Public opinion on nuclear energy in Europe, 1970 - 2018

Master's Thesis Innovation Sciences

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Author:
Max Schmal
1605539
M.O.Schmal@students.uu.nl

Supervisor:
Prof. dr. Koen Frenken

Utrecht University

NRG Nuclear. For life.

Master Program in Innovation Sciences
Copernicus Institute
Utrecht University

Abstract

Despite the nuclear inclusion objective of the European Commission in 2018 of nuclear energy in the power system and the historical reliance on nuclear energy, there seems to be a significant contrast of willingness between the member states to produce this nuclear energy. To understand why countries diverge in their choice for nuclear energy, one should understand the different perspectives on risks, costs, and benefits of nuclear power, which requires an analysis of public opinion in different countries. Unlike any other technology, the viability of nuclear energy seems to be subject to the course of the public opinion. This thesis study examines the public opinion of three European countries; The Netherlands, The United Kingdom, and Denmark from 1970 to 2018, to find out what explains the differences in public opinion on nuclear energy over time and cross countries. One finding holds that the higher the impact of adverse nuclear events on society, the more news articles related to nuclear energy are published. Interestingly, such events show a significant positive relationship with the number news articles on nuclear energy in Denmark and The Netherlands, but not in The United Kingdom. This suggests that avers events affect public opinion most in countries with low adoption of nuclear energy. This can explain why the Danish and Dutch governments remain an opponent of nuclear energy because of their higher public sensitivity for perceived risks of nuclear energy, contrary to the the United Kingdom.

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1. Introduction

Environmental pollution and climate change are challenging and pressing issues in the EU (European Commission, 2019). The European Commission emphasises the need to reduce pollutant and Greenhouse Gas emissions to limit the effects on the environment and its citizens (European Commission, 2019). To give direction to the green growth strategy, the European Commission committed to a climate-neutral European Union by 2050. However, realising a 100% renewable EU power system that could rely on renewable resources alone, based on the results of a 2017 and 2018 study (Heard, Brook, Wigley, Bradshaw, 2017; Zappa, Junginger & van den Broek, 2019), appeared to be a challenging task. These studies show that even when wind and PV capacity is spatially optimised and electricity can be transmitted across a fully integrated European grid, a 100% renewable power system would still require the significant flexible zero-carbon firm capacity to balance variable wind and PV generation and cover demand when wind and solar supply is low (Zappa et al., 2019).

Furthermore, these studies mention that even a 100% renewable system may not deliver the level of emission reductions necessary to achieve Europe's climate goals, as harmful emissions through carbon capture and storage technology are required. Heard et al. state that "the unsubstantiated premise that renewable energy systems alone can solve the challenge of climate change risks a repeat of the failure of decades past" (2017, p. 1130). From a cost perspective, Zappa et al. (2019) concluded that the additional costs of such a 100% renewable system would be at least 530 €bn y^{-1}, which is approximately 30% higher than a system in which nuclear or carbon capture and storage are included. Therefore, both studies conclude their study with a similar statement: to steer the energy transition to a reliable and cost-effective power system that is consistent with Europe's climate ambitions, policymakers should ensure that all technology options are taken into consideration including nuclear and carbon capture and storage (Zappa et al., 2019; Heard et al., 2017).

Other environmental studies (Connolly, Lund & Mathiesen, 2016; Brown, Bischof-Niemz, Blok, Breyer, Lund & Mathiesen, 2018) however, introduce scenarios arguing that it is indeed possible to convert the current EU system from primarily fossil fuels to a 100% renewable energy system. Connolly et al. (2016) state that besides the energy production from fossil fuels, also nuclear power should be removed from the EU energy system due to its economic, environmental, and security concerns. Like Connolly et al. (2016), Brown et al. (2018) argue that a mix of renewables and nuclear do not mix well because the energy production from nuclear power plants is not flexible, whereas the variability of renewables requires a flexible balancing power fleet.

The scientific proponents and opponents of an EU power system consisting of both renewable energy and other energy technologies seem to clash on the inclusion of one technology in particular: nuclear energy. There does not seem to be a consensus within the scientific community on whether nuclear energy should be included in the renewable EU power system to achieve the 2050 climate-neutrality objective. Furthermore, there seems to be a significant contrast between individual EU countries in the attitude towards the future of nuclear energy.

In 2007, the European Commission launched the "Nuclear Illustrative Programme" that provided information on nuclear energy in the European Union, the Member States objectives for nuclear power production, and the investment required to achieve them (European Commission, 2007). In 2010, the European Commission published the "2020 Energy Strategy" and continued to assign a crucial role to nuclear energy in the energy mix of the European Union (European Commission, 2010). In the "Green Paper" document, a 2030 framework for climate and energy policies, the European Commission again encourages next-generation nuclear technology to secure the supply and affordability of energy in the internal energy market (European Commission, 2013). In 2018, the European Commission introduced "A Clean Planet for all", a document that contained the European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy in 2050 (European Commision, 2018). According to the European Commission, by 2050, more than 80% of electricity should come from renewable energy sources. With a nuclear power share of approximately 15%, it would function as the backbone of a carbon-free European power system (European Commision, 2018). Judging from the current and future strategies of the European Commission, it seems that a rather significant role is assigned to nuclear energy in the future energy mix of the EU despite the ongoing disagreement in the scientific community whether to include nuclear power or not.

Examining the historical gross nuclear electricity production with the overall electricity consumption demonstrates the importance of nuclear energy for the European power system. The most recent available data until 2019 shows that the EU continues to be the largest producer and consumer of nuclear electricity world-wide (Eurostat, 2021; U.S. Energy Information Administration, 2020). In terms of gross nuclear electricity production, the EU produced 821 TWh where the U.S., being the second largest producer worldwide, generated 809 TWh of electricity in 2019 (Eurostat, 2021; U.S. Energy Information Administration, 2020). Nuclear plants generated around 26.4% of the electricity produced in the EU in 2019 (Eurostat, 2021); again, for comparison, the U.S. generated about 20% of their electricity consumption by nuclear power plants in 2019 (U.S. Energy Information Administration, 2020). Both the absolute numbers and relative shares demonstrate that the EU still heavily relies on nuclear energy.

