the in-group, while in this thesis the most prototypical member is the individual who identifies most strongly with the in-group's identity.

Salzarulo found that "consensus, polarization or extremism are possible outcomes, even without explicit introduction of extremist agents" [70]. In model runs with no or low out-group aversion, all agents converge to one opinion which is close to the initial average (comparable to the setup and outcomes of model-version 1). With a higher out-group aversion, the opinions of the agents tend to polarize to the extremes (comparable to the setup and outcomes of model-version 2 and 3, with one active identity). Salzarulo's model outcomes do not include situations in which the opinions stay dynamic, this happens because of the difference in determination of group membership. In Salzarulo's model the agents can switch between groups or create new groups, which allows them to find an equilibrium.

Furthermore, the outcomes of this thesis were compared to an experimental study conducted by Balietti et al. [80], which investigated the effects of exposure to individuals with differing political views but similar interests and demographics. They found that such exposure increased the likelihood of adopting their political views. The study suggests that encouraging conversations based on shared nonpolitical interests could help reduce polarization and promote consensus. These outcomes are comparable to one of the main outcomes of this thesis, exposure to multiple social identities and different contexts leads to opinion depolarization.

Similar patterns are found in this research and similar other research, increasing the validity of the outcomes.

6 Discussion

In this chapter the implications and limitations of the results are discussed. First, analyzing the key findings and establishing their connection to the underlying theory through the hypotheses, as well as their relevance to the broader research perspective. Subsequently, the impact of the assumptions and simplifications is discussed, along with the limitations of this research.

6.1. Implications

6.1.1. Model outcomes

Model-version 1

Model-version 1 shows what happens when people only focus on inclusion in their in-group. When people then only behave in the context of one identity, they will reach consensus with their in-group. This finding supports Hypothesis 1, which will be further explained in subsection 6.1.2. This could be related to situations where nuclear energy discussions are limited to specific social groups, always in the context of the same social identity. For example, when a set of social groups (a small community) mainly consist of right-wingers, and whenever nuclear energy is discussed it is always in the context of their political affiliation. Then the community will converge approximately to the average opinion of its members. If there are multiple communities like this, this would lead to clusters on the opinion spectrum of the public. If a whole country would consist of such communities, this would mean that the public opinion would not be able to diverge significantly from the current situation. The public would not be able to reach a consensus, since they converge to the average opinion of their social groups.

When people would discuss nuclear energy in the context of multiple social identities and only focus on inclusion in their in-group, then the whole population would reach consensus. This is the result of the possibility of changing context (e.g. a younger and older person who were not able to able to agree, might now be able to find common ground if they both identify as a left-wing voter). Because they only focus on inclusion in the in-group (converge in opinion), the public would reach a consensus. The consensus opinion will be close to the average of the whole population (France would converge to a pro-nuclear consensus and Germany would converge to an anti-nuclear consensus).

Model-version 2

Model-version 2 demonstrates what happens when people both converge in opinion with respect to their in-group and diverge from their out-group. When people only behave in the context of one identity, then they will reach consensus with their in-group at an extreme, away from the out-group (supporting both Hypothesis 1 and Hypothesis 2, see subsection 6.1.2). All members of the social identity will become either completely anti-nuclear or completely pro-nuclear, the opposite identity group will settle at the other end of the spectrum, i.e. extreme polarization occurs. This means that in a society in which the topic of nuclear energy is only discussed in the context of one social identity, and people both converge within their in-group and diverge from their out-group, there will only be extreme opinions.

When multiple identities are introduced and people both converge on their in-group and diverge from their out-group, the public opinion will stay dynamic (no static equilibrium is reached). This is caused by the fact that with multiple identities, an individual is able to move their opinion towards or away from the opinion of anyone else in the population in different contexts (e.g two individuals with a high socio-economic status initially agreeing in discussion, might move their opinion away from each other if their differences as female and male become more visible). A higher number of possible contexts has an increasing depolarizing effect. Thus, when people discuss nuclear energy in multiple social groups with different identity compositions and multiple contexts, this leads to less extreme opinions and an increase in opinion diversity.

Model-version 3

Finally, model-version 3 displays what happens when people focus on inclusion or differentiation depending on the context of their social group. When people then only behave in the context of one identity, the same pattern emerges as observed before (in model-version 2, further supporting Hypothesis 1 and Hypothesis 2, see subsection 6.1.2). Polarization happens and an equilibrium is reached with the identity groups at the extreme ends of the opinion spectrum.

When multiple identities are introduced, depolarization occurs and the opinions keep moving around. The different contexts in which discussions take place cause the opinions to stay dynamic like in the second model version, however, different patterns emerge than before. Where the previous model-version showed a more uniform distribution of opinions, this version often shows a close-to-normal distribution. This is caused by the fact that individuals will converge to their in-group, unless there is no other member of their in-group present in the social group (then they will want to differentiate from their out-group). Overall, this means that an individual will find a balance that involves regular convergence to their in-group (need for inclusion) and occasional divergence from the out-group (need for differentiation). This leads to a more narrow distribution when more identities are added, because the chance that a person converges on the opinion of another individual increases (more than the chance that a person diverges from the opinion of another individual). In this situation, the public opinion becomes more moderate with less extreme opinions. Not much can be said about the majority of the opinions being pro or anti-nuclear, as the distribution keeps shifting around in the middle of the spectrum.

Finally, next to the way of opinion adaptation; the size of the social groups and the speed of opinion adaptation also affect the emerging patterns. Bigger social groups seem to increase the depolarizing effect of multiple identities, with bigger groups people are exposed to more people and more possible contexts. Furthermore, when people are more susceptible to the opinion of others (i.e. they adapt their opinion significantly after a discussion), this leads to more chaotic and less predictable behavior.

6.1.2. Hypotheses

The outcomes of the research support the two hypotheses, which will be elaborated in this section. The establishment of the hypotheses is explained in section 3.3. First, the two hypotheses will be repeated:

Hypothesis 1: In-group favoritism leads to consensus within social identity groups
It was hypothesized that this in-group favoritism will lead to intra-group consensus, meaning that individuals within the same social identity group will converge on similar attitudes toward nuclear energy.

Hypothesis 2: Out-group aversion leads to polarization between social identity groups
It was hypothesized that out-group aversion is will contribute to inter-group polarization, meaning that different social identity groups will exhibit contrasting attitudes toward nuclear energy, driven by their need to differentiate from out-groups.

The outcomes of model-version 1 align with Hypothesis 1, demonstrating the impact of in-group favoritism on opinion dynamics. When individuals conform to the opinions of their in-group, this behavior leads to consensus within each identity group, with opinions converging to an average that reflects the majority view of the respective group. When nuclear energy is discussed in the context of multiple social identities, this also leads to consensus between identity groups (and therefore consensus within the whole population).

The outcomes of model-version 2 and 3 support Hypothesis 2, illustrating the role of out-group aversion in opinion polarization. When people show aversion towards out-groups and move their opinion away from theirs, this behavior leads to polarization between identity groups. While the out-group aversion leads to extreme polarization between social identity groups, the in-group favoritism again leads to consensus within social identity groups, further supporting Hypothesis 1. When discussions involve individuals from multiple social identity groups and individuals discuss nuclear energy in the context of multiple identities, the dynamics change. The possibility of changing contexts allows individuals to find common ground and reach consensus, even if they initially held opposing views. As a result, a depolarizing effect is observed, with the entire population having less extreme opinions and more people being able to reach consensus.

6.1.3. The broader picture and real-life implications

The outcomes of the model confirm the hypotheses: in-group favoritism leads to consensus within social identity groups, while out-group aversion leads to polarization between social identity groups. Additionally, this research shows that discussing nuclear energy in the context of multiple social identities leads to depolarization of opinions between social identity groups. Furthermore, these outcomes do not seem to depend on the initial conditions, as indicated by the similar outcomes between Germany and France.

Discussing nuclear energy solely within the context of one social identity, results in polarization of opinions within a population. For example, if the topic is always discussed in a political setting, the differences between people with different political beliefs might become more pronounced, leading to the divergence of opinions and potential extremism. This highlights the potential danger of limiting discussions to the context of a singular social identity, hindering the possibility of a diverse and balanced public opinion. Leaders and stakeholders involved in climate strategy negotiations should be cautious of allowing discussions to become isolated. Instead, they should actively seek ways to involve individuals with diverse identity combinations and they should consider strategies to encourage discussions in the context of multiple identities (in other words, they should facilitate inclusive conversations).

When discussions involve individuals from multiple social identity groups and individuals discuss nuclear in the context of multiple identities, this leads to depolarization of the opinions in a population. For example, instead of discussing nuclear energy in a political setting, where people's differences in political views might be the most noticeable. A different setting could be created where people's similarities as members of other shared social identities are emphasized, making their opinions move closer together. This finding underscores the potential of social identities to depolarize opinions through inclusive discussions. Encouraging individuals to consider various aspects of their identity when engaging in debates on nuclear energy and other complex issues can lead to increased consensus and a more balanced public opinion.

Linking back to the broader picture, this research emphasizes the significance of social identities in shaping public opinion on nuclear energy and other controversial topics. The effects of social identities contribute to diverse opinion dynamics, ranging from extreme polarization in isolated identity groups to depolarization and consensus when considering multiple identities in discussions. Understanding these dynamics is crucial for informing effective strategies for public engagement and climate governance. Policymakers and stakeholders should recognize the potential of considering multiple identities to encourage inclusivity and bridge gaps in discussions. By facilitating interactions between individuals from diverse social identity groups, policymakers can promote more balanced debates on nuclear energy and other climate-related matters. Furthermore, these findings can be extended beyond the specific context of nuclear energy and climate action. Social identity dynamics offer insights for addressing other complex challenges where public opinion plays a significant role, and knowledge on the subject is limited within the population.

6.2. Limitations & the effect of assumptions and simplifications

As with every study, the research decisions, assumptions, and simplifications lead to limitations on what can be concluded about the results. This section will discuss these limitations, and the effect of the main assumptions and simplifications (which were presented in subsection 4.3.1) will also be addressed.

Population and opinion distribution

Firstly, the population and opinion distributions are based on survey data which might not be representative of the entire country. Furthermore, the combination of identities of a person is assigned randomly in the model, while the chance that for example a person with a high socio-economic status votes for a right-wing party might be higher than the chance that they vote for a left-wing party. Improving the accuracy of the population and opinion distributions might allow us to better understand the differences between social identities and the differences between Germany and France. However, this simplification should not affect the general conclusions, because even if the population and opinion distributions were to be adjusted to be more representative, the underlying mechanisms of social identity effects and opinion adaptation would still be present. These mechanisms are the main drivers of the outcomes, as demonstrated by the similarities in outcomes between Germany and France.