Despite the nuclear inclusion objective of the European Commission (2018) of having nuclear energy in the power system and the historical reliance on nuclear energy, there seems to be a significant contrast of willingness between the member states of the EU-28 to produce this nuclear energy. France heads the nuclear production list with a nuclear generation of 399 TWh, or 70% of the country's total electricity production of 570 TWh in 2019 (IEA, 2020). Following France, there were EU states in 2019 that produced a moderate amount of nuclear electricity like Spain (58 TWh), The UK (56 TWh), Belgium (43 TWh), Germany (75 TWh), The Netherlands (16 TWh) and nine other states (Eurostat, 2021). However, of these nuclear energy-producing EU states, three (Germany, Belgium, Spain) have plans to close all their nuclear plants in the future and generate all their electricity from renewable sources (Psaledakis, 2019; Käckenhoff, 2019; Staff, 2019). Finally, there are EU states that do not produce nuclear energy (anymore), such as Italy, Denmark, Greece, Luxembourg, Austria and seven other member states (Eurostat, 2021). This data demonstrates that there is considerable variance between the single members of the EU concerning the willingness to produce nuclear energy.

According to Hultman (2011), to understand why countries diverge in their choice for nuclear energy, one should understand the different perspectives on risks, costs, and benefits of nuclear power. This requires an understanding of both the technocratic perspective on these issues as well as the public opinion in each country. This remark follows the conclusion of various studies that examined the drivers and barriers for nuclear power (Greenhalgh & Azapagic, 2009; Ahearne, 2011; Geels & Verhees, 2011) which found that besides the economic rationales of adopting nuclear energy, the public opinion associated with nuclear energy is an essential factor affecting the plans for nuclear power adoption as well. Unlike any other technology, the viability of nuclear energy seems to be subject to the course of the public opinion. After introducing the United States' Atoms for Peace program in the 1950s, nuclear power initially appeared to be a desirable solution to humanity's energy problems (Kirchhof, 2019). Many West-European countries such as France, The Netherlands, Belgium, Denmark, and The United Kingdom initiated strategies to supply nuclear energy nationwide (Trischler & Bud, 2018). However, after extensive testing of nuclear bombs in the Pacific by the U.S. in 1954, the public in Europe became concerned about the dangers of nuclear technology. While these concerns in 1954 initially were directed against the military use of nuclear power and atomic weapons, the protests during the 1970s shifted the focus to civilian use of nuclear energy technology. While the public opinion on this technology began to shift in many EU countries, the way nuclear energy programs in the EU were affected by public opinion was completely different.

For example, Germany was politically convinced by the technological advantages of nuclear technology and had the public support of nuclear policy at first but following the governmental plans for the construction of a giant nuclear processing centre and the nuclear meltdown in Chernobyl, protests from the local farming population and anti-nuclear groups from around the country prompted a substantive re-evaluation of nuclear energy (Jahn & Korolczuk, 2012). Bringing this nuclear debate in Germany to an end on 1 August 2011, it was decided in the Bundestag that by 2022 all of Germany's 17 nuclear reactors would be shut down, and renewable resources would be expanded (Jahn & Korolczuk, 2012). Meanwhile, in France, for a long time, neither major shocks (e.g., Chernobyl accident) nor the resulting social mobilisation affected the French nuclear policy (Brouard & Guinaudeau, 2014). How is it possible that national governments in comparable countries in the EU differ so much in their attitude towards nuclear energy, while there seems to be an everlasting objective of the European Commission to include nuclear energy in the energy mix? Given the seemingly important role of the public opinion in influencing the adoption decision of nuclear energy for governments, how can we then explain differences in public opinion in European countries and over time?

To answer these questions, this thesis study examines the public opinion of three European countries; The Netherlands, The United Kingdom, and Denmark from 1970, the year that protests directed at nuclear energy supply started, until the year 2018, to find out what explains the differences in the current attitude on nuclear energy. A cross-country comparison of the public opinion of nuclear energy in Europe is expected to provide a novel perspective on the source of variation in public acceptance of nuclear energy. Current literature has confirmed the relationship between the influential factors of public opinion and the effect on nuclear energy (Tanaka, 2004; D. C. Brown, 2007; Kim, Y., Kim, W., Kim, M, 2014; Ho et al., 2018) but it does not yet address why the influential factors evolved differently over time per country. Knowledge about the historical construction of influential factors of different European countries helps to interpret the current attitude to nuclear energy but could also provide additional knowledge about the future of nuclear energy and what could influence these future paths.

Considering this gap in the current literature of the social acceptance of nuclear energy - together with the recent renewed media and European interest in nuclear power (Wetzel, 2020; Cherki, 2020; NOS, 2020; Rowlatt, 2020) - this thesis seeks to explore the differences in public opinions towards nuclear energy and the forces underlying these differences in Europe by answering the following research question:

"What explains the difference in public opinion on nuclear energy in Europe, and its evolution over time?"

More specifically, this study aims to empirically research the differences of public opinions towards nuclear energy and the origin of these differences by applying semantic analysis methods. Understanding what explains the difference in public opinion of nuclear energy between European countries by employing a cross-country longitudinal sentiment analysis could well reveal new insights into the development of public opinion in addition to the more traditional research methods such as surveys.

The verification of the most important factors influencing the public attitude and opinion is crucial for the analysis of the historical paths of different paths in the construction of public acceptance of nuclear energy. Using these factors in a historical perspective could give insight into the reason why differences in public acceptances of nuclear energy exist between European countries which at first might seem similar in their appearance.

2. Theory

2.1 Public acceptance

In the European Union, the public opinion on nuclear technology between countries is polarized for both the civil and military nuclear programs (Mulder, 2012; Brouard & Guinaudeau, 2014; Latré; Kristiansen, Bonfadelli, Kovic, 2016; Thijssen, Perko, 2019). While both the civilian and military nuclear programs are the subject of public debate, this thesis study will concentrate on the public opinion associated with civil nuclear programs in the EU, given the potential relevance of nuclear energy in the European energy transition.

While little research has been done on public opinion on nuclear energy, much more research has been carried out on public acceptance. Public acceptance mostly refers to private opinions held by individuals regarding a technology. Public opinion, by contrast, is not an aggregate of privately held opinions, but the outcome of a social process among different groups and in different media (e.g., in newspapers, online, etc.) Many nuclear projects have been met with public resistance or dissatisfaction, which in many situations played a significant role in obstructing the development of nuclear programs (Jahn, Korolczuk, 2012; Cohen, Reichl, Schmidthaler, 2014; Thijssen, Perko, 2019). Several studies have examined this phenomenon extensively over the years and have been interchangeably referred to as social acceptance, local acceptance, public acceptance, or – reversely – as social, local, or public opposition (Tanaka, 2004; Bronfman, Jiménez, Arévalo, Cifuentes, 2012; Gaede & Rowlands, 2018).

Elaborating on the concept of public acceptance, various researchers have developed different conceptual frameworks for public acceptance (Dear, 1992; Upham, Oltra, Boso, 2015; Dermont, Ingold, Kammermann, Stadelmann-Steffen, 2017). The NIMBY (not in my backyard) principle by Dear (1992) is well known for describing the protectionist attitudes of community groups facing an unwelcome development in their neighbourhood. Such unwanted developments include a wide range of destination plans, such as airports and nuclear facilities (Dear, 1992). More specifically, people may enjoy the benefits of a new (infra)structure from a distance, but they will protest having to bear the costs of having such an (infra)structure in their community. Although the NIMBY is a legitimized concept, it also has been criticized for only partially explaining the complex formation of public acceptance (Wolsink, 2006; Feldman, Turner, 2010). Wolsink (2006) deconstructs the NIMBY concept by applying it to wind power. His finding is in line with Burningham (2000) which is that conflicts that are subject of the NIMBY literature are about fairness and that the label NIMBY is likely to aggravate conflict and result in those so labelled feeling excluded and aggrieved (Wolsink, 2006). Therefore, the NIMBY label on a community could also be making a weaker moral claim so much that their preferences are taken into consideration differently.

Meanwhile, Devine-Wright (2005) proposes place theory; a multidimensional framework that goes beyond the NIMBY label that provides a basis for recognizing how public perceptions are shaped by technical, environmental, economic, social, and psychological aspects. Originally this framework was tested by Davine-Wright on wind-energy but in 2012 Venables, Pidgeon, Parkhill, Henwood & Simmons successfully applied this framework to local host communities exposed to nuclear power. Equally important for the understanding of public acceptance, is the study of Wüstenhagen, Wolsink, & Bürer (2007) in which they show that public acceptance can be broken into three dimensions each corresponding to different agents: socio-political acceptance, community acceptance and market acceptance. Finally, in 2008, Devine-Wright constructed three categories that defined the factors influencing public acceptance: personal factors, psychological factors, and contextual factors. He explained that each of these factors affecting public acceptance is influenced by the perceptions and awareness of both the outcome of new (nuclear) energy projects and the procedures during the development of these projects (Devine-Wright, 2008).

While different studies have studied the phenomenon of public acceptance and presented helpful frameworks, there used to be a lack of a widely accepted understanding of what is precisely meant by the term "public acceptance" (Cohen et al., 2014). Studying the research efforts on the public acceptance of energy infrastructure, Cohen et al. concluded that most definitions are questionable, because scholars remained ambiguous what behaviours and opinions are sufficient to establish public acceptance. Hence, few frameworks allowed for the empirical measurement of acceptance (Cohen et al., 2014). One possibility is to start from welfare economics. Welfare in economic theory refers to the idea of individual utility in which a positive change in utility can ameliorate one's living standards whereas a negative change can deteriorate the living standards (Cohen et al., 2014). Social acceptance, however, is driven primarily by perceptions. For that reason, Cohen et al. define welfare decreasing aspects of a new (infra)structure as aspects that are perceived as 'bad' by the community (e.g., noise, ecological change, decreased property values) (Cohen et al., 2014). Likewise, welfare increasing aspects of a new project are aspects that are perceived as 'good' by the community (e.g., economic development, environmental benefits, energy supply security) (Cohen et al., 2014).

The significance of the introduced definition of Cohen et al. is that public acceptance of nuclear energy does not represent a lack of social, local, or public opposition, but an aggregate of the perceived positive changes to the living standards of individuals in a community because of the introduction of nuclear energy.

2.2 Factors affecting public acceptance

The research efforts to understand public acceptance, illustrate the complex nature of this phenomenon. The studies so far (Dear, 1992; Devine-Wright, 2005, 2008; Wolsink, 2006; Cohen et al., 2014; Upham et al., 2015; Gaede & Rowlands, 2018) provided an elaborate explanation of public acceptance, but do not provide a detailed clarification on the factors affecting the public acceptance of nuclear energy. However, other researchers have examined the relevant factors affecting the public acceptance of nuclear energy extensively (Hao, Y., Guo, Tian, & Shao, 2019; Kidd, 2013; S. Wang et al., 2020; Liu, C., Zhang, & Kidd, 2008). These studies are dedicated to the understanding of the factors affecting public acceptance of nuclear energy and there is one study that was able to quantify the mainly qualitative studies (Slovic, Fischhoff, Lichtenstein, 1980; Blee, 2001; Grimston, Beck, 2002) and by doing so found the sub-factors influencing the main factors. Liu et al. (2008) found that public acceptance of nuclear energy is the outcome of considering the perceived benefits, perceived risks, knowledge, and trust by the public.

2.2.1 Perceived benefits

In this context, the perceived benefit refers to the perception of the positive consequences that are associated with a recommended course of action (Leung, 2013). In this thesis, perceived benefits are defined as the extent to which an individual believes he/she or the whole community will benefit from developing and employing nuclear energy. For example, one could argue that nuclear energy reduces carbon emissions, alleviates global warming, lowers energy prices, decreases fossil fuel dependency, and enhances energy security (de Groot, Steg, Poortinga, 2012). While these perceived benefits of nuclear energy are taken for granted by one group or individual, someone else might completely disagree with the opinion that these statements are indeed true benefits associated with nuclear energy. A study performed in 2017 measured the attitudes towards nuclear energy of different groups and found that individuals who have greater familiarity and knowledge of nuclear energy are more likely to perceive the benefits of nuclear energy (Dermont et al., 2017). This highlights the importance of separating public acceptance from public opinion, which the latter as a key factor driving the former.