Furthermore, the outcomes per run in the model are path dependent, meaning that they depend on the initial conditions (population and opinion distribution) as well as the specific order in which agents take action. To draw meaningful conclusions, the model is run multiple times, and observations are based on identifying patterns and calculating averages across these runs. For future research, it could be beneficial to run the model with a fixed seed. Setting a specific seed value ensures that the sequence of random numbers generated within the model remains identical across simulations, enabling reproducibility and precise analysis of sensitivity to initial conditions [44]. This will allow researchers to investigate under what specific conditions certain outcomes emerge and to show critical transition points between those outcomes.

Complexity of social identities

Secondly, the complexity of social identities might not be accurately represented. This research only considers four identities, while real-life identities are more diverse. It is also important to recognize that identities can change over time, which can impact the opinion dynamics. Furthermore, dividing the identities into two groups may oversimplify group membership, e.g. people may only see the party they vote for, rather than all left-wing voters, as part of their in-group. Therefore, the model might not accurately represent the complexity of social identities, which could significantly affect the results. Introducing more complexities might uncover a wider range of patterns (e.g. more opinion clusters) [70]. However, it should be taken into account that introducing more complexities could lead to less interpretable and explainable results [77].

Behaviour of the agents

Thirdly, the behaviour of the agents in the model might not be representative of real life. How and when people adapt their opinion, differs per person and situation. The model assumes that everyone follows the same rules for opinion adaptation, and opinions are simplified as numerical values, which might take away the complexity of opinions and opinion adaptation. Furthermore, in reality, people do not interact randomly with anyone. Instead, they form social circles that may or may not be diverse. For instance, some people might only form social groups with people they share multiple identities with. According to current research on opinion dynamics, model outcomes are highly dependent on the network topology [61]. In a less connected network, polarization and fragmentation would be more prevalent. However, introducing more connections in the network leads to a higher likelihood of achieving consensus [61, 68, 69]. Therefore, by facilitating inclusive discussions (as explained in subsection 6.1.3) between individuals who were not connected before, the network could become more interconnected, leading to an increased consensus. Future research could explore the relationship between the level of connectedness and the corresponding level of consensus that can be achieved.

In addition, the chance that an identity becomes salient in the model is roughly equal for all four identities. In real life, certain identities might have a higher chance of becoming salient in the context of nuclear energy. For instance, political affiliation might have a higher chance of becoming salient due to its strong connection to environmentalism [26]. Consequently, polarization would occur more frequently. Facilitating discussions in different settings would result in more depolarization (as explained in the sections above). Furthermore, in Salzarulo's model, the person with the most prototypical opinion is considered the most prototypical member. While in the current model, a prototypical member might not necessarily hold a prototypical opinion. The question remains of how to accurately model this, however, note that individuals may not even know what the most typical opinion is within their own identity group.

General

Finally, it is important to acknowledge that this research primarily focuses on the impact of social identities, however, there are other factors that can also influence attitudes and individuals' influence on others (e.g. knowledge on the subject of nuclear energy) [26, 81]. Additionally, while the research primarily focuses on Germany and France, the similarity in the main outcomes suggests that the findings could potentially apply to other countries as well. Furthermore, the model was only validated by comparison to other research. To improve the validity of the model, domain experts could be interviewed or the model could be recreated with a different system decomposition by other researchers to validate the patterns, outcomes and conclusion of this research [44]. While the model has limitations and potential adaptations could be made, it is important to consider the balance between model complexity and interpretability. Increasing the complexity of the model, in order to more accurately represent the real world, could lead to incomprehensible and unexplainable results [77]. This is why the research adhered to the KISS principle.

7

Conclusion

The aim of this research was to explore the effect of social identities on the opinion dynamics of nuclear energy. The main research question was divided in three research sub-questions, the conclusions for each question are provided below. Furthermore, the scientific and societal relevance of the study is discussed, followed by recommendations for future research.

7.1. Research sub-questions

This section provides conclusions on the research sub-questions. For more detailed explanations with more context and references, please refer to the corresponding chapters. Research sub-question 1 and 2 are answered in chapter 3. Research sub-question 3 is answered in chapter 5 and chapter 6.

"How can social identity research be used to model the opinion dynamics of nuclear energy?" (S1)

The extensive body of research on social identities reveals that identification with a group can significantly affect our behavior and opinions. The social identity approach, consisting of social identity theory and self-categorization theory, provides a framework for understanding how group interactions shape attitudes. Social identity theory emphasizes conformity to maintain a positive identity, while self-categorization theory highlights context-based identity shifts. Opinion dynamics hinge on conversational context which is determined by social comparison, impacting how individuals act in a given situation. In general, in-group favoritism leads individuals to conform to in-group norms, while out-group aversion leads individuals to differentiate themselves from the out-group.

Studies focused on social identities underscore the effect of social influence on opinion formation. Researchers have developed various agent-based models (e.g., voter, bounded confidence) to simulate these dynamics, simplifying complex scenarios. Ultimately, combining research on the effects of social identities on opinion dynamics with research on how social identity groups perceive nuclear energy, offers a pathway to create a model that captures the effect of social identities on nuclear energy opinion dynamics.

"How are social identities related to attitudes on nuclear energy in Germany and France?" (S2)

The general research on the relationship between social identities and attitudes toward nuclear energy reveals the most influential identities. Political affiliation, age group, socio-economic status, and gender are identified as the most dominant. This research examined the attitudes in two contrasting countries: one with majority support and the other with majority opposition to nuclear energy. By studying France and Germany, representing both sides of the opinion spectrum, this thesis aimed to uncover general insights applicable to the debate on nuclear energy. The opinion distribution in Germany and France can be found in Table 7.1 and Table 7.2. The numbers further support the findings of general research. In both countries, women, left-wing supporters, and younger individuals are generally more opposed to nuclear energy, while men, right-wing supporters, and older individuals tend to be more supportive. However, the difference between Germany and France is that the majority of all these social identity groups in France is pro-nuclear, while in Germany the majority is against it.

Table 7.1: Opinion distribution on nuclear energy in Germany (anti-nuclear vs pro-nuclear)

Social Identity	Anti	Pro
Political affiliation		
Left wing	75.2%	24.8%
Right wing	58.6%	41.4%
Age group		
Young	71.7%	28.3%
Old	62.7%	37.3%
Socio-economic status		
Low	64.3%	35.7%
High	67.7%	32.3%
Gender		
Male	62.1%	37.9%
Female	69.6%	30.4%

Table 7.2: Opinion distribution on nuclear energy in France (anti-nuclear vs pro-nuclear)

Social Identity	Anti	Pro
Political affiliation		
Left wing	42.8%	57.2%
Right wing	13.9%	86.1%
Age group		
Young	30.2%	69.8%
Old	19.8%	80.2%
Socio-economic status		
Low	28%	72%
High	13%	87%
Gender		
Male	17%	83%
Female	32%	68%

"What patterns will emerge in the public opinion on nuclear energy in Germany and France if communication is only influenced by social identities?" (S3)
The developed model helps to understand the mechanisms behind the spread of opinions through the lens of social identities in Germany and France. The emerging patterns mainly depend on how individuals behave within their social groups, the composition of these social groups, and the context in which a discussion takes place. The model outcomes for both countries show that in-group favoritism leads to consensus within social identity groups, while out-group aversion leads to polarization between social identity groups. Furthermore, discussing nuclear energy solely within the context of one social identity results in polarization of opinions within a population, while discussing nuclear energy in the context of multiple social identities leads to depolarization of opinions between social identity groups. Similar existing research shows comparable results, providing support for the validity of the outcomes.

7.2. Main research question

This section provides conclusions on the entire research by answering the main research question. In doing so, it uncovers both the scientific and societal relevance, along with the possibilities for future research. Again, for more detailed explanations with more context and references, please refer to the corresponding chapters and sections mentioned in the text. This conclusion is a synthesis of the insights gained from this study and does not introduce new information.

"What is the effect of social identities on the opinion dynamics regarding nuclear energy in Germany and France?"
In conclusion, the literature review clearly revealed that social identities play a pivotal role in influencing opinion dynamics in general. This thesis adds that this influence might be even more substantial in the context of nuclear energy opinions. This is due to limited individual knowledge about the subject and the intense, divisive nature of nuclear energy debates, amplifying the impact of social identities. Notably, political affiliation, age group, socio-economic status, and gender stand out as key social identities that contribute to shaping attitudes towards nuclear energy.

This study discovered that the critical factor that determines how people affect each other's opinions is the context in which a conversation or discussion takes place. It was observed that this context, determined by social comparison and the salience of particular social identities, significantly impacts how individuals act in a given situation. The outcomes of the model confirm the hypotheses: in-group favoritism leads to consensus within social identity groups, while out-group aversion leads to polarization between social identity groups. Additionally, this research shows that discussing nuclear energy in the context of multiple social identities leads to depolarization of opinions between social identity groups. Notably, these outcomes do not seem to depend on the initial conditions, as indicated by the similar outcomes between Germany and France.

7.2.1. Scientific relevance

This research significantly advances our current understanding of how social factors shape attitudes toward nuclear energy, bridging a critical gap in the existing literature. It was found that prior studies predominantly concentrate on individual factors, such as perceived risk, perceived benefit, knowledge, trust, and socio-demographic attributes. However, what is currently lacking in research is the consideration of social influence and the dynamic nature of public opinion on nuclear energy. The majority of current research overlooks the impact of our social circles on our viewpoints. It remains crucial to acknowledge that our opinions are not formed in isolation, they are shaped by the people around us.

The findings of this research contribute to existing knowledge by emphasizing the importance of social identities in shaping public opinion in general and highlighting the increased influence it might have on nuclear energy opinions. Another noteworthy contribution of this research is the integration of contextual behavior (from self-categorization theory) in the model. The literature review revealed that this is a feature that is often missing in other social identity models. To enable contextual behavior within the model, integration of multiple identities, salience, and fit is needed. The inclusion of salience and fit, two fundamental aspects of the self-categorization theory, is not prevalent in most social identity models. This thesis model did include those aspects by implementing multiple identities and making a social identity salient in a social group through fit. The salience of an identity determines the context of the discussion and consequently the behavior of the agents. The results of this thesis model underscore how the context of discussions plays a pivotal role in shaping behavior and, consequently, public opinion on nuclear energy. Engaging in conversations within various contexts leads to depolarization of the public opinion. The effect of context on the results strongly highlights the significance of incorporating these aspects of the self-categorization theory.

This research aligns with ideas deducted from theory, as the model's outcomes substantiate the hypotheses. The results underscore the power of in-group favoritism in fostering consensus within social identity groups. Conversely, they demonstrate how out-group aversion creates polarization between social identity groups. Additionally, the model outcomes unveil that discussing nuclear energy solely within the context of one social identity, results in polarization of opinions within a population. Discussing nuclear energy in the context of multiple social identities leads to depolarization of opinions between social identity groups. Finally, while the research focuses on attitudes toward nuclear energy in Germany and France, it also gives insights into the effect of social identities on opinion dynamics in general. This research emphasizes the importance of considering social influences in understanding the acceptance of emerging technologies such as nuclear energy.