2.2.2 Perceived risks

One of the most well-known factors influencing public acceptance of nuclear energy is the associated perceived risk. The judgement of the risks in this context reflects the public’s perception of the safety of nuclear energy. A study performed by Chao-jun, Chun-ming, Yan, Jia-xu, & Jia-yun. (2013) studied the relationship between the perception of safety and public acceptance of nuclear energy and found that there is indeed a positive relationship between these two variables. Furthermore, researchers Parkhill, Pidgeon, Henwood, Simmons, & Venables, (2010) found that the perception of safety is susceptible to external nuclear disasters and the geographical distance to these disasters. Such a conclusion illustrates the ability of nuclear disasters to influence the perceived risks of nuclear energy.

2.2.3 Perceived knowledge of nuclear power

Knowledge of nuclear power relates to the public understanding of nuclear energy power generation, nuclear power operations, and nuclear radiation risks (Hao et al., 2019, p. 751). The knowledge of nuclear power is defined as the basic understanding of the public about the involved mechanisms and the development of nuclear energy and its utilization. An earlier study by Otway, Mauren, & Thomas (1978) concluded that the level of nuclear knowledge significantly influences the level of public acceptance of nuclear energy. This study shows that a better-perceived understanding of the technological, economic, social, and environmental effects, may help to increase the level of public acceptance of nuclear energy.

2.2.4 Perceived trust in authoritative parties associated with nuclear energy

Trust in parties concerns the willingness to rely on those who have the authority for making decisions and taking actions related to the employment of nuclear technology and policies (Siegrist, Cvetkovich, 2000). The concept of trust in this context is linked to the earlier mentioned concept of knowledge. The involvement of nuclear technology involves a limitation of possible acquired knowledge for individuals who are not directly related to the nuclear industry and, thus, construct their level of acceptance of nuclear energy by trusting on the knowledge and opinions of nuclear authorities and experts (Siegrist, Cvetkovich, 2000).

So far, the main categories that influence the level of public acceptance of nuclear energy have been found through mainly qualitative research and the related studies cannot further describe the influential factors. As mentioned earlier, Liu et al. (2008) took a different approach and were able to identify these influential factors by conducting a quantitative study. This study showed that it was indeed possible to identify the most important factors that can explain the construction of each main category which in turn determines the level of public acceptance of nuclear energy in a country. Liu et al. (2008) considered the four main categories to be relatively abstract and needed to be subdivided into eight issues to be measured, as follows:

- *Perceived benefits of nuclear energy*: (1) perceived energy benefits; (2) perceived economic benefits.
- *Perceived risks of nuclear energy*: (3) perceived operation risks.
- *Perceived knowledge of nuclear energy*: (4) perceived understanding of nuclear technology; (5) self-assessed familiarity with nuclear power.
- *Perceived trust in the parties associated with nuclear energy projects*: (6) perceived trust in nuclear experts.

In this framework, every main category is linked to one or more issues that, according to survey data are part of the construction of each main category. An individual opinion on the benefits of nuclear energy is formed by the perceived benefit nuclear energy has to the national power supply, the perceived benefit of nuclear energy to lower the energy prices and the perceived benefit of nuclear energy to protect the environment. To verify these linkages and the relationship with the final most important variable, public acceptance, they carried out a correlation analysis. The significance test between every independent variable (issues) and the dependent variable (main categories/public acceptance) showed the existence of the statistical association. These factors can therefore be the subcategories that indirectly influence the level of public acceptance.

2.3 Public opinion

Until now the literature on public acceptance examines factors from an individual perspective. However, public acceptance and government decision cannot be simply derived from the sum of individual attitudes and opinions (Glynn, Huge, 2008). Rather, the outcome of a collective process of debate in society as reflected in (mass) media (Glynn, Huge, 2008). Indeed, as research by Wang and Kim (2017) demonstrated, the aggregate of individual opinions correlates only weakly with the presence of nuclear energy. This study found that even in countries where there is or never has been any source of nuclear energy, more than 50% of the people express a positive public acceptance of nuclear energy. This suggests that public acceptance alone does not equal the implementation of nuclear energy. They found that the governmental level of benevolence towards nuclear energy as a product of public acceptance should be analysed as well. More specifically it is expected that countries differ in the effect the public acceptance can have on the policy regime. This phenomenon refers to public preferences and their role in the design of (nuclear-)energy policies.

As public opinion regarding nuclear technology is not an aggregate of privately held opinions, but the outcome of a social process among different groups and in different media, public opinion can also change much more abruptly than private opinion. Once some influential actors or groups change their opinion, they can ‘tip’ public opinion from one dominant opinion to another. Relatedly, external events can have very different effects on public opinion in different countries. For example, the history of nuclear energy demonstrates a large contrast between the effects of events outside Europe on the public opinion in European countries (de Boer & Catsburg, 1988): after the Chernobyl disaster the public opinion on nuclear energy in France remained stable thus the public acceptance towards nuclear energy was conserved and eventually the nuclear energy program of France was able to continue and improve. Meanwhile, the public opinion in The Netherlands was heavily influenced because of the Chernobyl disaster, anti-nuclear protests emerged, and the public acceptance of nuclear energy declined so much that earlier plans of expanding the nuclear capacity were halted and a total reconsideration of nuclear energy announced.

Privately held opinions do not result into public acceptance or rejection unless private individuals actually express their opinions which collectively form – as a social process – the public opinion. This can be one through events such as street demonstrations or even more radical means (such as sabotage or violence), but also through letters to newspapers or online messages. What is more, journalists try to reflect public acceptance or rejection by reporting on events, interviewing citizens, or reflecting on the outcomes of surveys among citizens. This is why public opinion is commonly analysed using news articles.

This thesis study will use semantic analysis to answer this question and explain the differences in public opinion on nuclear energy between three European countries: The Netherlands, The United Kingdom, and Denmark. The discourse of the national news articles will be analysed to highlight similarities and differences in public opinion and to explain the key differences in the acceptance of nuclear energy in all three European countries.

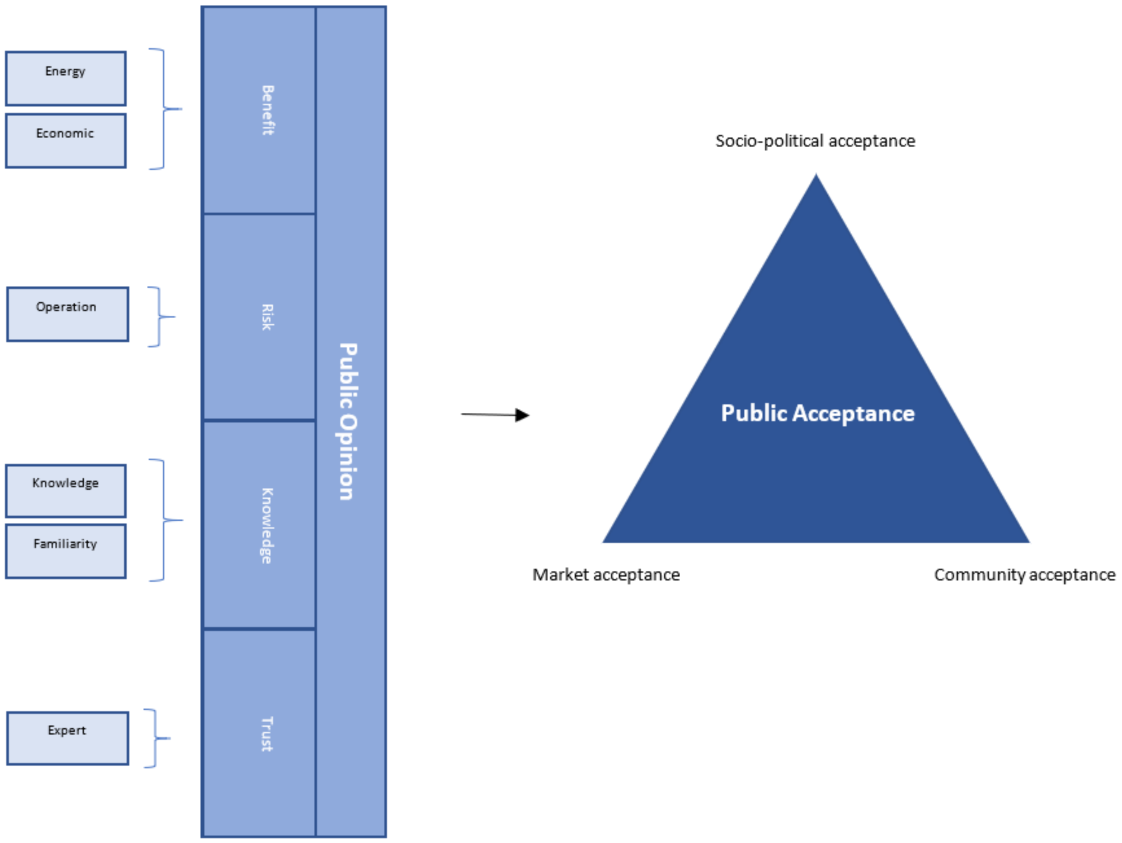

Figure 1. Representation of the relationship between public opinion and public acceptance

This visual representation demonstrates the relationship between public opinion on public acceptance. Public opinion factors influence the three dimensions of public acceptance. This model could be used to examine the differences in countries regarding the public opinion of a new technology and how this public opinion affects public acceptance. It is expected that this insight could help in explaining, from a socio-technical perspective, why one country adopts technology, and another country refuses such a technology.

3. Methods

3.1 Methodological approach

Our question holds: what explains the difference in public opinion on nuclear energy in Europe, and its evolution over time? Previous studies have shown that nuclear energy is not equally popular in every European country, in contrast to the recurring objective of the European Commission to include nuclear energy in the future EU energy mix (Koopmans, Duyvendak, 1995; Luoma-aho, Vos, 2009; Anderson, Böhmelt, Ward, 2017; Latré et al., 2019; Stadelmann-Steffen, Eder, 2020). However, the available studies concerned with the public opinion on nuclear energy in Europe are derived from surveys only (Vos, 2009; Anderson, Böhmelt, Ward, 2017; Latré et al., 2019; Stadelmann-Steffen, Eder, 2020). Such surveys provide a rather static and individualistic impression of the attitude towards nuclear energy while public opinion is the outcome of a collective process of debate in society as reflected in (mass) media. Furthermore, survey studies are mostly employed in a very short time period which does not allow for the analysis of the development of the attitude towards nuclear energy. Because of this unsatisfactory data situation, troubled conclusions based on static snapshots of individual attitudes towards nuclear energy are drawn and confused with the concept of public opinion which is derived from the debate in mass media.

This thesis study, however, takes a quantitative methodological approach and is based on data from mass media. It also expands the scope of the research to a cross-country comparison of the development of public opinion of nuclear energy in three European countries: The Netherlands, Denmark, and The United Kingdom. A “cross-cultural case study” research design is chosen due to the possibility of discovering new dimensions in the public opinion theory due the supposed similar social, cultural values in Europe. These three countries have specifically been chosen because they are member states of the EU, combined provide a contrast of nuclear energy adoption throughout history and the presence of a national news archive per country. This “cross-cultural case study” thus suits the objectives of this research, which are to identify and explain the differences in public opinion of nuclear energy in Europe and explore the broader implications of these findings. Furthermore, a longitudinal approach is taken to allow the public opinion to be tracked over time and the explanation of the differences to be identified.

3.1.1 Dataset and Pre-Processing

Data collection

The period 1970 - 2018 has been chosen because 1970 marks the start of the anti-nuclear movements in Europe, it includes multiple large nuclear disasters such as Chernobyl and Fukushima of which the effects on the public opinion are valuable for analysis and this period is expected to provide the most complete data. In total there will be 49 years of news articles extracted and analysed for the three European countries. Unlike the Internet today, newspapers have been the main written mass medium for the largest part in this period in Europe, which justifies the choice of newspaper articles for the sentiment analysis (Prat & Strömberg, 2011).