7.2.2. Societal relevance

Beyond its scientific contributions, this research holds substantial societal implications, providing insights into the opinion dynamics of nuclear energy. These findings contribute to the understanding of how social identity dynamics can impact public opinion in complex debates. The implications of this research extend beyond its specific focus on nuclear energy and climate governance. It emphasizes the pivotal role that social identities play in shaping public opinion on issues for which knowledge on the subject is limited within the population.

By identifying the problem situation, it became evident that the public opinion on nuclear energy is one of the most divisive and polarized compared to other energy sources. These strong opinions often lead to intense arguments, making it hard to find common ground. This lack of consensus poses a challenge for making decisions about climate action. Consensus decision-making is important in climate negotiations as it will lead to strategies that are widely supported and can be effectively implemented. Although nuclear energy may not be a preferable solution for addressing climate change, this research on public opinion regarding nuclear energy offers valuable insights into reaching a consensus (whether to adopt or discard nuclear energy) and can potentially inform decision-making regarding other emerging technologies.

This research shows how social identities play a big role in shaping public opinion in general and especially when it comes to nuclear energy. The findings of this research underscore the pitfalls of restricting discussions solely to the context of a single social identity. When nuclear energy is discussed

in a single context (for example in a political setting), differences are amplified, causing opinions to diverge further. Consequently, a broader consensus among the population or stakeholders would remain unattainable. Introducing the possibility of changing contexts allows individuals to find common ground and potentially reach consensus, even if they initially held opposing views. This finding underscores the potential for climate action leaders and stakeholders to mitigate polarization through inclusive discussions in multiple different contexts. This approach could potentially lead to consensus formation among stakeholders and the public, determining the fate of nuclear energy.

7.2.3. Recommendations

Based on the insights gained from this research and the existing literature, several recommendations can be made for future research.

First of all, the current model and research could be improved to increase its accuracy. The model should take into account that individuals do not interact randomly with anyone, e.g. by implementing a small world network. This allows for the exploration of the relationship between the network topology and the corresponding level of consensus that can be achieved. Additionally, assigning identities randomly overlooks the fact that certain combinations of identities are more common in real life. Future research could take into account that a specific identity might become dominant or salient when the topic of nuclear energy comes up. An improved model could also include more identities and divide the identities into smaller subgroups, to prevent oversimplification. Furthermore, experiments could be conducted in the model with a fixed seed. Such experiments could reveal under what specific conditions certain outcomes emerge and what critical transition points are between those outcomes. Finally, more validation is needed, domain experts could be interviewed or the model could be recreated by another researcher to validate the outcomes. Gathering empirical data would even more significantly improve the validity, this could be achieved by conducting real-life experiments.

Regarding the broader research scope, future research should further explore the effects of social identities and social influence on the opinion dynamics of nuclear energy, both to validate and expand upon the findings of this study. It could explore the effect of events like government campaigns, nuclear accidents, or energy crises, within the context of social identities. Furthermore, it could be researched how discussions on nuclear energy and negotiations for climate action currently take place and what can be done to prevent conversations in the context of a singular social identity and to facilitate conversations in the context of multiple social identities, to increase the ability to reach consensus. Finally, it is important to keep in mind that this research focuses on the impact of social identities. Future studies should look at additional factors that impact attitudes toward nuclear energy, e.g. knowledge on the subject.

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A

Opinion and population distribution

Here the calculations for the survey participant distribution and opinion distribution are explained. For both surveys, the participant distribution is assumed to reflect the population distribution of the respective country. Therefore also the opinion distribution of the surveys is assumed to reflect the opinion distribution of the respective country.

A.1. Germany data

A.1.1. German survey data

This data is obtained from the 2021 IfD Allensbach survey [40].

Political affiliation:

- CDU/CSU: 55% against, 22% pro, 23% unsure
- SPD: 59% against, 25% pro, 16% unsure
- FDP: 40% against, 43% pro, 17% unsure
- Grüne: 80% against, 7% pro, 13% unsure
- Linke: 47% against, 26% pro, 27% unsure
- AfD: 29% against, 49% pro, 22% unsure

Age group:

- 16-29yo: 71% against, 13% pro, 16% unsure
- 30-44yo: 55% against, 24% pro, 21% unsure
- 45-59yo: 54% against, 31% pro, 15% unsure
- 60+yo: 53% against, 25% pro, 22% unsure

Socio-economic status:

- Low: 53% against, 24% pro, 23% unsure
- Middle: 55% against, 26% pro, 19% unsure
- High: 64% against, 22% pro, 14% unsure

Gender:

- Male: 52% against, 27% pro, 21% unsure
- Female: 61% against, 22% pro, 17% unsure

A.1.2. Participant distribution of the German survey

For the model, the distribution of social identities is simplified. Each identity is divided into two groups, the division will be explained here.

- Political affiliation: the participants were divided into left-wing (SPD, Grüne, Linke) and right-wing (CDU/CSU, FDP, AfD).
- Age group: the two youngest groups were classified as young and the two oldest groups were classified as old.
- Socio-economic status: the middle group was divided between the low and high group to form two groups, low-ses and high-ses.
- Gender: the gender divide was taken straight from the data.

The German survey provided numbers on the distribution of participants that took part. With these numbers and the above division, the simplified distribution is calculated and can be found in Table A.1.

A.1.3. Opinion distribution of the German survey

With this simplified participant distribution, the corresponding opinion distribution can be calculated, see Table A.3. For the German survey, the people that were unsure about their opinion are evenly divided between anti and pro. This allows for comparison to the French data and it allows for the distribution to be modelled.

Table A.1: Participant distribution for Germany data

Social Identity	Percentage
Political affiliation	
Left wing	47.4%
Right wing	52.6%
Age group	
Young	34.5%
Old	65.5%
Socio-economic status	
Low	49.2%
High	50.8%
Gender	
Male	48.2%
Female	51.8%

Table A.2: Assumed participant distribution for France data

Social Identity	Percentage
Political affiliation	
Left wing	31.1%
Right wing	68.9%
Age group	
Young	48.7%
Old	51.3%
Socio-economic status	
Low	50.0%
High	50.0%
Gender	
Male	47.5%
Female	52.5%

Table A.3: Opinion distribution on nuclear energy for Germany data (anti-nuclear vs pro-nuclear)

Social Identity	Anti	Pro
Political affiliation		
Left wing	75.2%	24.8%
Right wing	58.6%	41.4%
Age group		
Young	71.7%	28.3%
Old	62.7%	37.3%
Socio-economic status		
Low	64.3%	35.7%
High	67.7%	32.3%
Gender		
Male	62.1%	37.9%
Female	69.6%	30.4%

Table A.4: Opinion distribution on nuclear energy for France data (anti-nuclear vs pro-nuclear)

Social Identity	Anti	Pro
Political affiliation		
Left wing	42.8%	57.2%
Right wing	13.9%	86.1%
Age group		
Young	30.2%	69.8%
Old	19.8%	80.2%
Socio-economic status		
Low	28%	72%
High	13%	87%
Gender		
Male	17%	83%
Female	32%	68%

A.2. France data

A.2.1. French survey data

This data is obtained from the 2022 IFOP survey [41].

Political affiliation:

- La France insoumise: 56% pro, 44% against
- Parti socialiste: 83% pro, 17% against
- Europe Écologie Les Verts: 53% pro, 47% against
- La République en marche: 90% pro, 10% against
- Les Républicains: 87% pro, 13% against
- Reconquête: 93% pro, 7% against
- Rassemblement National: 79% pro, 21% against

Age group:

- 18-24yo: 36% against, 64% pro
- 25-34yo: 28% against, 72% pro
- 35-49yo: 29% against, 71% pro
- 50-64yo: 24% against, 76% pro
- 65+yo: 16% against, 84% pro

Monthly income:

- below €900 per month: 39% against, 61% pro
- €900 - €1300 per month: 26% against, 74% pro
- €1300 - €1900 per month: 19% against, 81% pro
- €1900 - €2500 per month: 18% against, 82% pro
- €$2500+$ per month: 8% against, 92% pro

Gender:

- Male: 17% against, 83% pro
- Female: 32% against, 68% pro

A.2.2. Participant distribution of the French survey

In contrast to the German survey, the creators of the French survey did not disclose the distribution of their participants, however, they confirmed the use of the quota sampling method[1], where the quotas were obtained from the French population. Therefore, the population distribution data for France is based on data from statistics. The division of the identities is explained below

- Political affiliation: data was taken from the French presidential elections in 2022 [83], the parties (that were used in the survey) were divided between left-wing (LFI, PS, EELV) and right-wing (LREM, LR, R!, RN).
- Age group: the youngest three groups are classified as young and the oldest two groups are classified as old. The distribution per group is given by Insee (Institut national de la statistique et des études économiques) [84].
- Socio-economic status: In the survey, socio-economic status was not used as a category. However, income is a common indicator for socio-economic status [85] and will therefore be assumed to reflect socio-economic status. The median monthly income of France in 2022 was found to be €1940 [86]. Given the survey data division, the median income was assumed to be €1900 to allow for division of the provided groups, below €1900 is low-ses and above €1900 is high-ses.
- Gender: data was taken from Insee [87], not including the ages 0-18 because they were not interviewed for the survey.

With the population statistics of France and the created divisions, a simplified participant distribution was calculated, see Table A.2. This distribution is assumed to represent the survey participants.

[1] Quota sampling is a non-probability sampling technique where participants are selected based on predetermined quotas for specific characteristics to create a sample representative of the population [82]

A.2.3. Opinion distribution of the French survey

The calculated opinion distribution can be found in Table A.4. For the French income distribution the median was assumed to be €1900 per month, meaning that below €1900 is low-ses and above €1900 is high-ses. Here, the distribution within low-ses and high-ses is assumed to be evenly spread between the survey groups, the two high-ses categories therefore both contain 25% of the population and the three low-ses categories each contain 16.7% of the population.