In this study, a total of three European countries were selected to extract the published news articles related to nuclear energy between 1970 – 2018 from: The Netherlands, The United Kingdom, and Denmark. These countries were selected because each country represents one of the three most common participants in the public debate of nuclear energy: the anti-nuclear (Denmark), the doubter (The Netherlands), and the pro-nuclear (The United Kingdom). These countries were categorised according to their nuclear energy plans: Denmark deliberately chose not to pursue nuclear power in the 1980's (OECD & NEA, 2015), The Netherlands has had two nuclear power plants of which only one is currently running and does not expect to construct a new nuclear power plant before 2030 (Ministerie van Algemene Zaken, 2021), and finally The United Kingdom which has had a fairly large nuclear energy program since 1970 and has plans to increase their nuclear energy capacity as from 2025 (House of commons, 2021). For each of these three countries, three national newspapers were selected based on the availability of an online archive with articles published between 1970 – 2018. The selected newspapers are the only newspapers present per country having such an extensive online archive. It has been tried to create a selection of newspapers that represented every dimension of the political construct, but since the majority of the newspapers did not have an appropriate online archive, concessions were made.

Table 1*: exploited newspapers per country*

	The Netherlands	**The United Kingdom**	**Denmark**
Newspapers and their political orientation	NRC (centred), Trouw (left-wing), Volkskrant (left-wing)	The Times (conservative), The Sunday Times (conservative), Aberdeen Journal (conservative)	Bergens Tidende (liberal), Information (conservative), Nordjyske (centred)
Total number of nuclear energy related articles	13,815	8,066	5,597

The news articles were extracted using the syntax combination: "Nuclear-Energy" ("Kernenergie" in NL, "Atomenergi" in DK), and the date period 1970-2018 in the search engine of every newspaper website. The required presence of such a comprehensive searchable archive on the website of a newspaper excluded the availability of many national newspapers, except for the three newspapers per country as mentioned in table 1. After the search results appeared, each webpage was studied and, accordingly, the web scraping algorithms "Selenium" and "Beautifulsoup", were applied. These algorithms allowed for the extraction of the desired information using the HTML and JavaScript available on each website.

The extracted newspaper articles were transformed into a data frame in which each row represented a newspaper article related to "Nuclear Energy". The data frame included three columns: "Title of Newspaper", "Year of publication", "Month of publication", and "Content of the article". All the extracted newspaper articles were combined into one data frame per country.

Data cleaning

The first step of cleaning the data was to make sure that each column contained the desired data format. The column “Title of Newspaper” should only contain variables with the value of a string so that it represents the title of the newspaper of which each newspaper article is extracted from. The column “Year” should only contain variables with the value of an integer holding four digits that represent the year of publication of each newspaper article, and the range of these years should lie within 1970 – 2018. The “Month” column should only contain variables with the value of an integer holding one or two digits that represent the month of publication (January = 1, February = 2, etc.). The column “Content of the article” should only contain variables with the value of a string so that it represents the content text of a newspaper article related to nuclear energy.

Furthermore, in addition to the website search engine filter that retrieves only articles containing the words “Nuclear Energy”, another check was done making sure that each content variable contained the string “Nuclear Energy” somewhere in the text, all other articles were excluded.

Next, the content variable was cleaned by applying two rounds of ‘cleaning’. The first round of cleaning included making all the text lowercase, removing text in square brackets, removing punctuation and removing words containing numbers. The second round of cleaning removed additional punctuation and non-processable text that was missed the first round. The goal of both these cleaning exercises is to optimize the text for the sentiment analysis algorithm. The performance of the algorithm is influenced by punctuation and words that were either written incorrectly on the original website or were extracted incorrectly so that it cannot process such words.

Data translation

Once the columns contained the desired text in a clean format, each of the articles were translated to the English language using the Neural Machine Translation API from Amazon Web Services. This system is built on a neural network that considers the entire context of the source sentence as well as the translation it has generated so far, to create accurate and fluent translations. Of the three countries that are included, only two had to be translated because the United Kingdom does not need translation for its English origin.

Organizing the data

Having cleaned and translated the news articles, the next step was to organize the data in such a way that the sentiment analysis algorithm could handle the input. Therefore, it was needed to extract each individual year from the general data frame and create separate data frames for each year with all its related newspaper articles. Doing so allowed also for the verification of the availability of each year in the data set, in total 49 years per country were available.

For each year, the data was indexed based on the month. Doing so resulted in an overview per year in which the newspapers articles published per month were presented.

3.1.2 Sentiment analysis

The input of the sentiment analysis was the cleaned data frame (Corpus file) that contains the published newspaper articles per year. For the sentiment analysis, the package "TextBlob" was used. TextBlob is a python library for Natural Language Processing (NLP) using the lexicon-based approach for sentiment analysis.

For lexicon-based approaches, a sentiment is defined by its semantic orientation and the intensity of each word in the sentence (B. Liu, 2012) This builds upon a pre-defined dictionary classifying negative and positive words. The algorithm assigns individual scores to all the words and calculates the final sentiment by taking the average of all the sentiments in a text. TextBlob returns a polarity value and the subjectivity value of a sentence. The polarity score lies between [-1,1], in which -1 defines a negative emotion and +1 defines a positive emotion. The subjectivity score lies between [0,1]. The subjectivity score quantifies the amount of personal opinion and factual information in a text. The higher subjectivity score means that the text contains personal opinion rather than factual information sentence (B. Liu, 2012).

Table 2: *example of sentiment analysis using "TextBlob"*

Text (NL newspaper)	**Polarity score**	**Subjectivity score**
"Slovenia's only nuclear reactor is facing technical problems the reactor will not start up after it was automatically shut down last week according to the operators the nuclear power plant went down wednesday due to a small incident it was supposed to be a power outage the intention was to reboot the reactor last night but it failed a spokesperson for the nuclear power plant tells press agency ap that synchronization problems have been noticed when attempting to reboot the reactor if that problem is resolved the reactor can simply be restarted the reactor was put into operation and is owned by slovenia and Croatia."	-0.07033	0.319325
"Twenty volunteers have signed up to help the fifty people who are trying to save what is to be saved at the fukushima nuclear power plant says the süddeutsche zeitung this morning this and many other newspapers are writing that these people are actually engaged in a kamikaze action even though an ode to the kamikaze fire fighters written experience shows that you wont survive for long the amount of radiation you are exposed to the new york times also has an article devoted to the sense of duty of these technicians in one of the hundreds of responses to this they are already called the nuclear samurai people in similar situations say this belongs to the spirit de corps you remain loyal with your comrades to what your work is historian and japanese connoisseur sebastian conrad rejects the term kamikaze but underlines that in japan there is more strong involvement in the collective interest than in most western countries the süddeutsche writes that now in fact some fifty people are being sacrificed to prevent the death of many more people it is good to reconsider what has happened to the chernobyl liquidators few emergency workers who are still alive years later."	0.206738	0.368222

The expected polarity scores, representing a positive or negative emotion in a news article, are expected to range between -0.25 & +0.50. This expectation builds upon previous research of two researchers associated with IBM (Nelis & Vahdat, 2021) and the work of Bhagat et al. (2021) in which sentiment analysis was also applied on newspapers and a similar range of polarity scores was found. Their research shows that the distribution of such polarity scores is centred around the value 0.10, which, compared to the official polarity scale of -1 & +1, is rather low. Bhagat et al. (2021) mention that this phenomenon could be explained by the fact that sentiment analysis is responsive to opinionated sentences or words, but that newspapers are known for their factual writing style which builds upon objectivity instead of subjectivity.

For each country, the polarity and subjectivity score per news article belonging to a specific year in the period 1970 – 2018 was calculated. Having all the individual polarity and subjectivity scores of news articles per year allowed for the calculation of the average scores per year. Before calculating the average polarity and subjectivity score per year, it was necessary to correct for outliers in each year. In the context of polarity scores, if not corrected, outliers could provide a false indication of a positive or negative average in a year which would be impossible to explain by explanatory variables. Since the data involved is of such high volume, it could be possible that, despite the multiple cleaning rounds, unrelated articles are used that contaminate the average scores. Therefore, a Z-score outlier correction method was employed to remove any outliers in polarity and subjectivity scores per year. The Z-score is a numerical measurement that describes a value's relationship to the mean of a group of values in terms of standard deviations from the mean score. A Z-score of 1.0 would indicate a value that is one standard deviation from the mean. Z-scores can be either positive or negative, where a positive value indicates a score above the mean and a negative score below the mean. For this study, all polarity and subjectivity scores per year were measured for their Z-score, and only polarity and subjectivity scores with a Z-score values between +2 and -2 were included in the final data set. Reasoning for this Z-score correction of outliers is that the individual polarity and subjectivity scores per year are not expected to differ more than 2 points from the mean of the average polarity and subjectivity scores per year because of the relatively slow and long-running nuclear power debate.

3.2 Explanatory variables of the differences in public opinion

To explain a trend in the public opinion in a country, it is necessary to provide variables that could influence the construction of each sub-factor of public opinion. Testing a possible significant relationship between the independent (explanatory) variables and the dependent variables (sub-factors) would require the independent variables to be quantitative. By constructing a multilevel model with these variables included, this study attempts to test and find what independent variables influence the public opinion of nuclear energy per country. These insights contribute to the explanation phase of the analysis which is the final step in answering the research question of what explains the differences in public opinion of nuclear energy 1970 - 2018.

3.2.1 Energy (benefit)

Gralla, Abson, Møller, Lang, & von Wehrden (2017) tried to further understand the socio-economic, environmental, and technological factors that characterize countries to adopt nuclear energy production. By using development indicators of the World Bank for 213 countries between 1960 and 2013, they were able to follow four different nuclear strategies (nuclear production, phase-out, planning to produce, produce nuclear energy). Their analysis of country characteristics revealed that non-nuclear countries showed a higher share of fossil fuel energy production, but still less overall energy need and carbon emissions. By contrast, the characteristics of countries that adopted the production of nuclear energy as part of their energy mix seem to create additional energy needs and not a satisfaction of existing energy needs. This finding is supported by Vaillancourt, Labriet, Loulou, & Waaub (2008) in their research of analysing the role of nuclear energy in long-term climate scenarios with the World-TIMES model. They found that countries with high socio-economic growth are more likely to invest in the production of nuclear energy because renewable energy alone will not be sufficient to meet the corresponding increase in energy needs in future climate scenarios.

According to the studies of Gralla et al. (2017) and Vaillancourt et al. (2008), energy need, or similarly, energy consumption, seems to be a promising explanatory variable of explaining the energy benefit. For this reason, the energy consumption of a country will be used to explain the perceived energy benefit of nuclear energy per country.

3.2.2 Economic (benefit)

The perceived economic benefits associated with nuclear energy have a major impact on the public opinion of nuclear energy Visschers, Keller & Siegrist (2011). This study suggests that the perceived high value of the economic benefits associated with nuclear technology is the main reason proponents support nuclear energy. On the other hand, opponents of nuclear technology displayed a relatively low perceived value of the economic benefits associated with it and therefore are not willing to accept the risks associated with nuclear energy (Eiser, Pligt, 1979).

Since the economic benefits of nuclear energy depend on the perceived public value associated with nuclear energy, it is necessary to implement a quantitative variable that can be interpreted as either a financial advantage or disadvantage. The historical public debate about the economic benefits shows that the costs associated with nuclear energy are called upon frequently (Greif, 1980, p. 15; Cassuto, 1991, p. 57; Libération, 2014). To explain the economic benefits of nuclear energy, the costs of nuclear energy will be used as a variable.

More specifically, the historical construction costs of global nuclear power reactors by Lovering, Yip & Nordhaus (2016) will be used to determine the average costs of kilowatt capacity per year. Their study is composed of historical reactor specific overnight construction cost (OCC) data that allows for a more far-reaching scope, covering the full cost history for 349 reactors globally, encompassing 58% of all reactors built globally. The authors of this study were kind enough to share their source data with me after a request per mail.