B

Source Code

Here, the model code can be found, the full NetLogo model is available online.

```
globals [
  gender-divide
  political-affiliation-divide
  age-divide
  socio-economic-status-divide

  pro-nuclear-gender-male
  pro-nuclear-gender-female
  pro-nuclear-political-affiliation-left
  pro-nuclear-political-affiliation-right
  pro-nuclear-age-young
  pro-nuclear-age-old
  pro-nuclear-ses-low
  pro-nuclear-ses-high

  identities

  num-groups
  max-group-size

  decimals
  decimals-round
  distinct-opinions

  edge-margin
  person-size
  group-locations
]

turtles-own [
  opinion
  opinion-round

  gender
  socio-economic-status
  political-affiliation
  age

  dominant-identity
  salient-identity

  group-id
]

```

```
to setup
  clear-all
  initialize-country          ;; Germany or France
  set num-groups round (num-agents / avg-group-size)
  set decimals 9              ;; set the number of decimals of the opinions
  create-turtles num-agents [ ;; create population
    give-social-identities    ;; set gender, ses, political affiliation, and age (per individual)
    give-initial-opinion      ;; set initial opinion toward nuclear energy
    set shape "person"
    set person-size (5 - 0.002 * num-agents)
    set size person-size
  ]
  layout-circle turtles 30
  set group-locations patches with [group-location?]
  create-opinion-plots
  reset-ticks
end

to go
  create-groups                       ;; individuals come together in social group
  ask group-locations [
    if ( count turtles-here > 1 ) [ ;; run only when there is more than 1 person in the group
      set-salient-identity          ;; a social identity becomes salient
      discuss-and-update-opinion    ;; the topic of nuclear energy is discussed and afterwards people update their opinion
    ]
  ]
  ask turtles [ spread-out-horizontally ] ;; to make all the agents visible on the display
  create-opinion-plots
  tick
  check-distinct-opinions
  if length distinct-opinions <= 2 [ stop ] ;; if there are only 2 or less distinct opinions, stop running
end

to initialize-country
  if country = "Germany" [
    ;; population distribution in Germany
    set gender-divide 0.482                   ;; percentage of German population that is male
    set political-affiliation-divide 0.474
    set age-divide 0.345
    set socio-economic-status-divide 0.492
    ;; opinion distribution in Germany
    set pro-nuclear-gender-male 0.379 ;; percentage of pro-nuclear men in German population
    set pro-nuclear-gender-female 0.304
    set pro-nuclear-political-affiliation-left 0.248
    set pro-nuclear-political-affiliation-right 0.414
    set pro-nuclear-age-young 0.283
    set pro-nuclear-age-old 0.373
    set pro-nuclear-ses-low 0.357
    set pro-nuclear-ses-high 0.323
  ]
  if country = "France" [
    ;; population distribution in France
    set gender-divide 0.475                   ;; percentage of French population that is male
    set political-affiliation-divide 0.311
    set age-divide 0.487
    set socio-economic-status-divide 0.5
    ;; opinion distribution in France
    set pro-nuclear-gender-male 0.83 ;; percentage of pro-nuclear men in French population
    set pro-nuclear-gender-female 0.68
    set pro-nuclear-political-affiliation-left 0.572
    set pro-nuclear-political-affiliation-right 0.861
    set pro-nuclear-age-young 0.698
    set pro-nuclear-age-old 0.802
    set pro-nuclear-ses-low 0.72
    set pro-nuclear-ses-high 0.87
  ]
  ask patch (min-pxcor + max-pxcor / 8) (max-pycor - 1) [ set plabel country ]
end
```

```
113
114 to give-social-identities
115   ;; select the social identities that will be considered in this run of the model
116   set identities []
117   if gender? [ set identities lput "gender" identities ]
118   if political? [ set identities lput "political-affiliation" identities ]
119   if age? [ set identities lput "age" identities ]
120   if ses? [ set identities lput "socio-economic-status" identities ]
121
122   ;; Give an individual their social identities, given the population distribution of the
        country
123   if gender? [ ifelse random-float 1 < gender-divide  [set gender "male"] [set gender
        "female"]]
124   if political? [ ifelse random-float 1 < political-affiliation-divide [set
        political-affiliation "left"] [set political-affiliation "right"]]
125   if age? [ ifelse random-float 1 < age-divide [set age "young"] [set age "old"]]
126   if ses? [ ifelse random-float 1 < socio-economic-status-divide [set socio-economic-status
        "low"] [set socio-economic-status "high"]]
127
128   ;; assign each person an identity they identify with most, that will determine their
        initial opinion
129   set dominant-identity one-of identities
130 end
131
132 to give-initial-opinion
133   let pro-nuclear-threshold 0 ;; this parameter will contain the percentage of people that
        are pro-nuclear within the dominant identity of the individual
134
135   if dominant-identity = "gender" [
136     ifelse gender = "male" [
137       set pro-nuclear-threshold pro-nuclear-gender-male
138     ] [
139       set pro-nuclear-threshold pro-nuclear-gender-female
140     ]
141   ]
142   if dominant-identity = "political-affiliation" [
143     ifelse political-affiliation = "left" [
144       set pro-nuclear-threshold pro-nuclear-political-affiliation-left
145     ] [
146       set pro-nuclear-threshold pro-nuclear-political-affiliation-right
147     ]
148   ]
149   if dominant-identity = "age" [
150     ifelse age = "young" [
151       set pro-nuclear-threshold pro-nuclear-age-young
152     ] [
153       set pro-nuclear-threshold pro-nuclear-age-old
154     ]
155   ]
156   if dominant-identity = "socio-economic-status" [
157     ifelse socio-economic-status = "low" [
158       set pro-nuclear-threshold pro-nuclear-ses-low
159     ] [
160       set pro-nuclear-threshold pro-nuclear-ses-high
161     ]
162   ]
163
164   ;; set initial opinon, scale 0-1, completely anti (0) to completely pro (0.999999999)
165   ifelse random-float 1 < pro-nuclear-threshold [
166     ;; the percentage of people that is pro-nuclear gets an opinion between 0.5-1
167     set opinion 0.5 + random-float 0.5
168   ] [
169     ;; the percentage of people that is anti-nuclear gets an opinion between 0-0.5
170     set opinion random-float 0.5
171   ]
172
173   set opinion round( opinion * (10 ^ decimals) ) / (10 ^ decimals)
174   set color ifelse-value (opinion < 0.5) [violet] [orange] ;; anti-nuclear people are
        violet, pro-nuclear are orange
175 end
176
```

```
177 to-report group-location? ;; display-locations of the group
178   ;; the origin (0,0) is the bottom left corner
179   set edge-margin 5 ;; margin to keep the edges free
180   ;; determine the distance between groups
181   let group-interval floor ((2 * world-height - 4 * edge-margin) / num-groups)
182   ;; when an odd number of groups is given, 1 group will be added/subtracted, to be able to
        create 2 even columns
183   report
184     (pxcor = (min-pxcor + edge-margin)) or  ;; two columns of groups are created
185     (pxcor = ((max-pxcor / 2) + edge-margin)) and
186     (pycor > (min-pycor + edge-margin)) and ;; between top and bottom edge
187     (pycor < (max-pycor - edge-margin)) and
188     (pycor mod group-interval = 0) and      ;; spread the groups evenly over the y-axis
189     (floor (2 * (pycor - edge-margin) / group-interval) <= num-groups) ;; to ensure that the
          empty space is not filled with extra groups
190 end
191
192 to create-opinion-plots
193   create-opinion-plot ("public-opinion") (turtles)
194   create-opinion-plot ("opinion-male") (turtles with [gender = "male"])
195   create-opinion-plot ("opinion-female") (turtles with [gender = "female"])
196   create-opinion-plot ("opinion-left-wing") (turtles with [political-affiliation = "left"])
197   create-opinion-plot ("opinion-right-wing") (turtles with [political-affiliation = "right"])
198   create-opinion-plot ("opinion-young") (turtles with [age = "young"])
199   create-opinion-plot ("opinion-old") (turtles with [age = "old"])
200   create-opinion-plot ("opinion-low-ses") (turtles with [socio-economic-status = "low"])
201   create-opinion-plot ("opinion-high-ses") (turtles with [socio-economic-status = "high"])
202 end
203
204 to create-opinion-plot [title turtles-subset]
205   set-current-plot title
206   set-current-plot-pen "default"
207   clear-plot
208   set-plot-x-range 0 1
209   ifelse title = "public-opinion" [set-plot-y-range 0 30] [set-plot-y-range 0 60]
210   set-plot-pen-mode 1
211   ifelse title = "public-opinion" [set-histogram-num-bars 9] [set-histogram-num-bars 2]
212   histogram [opinion] of turtles-subset
213 end
214
215 to create-groups
216   set max-group-size 9
217   ask turtles [ setxy 0 (max-pycor / 2) ]          ;; first clear the field
218   ask turtles [                                    ;; then go to new group location
219     set group-id one-of group-locations
220     move-to group-id
221     while [count turtles-here > max-group-size] [ ;; do not exceed the maximum group size
222      set group-id one-of group-locations
223      move-to group-id
224     ]
225   ]
226   update-labels ;; display the country, agents in total, and number of groups
227 end
228
229 to update-labels
230   ask group-locations [ set plabel count turtles-here ]
231   ask patch (min-pxcor + max-pxcor / 8) (max-pycor - 1) [ set plabel country ]
232   ask patch (min-pxcor + max-pxcor / 2) (max-pycor - 1) [ set plabel word ( sum [plabel] of
        group-locations ) " individuals " ]
233   ask patch (max-pxcor - max-pxcor / 6) (max-pycor - 1) [ set plabel word ( count
        group-locations ) " groups " ]
234 end
235
236 to spread-out-horizontally ;; to line up the agents next to each other
237   set heading 90
238   fd 4
239   while [any? other turtles-here] [
240     ifelse [pxcor] of group-id = (min-pxcor + edge-margin) [ ;; left column of groups
241       ifelse pxcor < ((max-pxcor / 2) - person-size - edge-margin) [
242         fd (person-size / 2)
243       ]
```

```
      [ ;; if too close to the right column, make a new row below
        set ycor ycor - person-size
        set xcor (min-pxcor + edge-margin)
        fd 4
      ]
    ]
    [                                                    ;; right column of groups
      ifelse can-move? (person-size + edge-margin) [
        fd (person-size / 2)
      ]
      [ ;; if it does not fit on the display, make a new row below
        set ycor ycor - person-size
        set xcor ((max-pxcor / 2) + edge-margin)
        fd 4
      ]
    ]
  ]
end

to set-salient-identity
  ;; the salient identity is set to the most common dominant identity in the group
  let dom-ids [dominant-identity] of turtles-here
  let common-dom-ids modes dom-ids
  let most-common-dominant-identity one-of common-dom-ids
  ask turtles-here [ set salient-identity most-common-dominant-identity ]
end

to discuss-and-update-opinion
  let salient-identity-group ( one-of ([salient-identity] of turtles-here))

  let men turtles-here with [gender = "male"]
  let women turtles-here with [gender = "female"]
  let lefties turtles-here with [political-affiliation = "left"]
  let righties turtles-here with [political-affiliation = "right"]
  let youngsters turtles-here with [age = "young"]
  let oldies turtles-here with [age = "old"]
  let lowclass turtles-here with [socio-economic-status = "low"]
  let highclass turtles-here with [socio-economic-status = "high"]

  let zero-agents nobody    ;; the salient identity divides the group in two, group 0
  let one-agents nobody     ;; and group 1
  ;; both groups will have a prototype, which is one of the agents whose dominant identity
      is the same as the salient identity of the group
  let zero-prototype nobody
  let one-prototype nobody

  if salient-identity-group = "gender" [
    set zero-agents men
    set one-agents women
    set zero-prototype ( one-of men with [dominant-identity = "gender"] )
    ;; if there is no prototype, select a random agent in the group to be the prototype
    if zero-prototype = nobody [ set zero-prototype one-of men ]
    set one-prototype ( one-of women with [dominant-identity = "gender"] )
    if one-prototype = nobody [ set one-prototype one-of women ]
  ]
  if salient-identity-group = "political-affiliation" [
    set zero-agents lefties
    set one-agents righties
    set zero-prototype ( one-of lefties with [dominant-identity = "political-affiliation"] )
    if zero-prototype = nobody [ set zero-prototype one-of lefties ]
    set one-prototype ( one-of righties with [dominant-identity = "political-affiliation"] )
    if one-prototype = nobody [ set one-prototype one-of righties ]
  ]
  if salient-identity-group = "age" [
    set zero-agents youngsters
    set one-agents oldies
    set zero-prototype ( one-of youngsters with [dominant-identity = "age"] )
    if zero-prototype = nobody [ set zero-prototype one-of youngsters ]
    set one-prototype ( one-of oldies with [dominant-identity = "age"] )
    if one-prototype = nobody [ set one-prototype one-of oldies ]
  ]
```

```
314   if salient-identity-group = "socio-economic-status" [
315     set zero-agents lowclass
316     set one-agents highclass
317     set zero-prototype ( one-of lowclass with [dominant-identity = "socio-economic-status"] )
318     if zero-prototype = nobody [ set zero-prototype one-of lowclass ]
319     set one-prototype ( one-of highclass with [dominant-identity = "socio-economic-status"] )
320     if one-prototype = nobody [ set one-prototype one-of highclass ]
321   ]
322
323   ;; update opinion
324   if model-version = "Converge-on-prototype" [                    ;; VERSION 1
325     ask zero-agents [
326       let opinion-diff ( [opinion] of zero-prototype - opinion )
327       ;; move closer to the opinion of the prototype
328       set opinion opinion + ( opinion-diff * opinion-changerate )
329     ]
330     ask one-agents [
331       let opinion-diff ( [opinion] of one-prototype - opinion )
332       set opinion opinion + ( opinion-diff * opinion-changerate )
333     ]
334   ]
335
336   if model-version = "Prototype-repulsion" [                      ;; VERSION 2
337     let sign-pd 1
338     if zero-prototype != nobody and one-prototype != nobody [
339       let prototype-difference ([opinion] of zero-prototype - [opinion] of one-prototype)
340       ifelse prototype-difference = 0 [set sign-pd 1][set sign-pd (prototype-difference /
              abs(prototype-difference))] ;; returns the sign of the prototype-difference (-1 or
              1)
341       ask zero-prototype [
342         ;; prototypes move their opinion away from each other
343         set opinion opinion + (sign-pd * (1 - abs(prototype-difference)) *
              opinion-changerate)
344         ;; to make sure that the opinions stay within range 0-1
345         set opinion max( list min( list opinion (1 - (1 / (10 ^ decimals)))) 0)
346       ]
347       ask one-prototype [
348         set opinion opinion - (sign-pd * (1 - abs(prototype-difference)) *
              opinion-changerate)
349         set opinion max( list min( list opinion (1 - (1 / (10 ^ decimals)))) 0)
350       ]
351     ]
352
353     ask zero-agents [
354       let opinion-diff ( [opinion] of zero-prototype - opinion )
355       ;; the other agents move closer to the opinion of the prototype
356       set opinion opinion + ( opinion-diff * opinion-changerate )
357     ]
358     ask one-agents [
359       let opinion-diff ( [opinion] of one-prototype - opinion )
360       set opinion opinion + ( opinion-diff * opinion-changerate )
361     ]
362   ]
363
364   if model-version = "Balance-inclusion-differentiation" [        ;; VERSION 3
365     let sign-od 1
366     let opinion-diff 0
367     ask zero-agents [
368       ifelse count zero-agents > 1 [ ;; if there are 2 or more group members, move closer to
              the opinion of the prototype
369         set opinion-diff ( [opinion] of zero-prototype - opinion )
370         set opinion opinion + ( opinion-diff * opinion-changerate )
371       ][ ;; if there is only one member in the group, move opinion away from the prototype
              of the other group
372         set opinion-diff ( [opinion] of one-prototype - opinion )
373         ifelse opinion-diff = 0 [set sign-od 1][set sign-od (opinion-diff /
              abs(opinion-diff))] ;; returns the sign of the opinion-difference (-1 or 1)
374         set opinion opinion - ( sign-od * (1 - abs(opinion-diff)) * opinion-changerate )
375         ;; to make sure that the opinions stay within range 0-1
376         set opinion max( list min( list opinion (1 - (1 / (10 ^ decimals)))) 0)
377       ]
```

```
    ]
    ask one-agents [
      ifelse count one-agents > 1 [
        set opinion-diff ( [opinion] of one-prototype - opinion )
        set opinion opinion + ( opinion-diff * opinion-changerate )
      ][
        ifelse count zero-agents > 1 [set opinion-diff ( [opinion] of zero-prototype -
            opinion )][set opinion-diff (-1 * opinion-diff)]
        ifelse opinion-diff = 0 [set sign-od 1][set sign-od (opinion-diff /
            abs(opinion-diff))]
        set opinion opinion - ( sign-od * (1 - abs(opinion-diff)) * opinion-changerate )
        set opinion max( list min( list opinion (1 - (1 / (10 ^ decimals)))) 0)
      ]
    ]
  ]

  ;; make sure number of decimals stays the same
  ask turtles-here [ set opinion round( opinion * (10 ^ decimals) ) / (10 ^ decimals) ]
  ;; update color
  ask turtles-here [ set color ifelse-value (opinion < 0.5) [violet] [orange] ]
end

to check-distinct-opinions
  set decimals-round 2
  ask turtles [ set opinion-round round( opinion * (10 ^ decimals-round) ) / (10 ^
      decimals-round) ] ;; round the opinions
  set distinct-opinions remove-duplicates ([opinion-round] of turtles) ;; returns list of
      distinct opinions
end

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```

C

Assumptions and simplifications

This appendix contains a list of assumptions and simplifications made throughout the research. ”Assumptions are made either when there are uncertainties or beliefs about the real world being modelled” and ”simplifications are incorporated in the model to enable more rapid model development and use, and to improve transparency” [76].

C.1. Assumptions

Social identities

- Environmentalism can be seen through political affiliation.
- Post materialism can be seen through age group.
- Income level can be seen through socio-economic status.

Surveys

- In the German survey it was asked if the person agrees with the decision of the government to phase out nuclear energy, the results will be assumed to answer the question if the person is in favor of or against the use of nuclear energy in Germany.
- In the German survey there is a percentage of people that is unsure about their opinion, the assumption will be made that this percentage can be evenly divided between anti and pro.
- For the French survey, income level is assumed to reflect socio-economic status.
- For both surveys, the participant distribution is assumed to reflect the population distribution of the respective country. Therefore also the opinion distribution of the surveys is assumed to reflect the opinion distribution of the respective country.

Model

- An individual has a dominant identity (the identity that an individual identifies with most strongly), the distribution of these dominant identities is roughly balanced across all identity groups, and the dominant identity is assumed to determine the initial opinion of a person.
- People discuss nuclear energy in a social group with an average size of 5 people and a maximum of 9 people.
- In every social group there always is a salient identity, and this is determined by the most common dominant identity in the group.
- For every identity in a social group there always is a prototypical member. The most prototypical member of the identity group is one of the members whose dominant identity is the same as the groups identity. Each person is always able to identify the most prototypical member of their in-group and out-group.
- When individuals move their opinion away from the out-group, they move away from the prototype of the out-group.
- In model version 2 and 3, individuals will adapt their opinion more when it lies close to the opinion of the prototype of the out-group.

- In model version 3, to balance inclusion and differentiation, individuals will move their opinion away from the out-group when they are the only in-group member. When there are multiple in-group members, they will move their opinion closer to the in-group.

C.2. Simplifications

Model

- Only 4 social identities.
- Each identity is divided in 2 groups.
- Assignment of identities and opinions to the agents does not take into account that certain combinations of identities and opinions are more common in real life
- Social identities remain constant over time (people do not change their identities).
- Opinion is continuous on scale [0;1], where 0 is anti-nuclear and 1 is pro nuclear.
- Everyone can form a social group with anyone.
- The salient identity in a group does not change.
- Behavior is only affected by social identities (e.g. knowledge on the topic is not considered)
- Person always adapts their opinion after discussion, and every person uses the same adaptation technique (dictated by the model version and opinion-changerate).

D

Verification

According to Van Dam et al. [44], there are four parts in the verification of an ABM.

- Recording and tracking agent behavior
- Single-agent testing
- Interaction testing
- Multi-agent testing

D.1. Recording and tracking agent behavior

D.1.1. Agents

- Inputs:
Check whether agents receive social identities and a dominant identity, making sure that the identities that are turned off are not included - by output-print these parameters for 10 agents, with 0-4 identities turned on - when there are 0 identities the model gives an error, this makes sense because the agent behavior is based on identities - **Verified**
And check whether these parameters do not change after setup (during go procedure) - by output-print these parameters for 10 agents - **Verified**

- States:
Check whether the initial opinion is based on the dominant identity - by output-print these parameters and pro-nuclear-threshold for 10 agents, to see if the threshold matches the number for the dominant identity - **Verified**

- Output:
Check whether agents update their opinion - by plotting the opinion of 10 agents over time - **Verified**

D.1.2. Interntal processes

Group-location

Check whether all agents are assigned a group, the correct number of groups is created, and the maximum group size is obeyed - by displaying number of agents that has a group, the number of groups, and the biggest group size - when there is an odd number of groups the model adds or subtracts a group, this is intentional to be able to create two even columns in the display, as there is no requirement for a precise number of groups in the model - **Verified**

Set-salient-identity

- Inputs:
Check whether a list is created of the dominant identities of turtles in the group - by output-print the the dominant identities of turtles in the group and the list of dominant identities to see if they match - **Verified**

- States:
Check whether the most common dominant identities are selected - by output-print the dominant identities and the common dominant identities of agents in the group - **Verified**

- Output:
Check whether one of the most common dominant identities is selected as the most common dominant identity - by output-print the common dominant identities and the selected most common dominant identity of the group - **Verified**
And check whether the salient identity of all group members is correctly set to the most common dominant identity of the group - by output-print the selected most common dominant identity of the group and the salient identity of the group members - **Verified**

Discuss-and-update-opinion
- Inputs:
Check whether the salient identity of the group is set to the salient identity of the group members - by output-print the salient identity of the group members and the salient identity of the group - **Verified**

- States:
Check whether the salient identity subgroups have the same identity of other members of their in-group - by output-print the identity of members of the subgroups and the salient identity of the group - **Verified**
And check whether the dominant identity of the selected protptypes matches the salient identity (and if the dominant identity of none of the members matches the salient identity, a random member should be prototype. And if there are no members in a subgroup, there should not be a prototype) - by output-print the identity of members of the subgroups, the salient identity of the group, the dominant identities of the members of each subgroup and the dominant identity of the prototypes - **Verified**
For model version 2 and 3, check whether the signum function correctly returns the sign of the opinion difference - by output-print the opinion difference and the signum function output - the model gives a 'division by zero'-error when the opinion difference is 0, this is resolved by setting the sign to 1 whenever the opinion difference is 0 - **Verified**

- Outputs:
For model version 1, check whether the opinions of the agents converge to the opinion of their prototype (prototype opinion should stay the same) - by output-print the opinion of the agents before and after updating their opinion - **Verified**
For model version 2, check whether the prototype opinions move away from each other (and stay within the 0-1 opinion range) and the other agents converge to the opinion of their prototype - by output-print the opinion of the agents before and after updating their opinion - **Verified**
For model version 3, check whether the opinions of the agents converge to the opinion of their prototype (prototype opinion should stay the same). Unless there is only one agent in the subgroup, then they should move away from the opinion of the other subgroup prototype - by output-print the opinion of the agents before and after updating their opinion - when there is only one agent in each subgroup, it was observed that the agents do not move away from each other by the same number. This is because the opinion of the first agent was updated before the opinion of the second agent was, leading to calculation of the opinion change of the second agent with the already updated opinion of the first agent. This was resolved by using the opinion difference from before the update (with different sign), in the case there is only one agent of each subgroup - **Verified**

D.2. Single-agent testing
A single agent:

- Should receive identities and opinion
- Should be assigned a group
- Should not receive salient identity and not discuss/update opinion
- Opinion should stay the same, graphs should not change

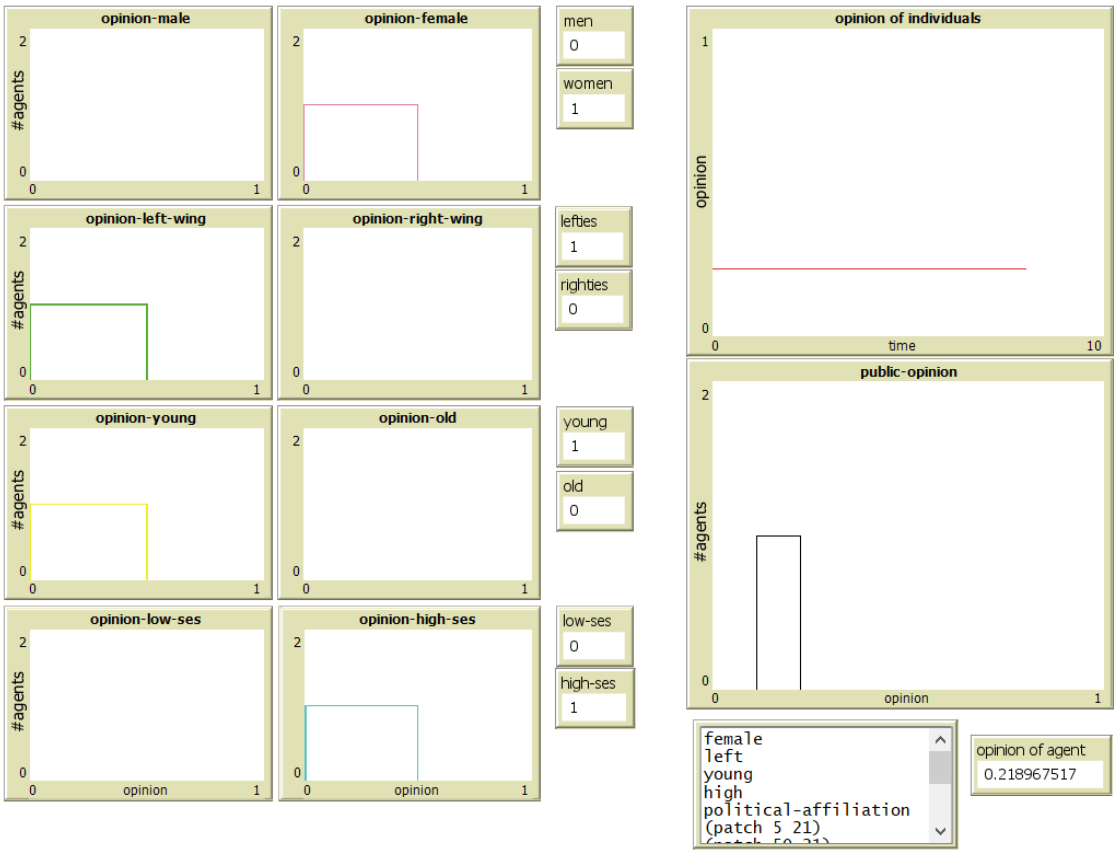


Figure D.1: A run of the single-agent test in Germany

Figure D.1 shows the model for a single-agent run. The output on the bottom right shows the identities, dominant identity, and group location of the agent (the group location is the indicated patch). As can be seen, the single agent receives their identities, dominant identity and group location. Also the agent is assigned an initial opinion (see the monitor on the bottom right). It can also be seen that the agent's opinion does not update (indicated by the straight line in the top right graph) as they have no other agents to discuss with.

D.3. Interaction testing

Two agents:

- Should do everything in the model
- In model-version 1, if the two agents share a social identity which is the dominant identity of either of them then they should converge. Otherwise, their opinions will not change (stay parallel over time).
- In model-version 2, if the two agents have the same social identity for both their dominant identities, then they should converge. If the two agents have opposing identities (e.g. different gender, a man and a woman) for both their dominant identities, then they should repulse. If they have both a common and opposing identity of their dominant identities, then they will both converge and repulse.
- In model-version 3, the same should happen as in model-version 2 for the single-agent test.

The interaction test was run multiple times in all model versions for both countries. All interactions happened as expected (as described above), and are therefore verified. To picture this, the tests for model version 3 are shown in Figure D.2. The output on the bottom shows the identities and dominant identity of the two agents. As explained there are 3 situations: one where they converge, one where they repulse, and one where they do both.

Figure D.2: 3 runs of the interaction test in France (model-version 3)

D.4. Multi-agent testing

Multiple agents:

- Should receive identities, opinion.
- Should be assigned a group
- Should receive salient identity and discuss/update opinion
- Graphs should change

Here the entire model is tested. All setups of the model are checked to see if the model behaves as intended. In Figure D.3 it can be seen that the opinions change over time.
Next, it was checked whether the setup procedure of the model creates a population distribution and opinion distribution as intended. The model was set up 100 times with 1000 agents for each country. As can be seen in Figure D.4a and Figure D.5a, the population distribution is close to the input numbers. Dominant identities are evenly divided between the 4 social identities as intended by the 'one-of' NetLogo function. The opinion distribution (in Figure D.4b and Figure D.5b) is close to the input numbers, however overall the average percentages are less spread than the input numbers. This is probably because of the fact that agents are assigned an opinion based on their dominant identity, for example, when a left-wing man's dominant identity is 'gender' then his opinion is based on the gender percentages however this will also then affect the opinion distribution of the left-wingers (and the other identities). Meaning that the model distributions average out a bit more. This means that the differences between social identities within a country might not be clearly visible in the analysis (model could be run with more extreme input numbers to analyze the differences and effects of social identities per country). There is still a clear difference between the countries, the majority of France is pro-nuclear and the majority of Germany is anti-nuclear. Therefore the data can be used for comparison between the countries

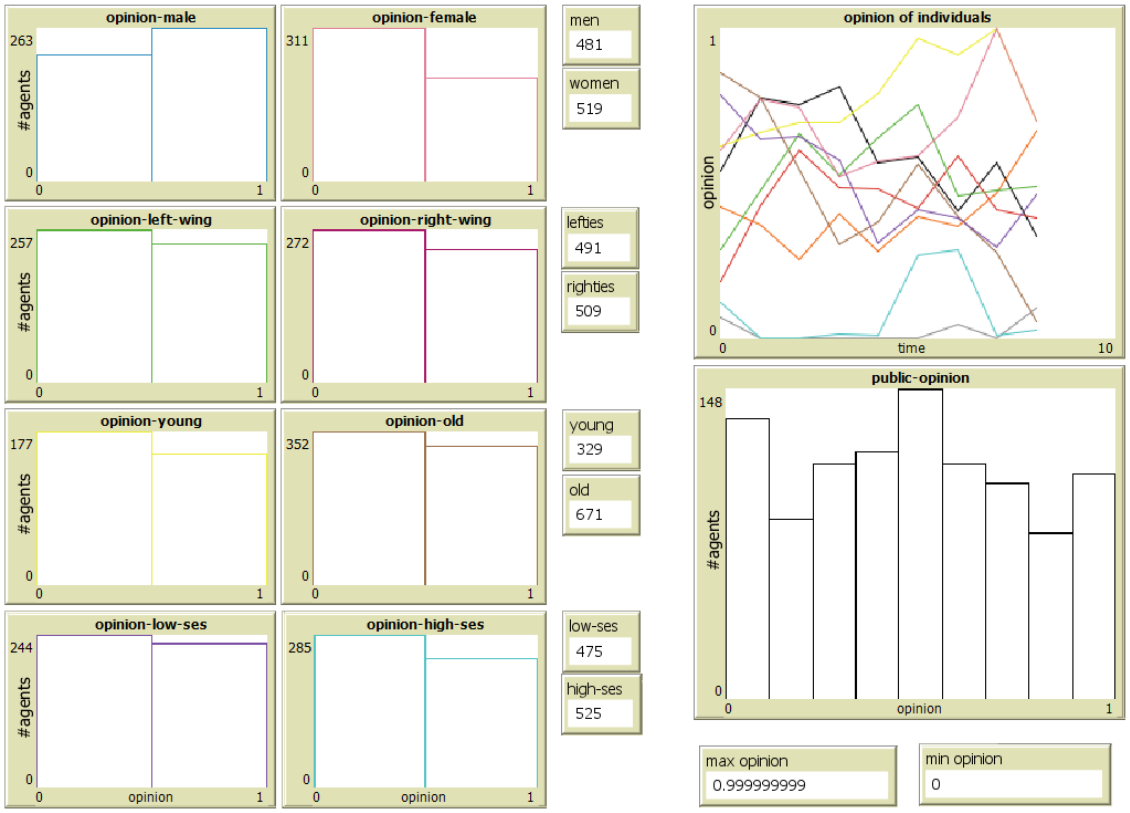
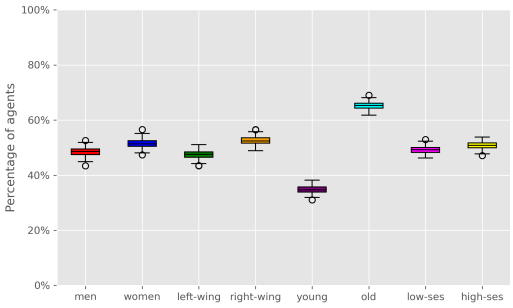


Figure D.3: A run of the multi-agent test in Germany

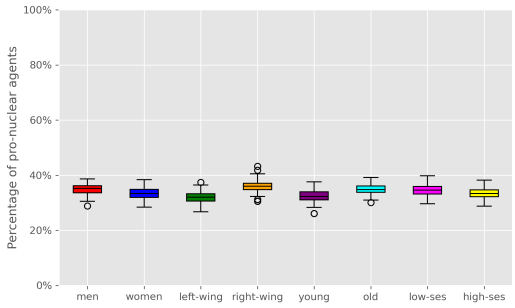
D.5. Additional measures

Next to the four verification steps, some additional measures were taken to ensure the model works as intended.

- Monitor added that displays the average group size to make sure it is close to the input, note that the input avg-group-size will not always be the same as the actual average group size (e.g. when there are 150 agents and the avg-group-size is set to 4, there have to be 37.5 groups to make this possible, half a group is not possible)
- Numbers are put in a variable to prevent hardcoding (e.g. max-group-size, decimals, edge-margin)
- Monitor added that displays the maximum and minimum opinion of all agents to make sure they stay within the 0-1 range
- Monitors added that display the number of groups and biggest group size
- Monitors added that display the number of agents per identity and the number of agents that is pro/anti, to make sure that the numbers make sense and add up.

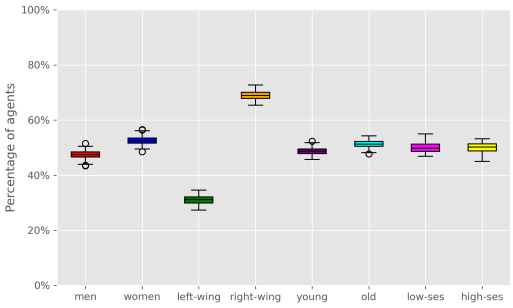


(a) The percentage of agents per social identity in Germany (1000 agents, 100 runs)

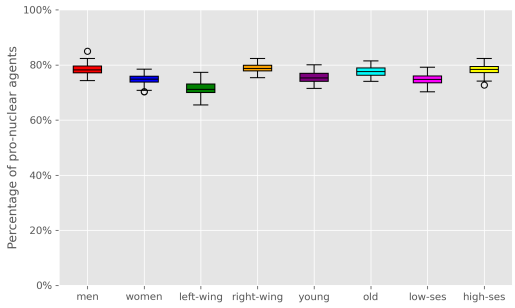


(b) The percentage of agents per social identity that is pro-nuclear in Germany (1000 agents, 100 runs)

Figure D.4: Agent characteristics in Germany



(a) The percentage of agents per social identity in France (1000 agents, 100 runs)



(b) The percentage of agents per social identity that is pro-nuclear in France (1000 agents, 100 runs)

Figure D.5: Agent characteristics in France

E

Additional results

E.1. Model-version 1

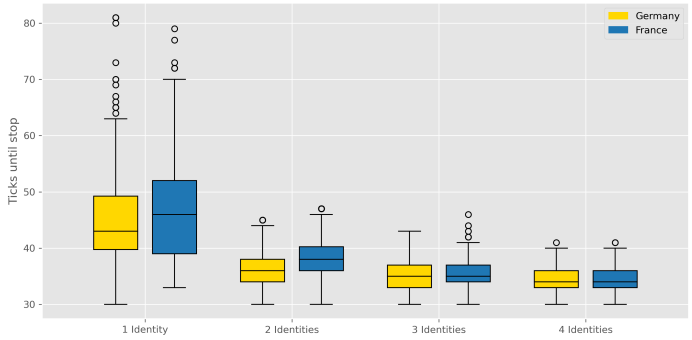


Figure E.1: Ticks until convergence in model-version 1

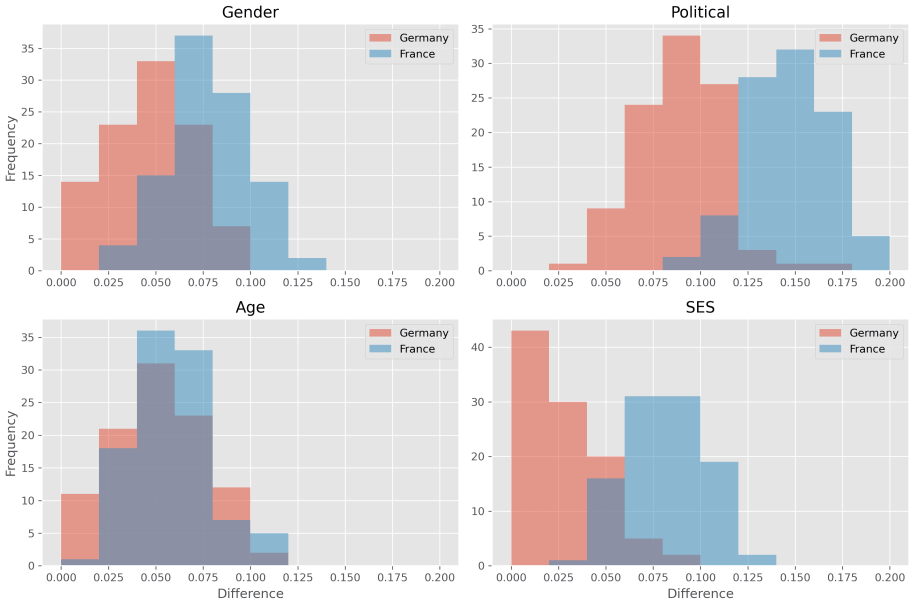


Figure E.2: Difference between the two final distinct opinions (1 identity only, model-version 1)

E.2. Model-version 2

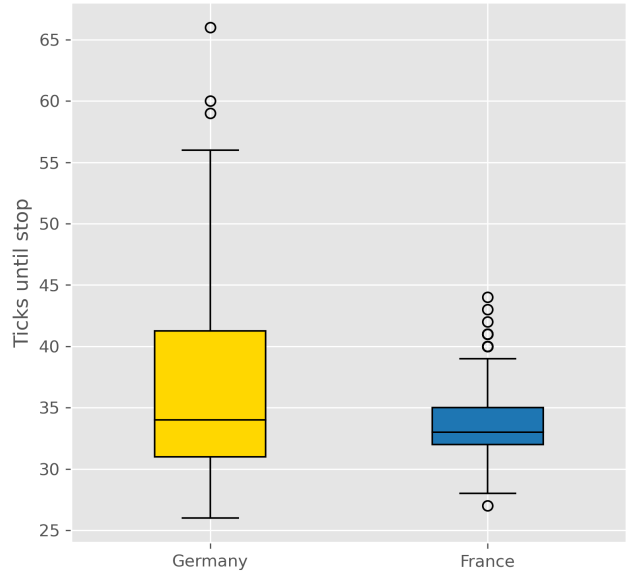


Figure E.3: Ticks until convergence in model-version 2 (all runs with 1 identity only)

E.3. Model-version 3

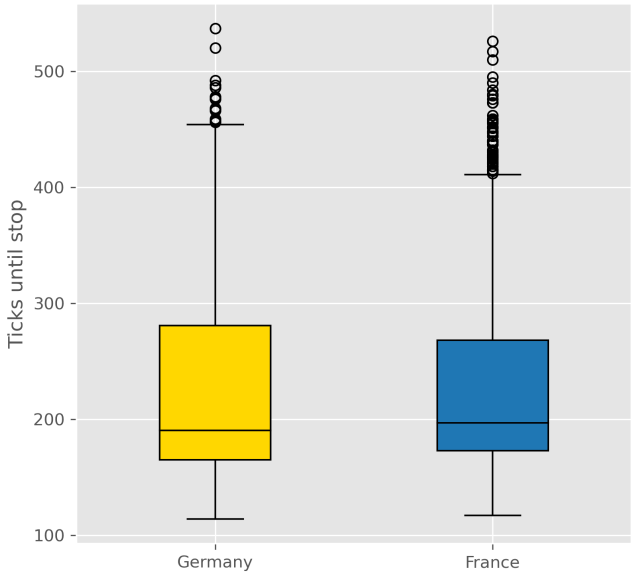


Figure E.4: Ticks until convergence in model-version 3 (all runs with 1 identity only)

E.4. Sensitivity analysis

E.4.1. Model-version 1

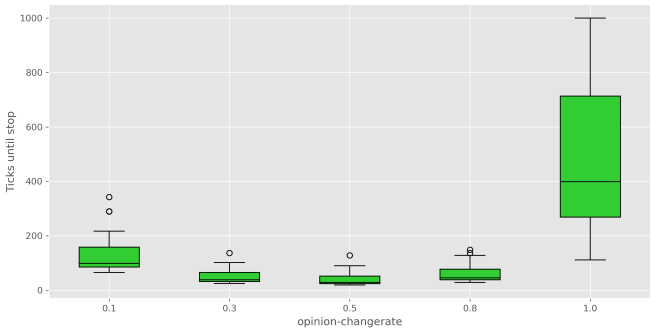


Figure E.5: Ticks until convergence per opinion-changerate in model-version 1

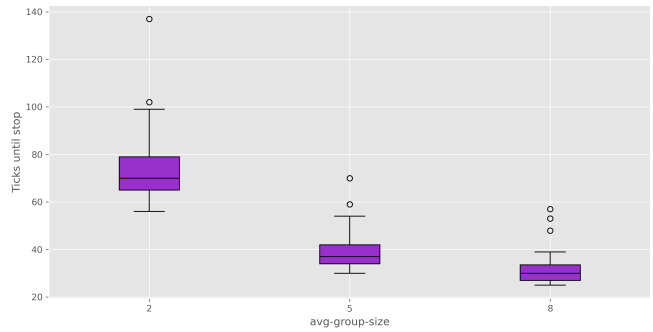


Figure E.6: Ticks until convergence per avg-group-size in model-version 1 (runs with opinion-changerate 1.0 excluded)

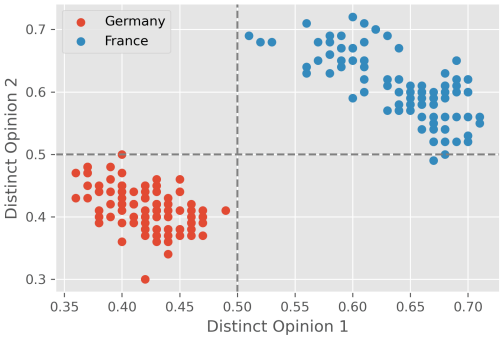


Figure E.7: The distinct opinions after convergence (model-version 1, all runs with 1 identity only, runs with opinion-changerate 1.0 excluded)

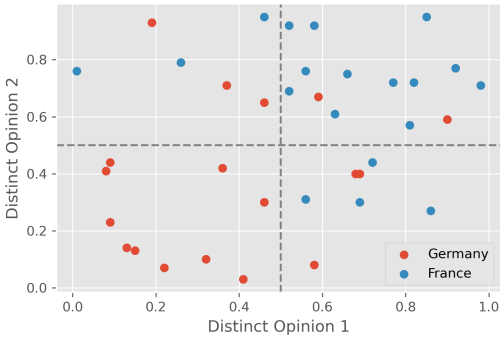


Figure E.8: The distinct opinions after convergence (model-version 1, all runs with 1 identity only, runs with opinion-changerate 1.0 only)

E.4.2. Model-version 2

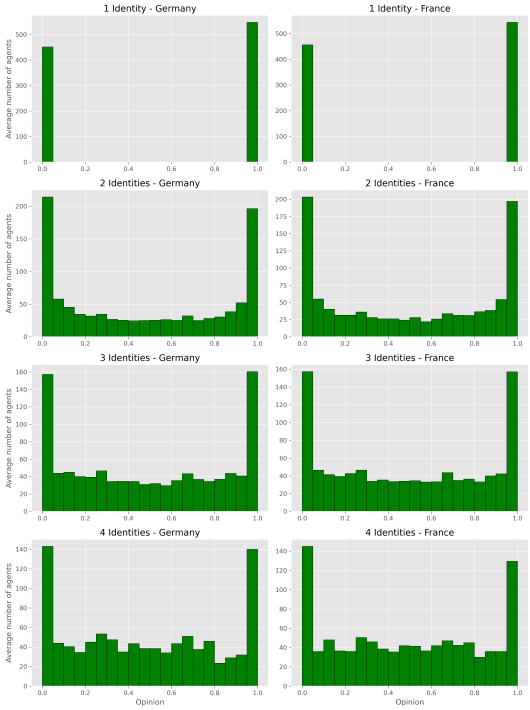


Figure E.9: Average final opinion distribution (model-version 2, opinion-changerate 0.3, avg-group-size 2)

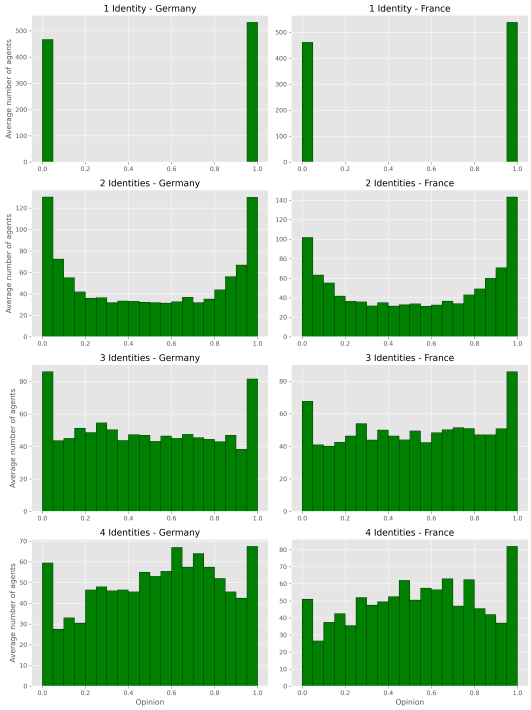


Figure E.10: Average final opinion distribution (model-version 2, opinion-changerate 0.3, avg-group-size 8)

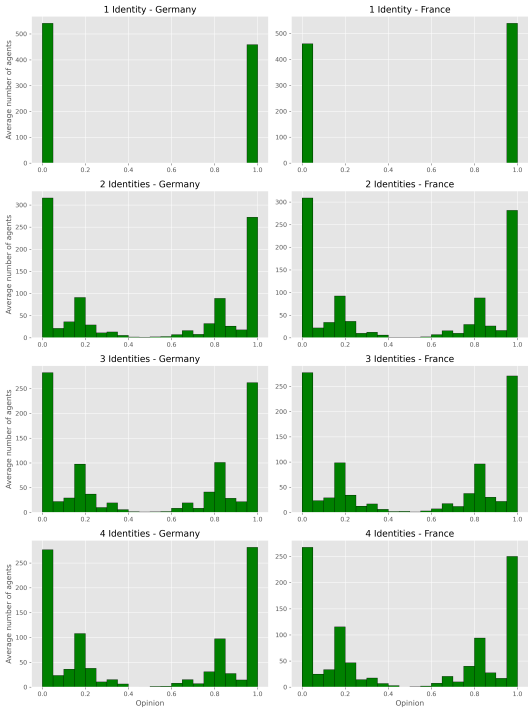


Figure E.11: Average final opinion distribution (model-version 2, opinion-changerate 0.8, avg-group-size 2)

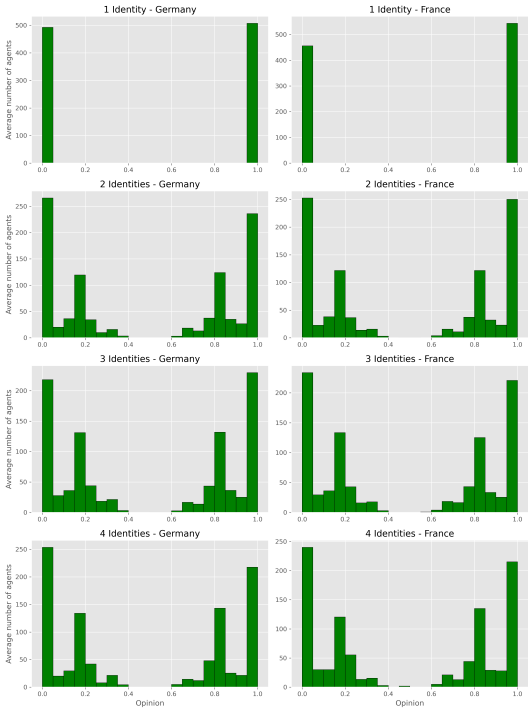


Figure E.12: Average final opinion distribution (model-version 2, opinion-changerate 0.8, avg-group-size 8)

E.4.3. Model-version 3

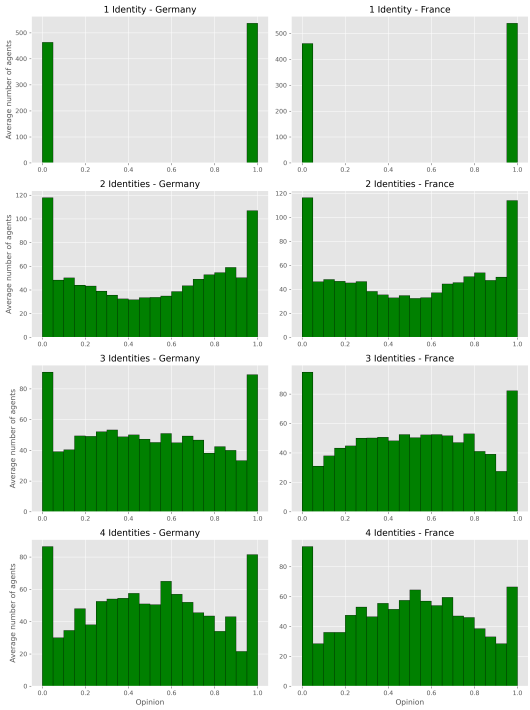


Figure E.13: Average final opinion distribution (model-version 3, opinion-changerate 0.3, avg-group-size 2)

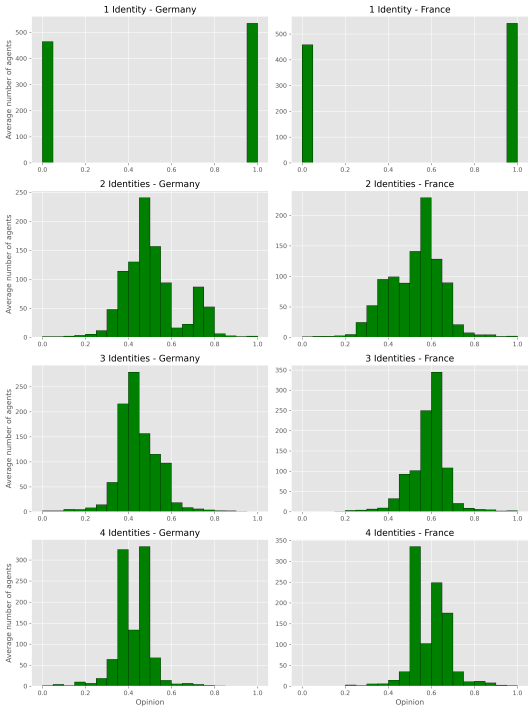


Figure E.14: Average final opinion distribution (model-version 3, opinion-changerate 0.3, avg-group-size 8)

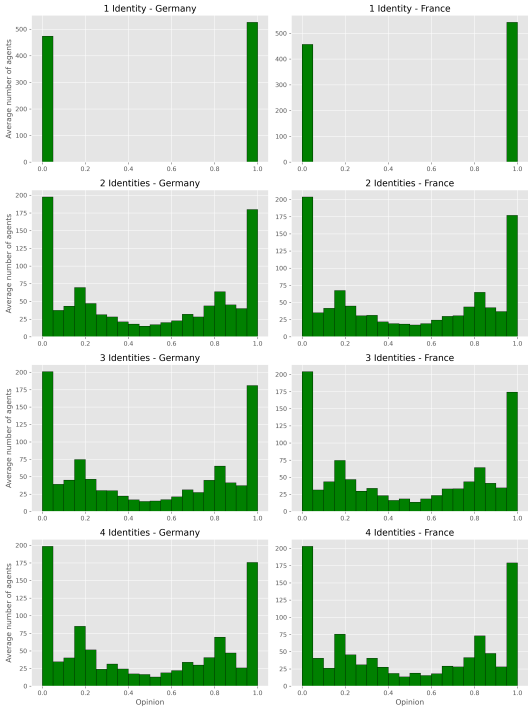


Figure E.15: Average final opinion distribution (model-version 3, opinion-changerate 0.8, avg-group-size 2)

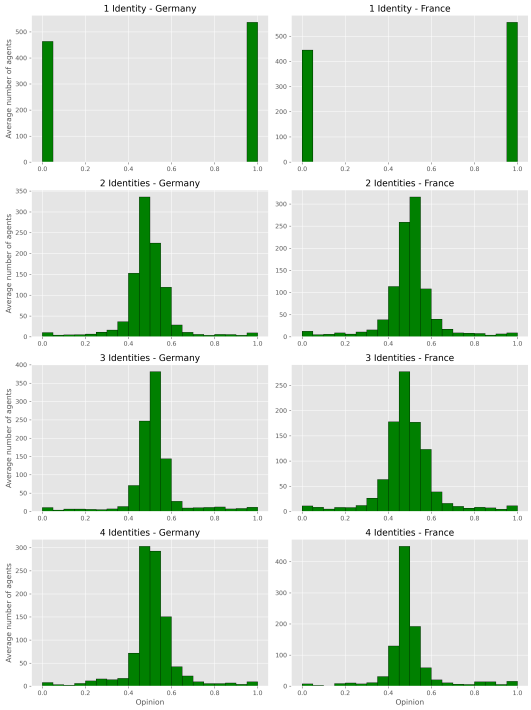


Figure E.16: Average final opinion distribution (model-version 3, opinion-changerate 0.8, avg-group-size 8)