3.2.3 Operation (risk)

The effect of risk perception on the public opinion was already recognized in 1987 when Rothman and Lichter completed their study on "Elite ideology and risk perception in nuclear energy policy". It became apparent that the risk perception of nuclear energy was influenced by nuclear disasters and accidents irrationally. Rothman and Lichter examined the risk perception of nuclear energy amongst different social groups such as lawyers, bureaucrats, scientists, and journalists. It became apparent that, depending on the group, people experienced different perceptions of the risk involved with nuclear energy which was influenced by previous nuclear disasters or accidents. Comparing the score on the nuclear support scale revealed a rather interesting outcome; the average score on the nuclear support scale for all scientists was 3.34, as where science journalists at New York Times and the Washington Post scored a 0.47. This illustrates the large contrast in risk perception between social groups on the same topic, nuclear energy. Even more striking is the fact that especially journalists can influence the public opinion via news media which in turn could be an explanation for a negative risk perception included in the public opinion in a country.

A more recent study by Wahlberg and Sjoberg (2000) in which a survey of research on how media influence risk perception found a similar conclusion. There seemed to be a correlation between the media coverage of a nuclear event and the risk perception of nuclear energy. An important finding that helps understand this phenomenon is that the media often present facts outside their contexts and leave them to the public to evaluate them.
Following the notion of both studies, the explanatory variable operation risk of nuclear energy will be measured according to maximum INES score obtained per year. The INES is used for the rating of events that result in a release of radioactive material into the environment and in the radiation exposure of workers and the public (IAEA, 1990). The INES ratings are described as follows: events rated with 1-3 are categorized as incidents and events rated 4-76 are categorized as accidents. Within every category, each rating indicates the significance of nuclear events; 1 = anomaly, 2 = incident, 3 = serious incident, 4 = accident with local consequences, 5 = accident with wider consequences, 6 = serious accident, 7 = major accident.

Applying the INES scale as an explanatory variable for the perceived operation risk of nuclear allows to measure the effect of the intensity of a nuclear event instead of the frequency which could be insignificant since there are many (small) events of which are not communicated to the general public.

3.2.4 Knowledge (knowledge)

Kreiman and Maunsell (2011) examined nine criteria for a measure of scientific output and argued that scientific research produces new knowledge which in turn can lead to the development of new technologies and social policies. While they do mention the limitations of quantitative measures for measuring the quality of scientific output, they acknowledge its use for identifying the knowledge domains. Since the purpose of this explanatory variable is to explore the nuclear energy knowledge domain of each country, the quantitative measure of scientific output in the form of nuclear publications per year per country seems justified.

In addition to the use of scientific output, also nuclear patents per country per year will be implemented to try to explain the knowledge as a possible influence on the public opinion of nuclear energy. This measure follows the beliefs in the innovation literature and associated studies such as the study of Acs, Anselin, Varga (2002) in which they examine whether patent data is a reliable proxy measure of knowledge flows and innovative activity at the regional level. They found that the measure of patented inventions provides a good representation of innovative activity and knowledge flows. According to Acs et al. (2012), this finding supports the use of patent counts in studies examining technological change.

3.2.5 Familiarity (knowledge)

The familiarity with nuclear energy and the effect it has on the attitudes toward nuclear energy has been examined on a small scale in a1986 study by Van Der Pligt, Eiser & Spears. In a survey of 719 residents of four small communities that were selected as possible locations for a new nuclear power station in the UK, they examined the effects of having lived near a nuclear power station on the attitude of the construction of a new nuclear reactor. The results showed a more favourable attitude in the community located near the existing nuclear power station than in the three communities without such a power station. The experience of having lived near a nuclear power station affected both the benefit and the risk perception associated with nuclear energy significantly.

Considering the results of this small-scale experiment, this variable will follow the same line of thought; the intensity of exposure to nuclear energy technology influences can be expressed as familiarity and is expected to influence the public opinion on nuclear energy in a country. To include this explanatory variable in statistical analysis in this thesis study, the nuclear energy production per year in a country will be used. The production of nuclear energy as a measure to explain the familiarity with nuclear technology has been examined and proved to be significant in a 2018 study by J. Wang and Kim. They analysed 27 European countries and found that the production of nuclear energy influenced the acceptance of nuclear energy.

3.2.6 Expert (trust)

Trust in this context relates to the level of trust the public has in the experts related to a scientific domain, in this study nuclear energy. Technologies associated with high risk have demonstrated to be the subject of discussions about the public loss of trust in science when these technologies are involved in accidents and displayed in the public media. However, according to Hendriks, Kienhues, Bromme (2016), trust in science reaches far beyond such incidents: trust is a much more fundamental importance for science. Trust seems vital in doing science since researchers rely on the knowledge produced by other scientists with different specializations and expertise. Likewise, trust is essential for the public understanding of science. People possess a bounded understanding of science, and, now more than in the old days, can access different kinds of scientific knowledge (online). To process this scientific information, people must trust scientists and their knowledge. This seems even more applicable to nuclear technology because this technology seems relatively more complex than other energy technologies. Not only the laypeople but also the general scientific community is expected to trust nuclear scientists because the technologies they use to generate energy are simply too complex to deal with based on bounded knowledge.

To measure the level of trust in the scientific community and its experts, the share of the population that has completed a form of tertiary education will be calculated and compared. For the sake of this study tertiary education is defined as higher education leading to the award of an academic degree. This measure follows the study of Nadelson, Jorcyk, Yang, Jarratt Smith, Matson, Cornell & Husting (2014) in which they developed an instrument to measure trust in science and scientists. Their comparison of composite scores of trust with years of college and the number of college-level classes indicated positive relationships such that as years of college increased and the number of science classes increased, trust in science increased. It is for this reason that the share of people with a completed tertiary education could help explain the level of trust in nuclear science and scientists.

3.2.7 Summary of the variables

The explanatory variables that will be utilized in this study to explain the differences in public opinion between the three European countries in 1970 - 2018 have been visualized in figure 4. This figure shows the expected relationships between public opinion and the main factors, sub-factors, and explanatory variables.

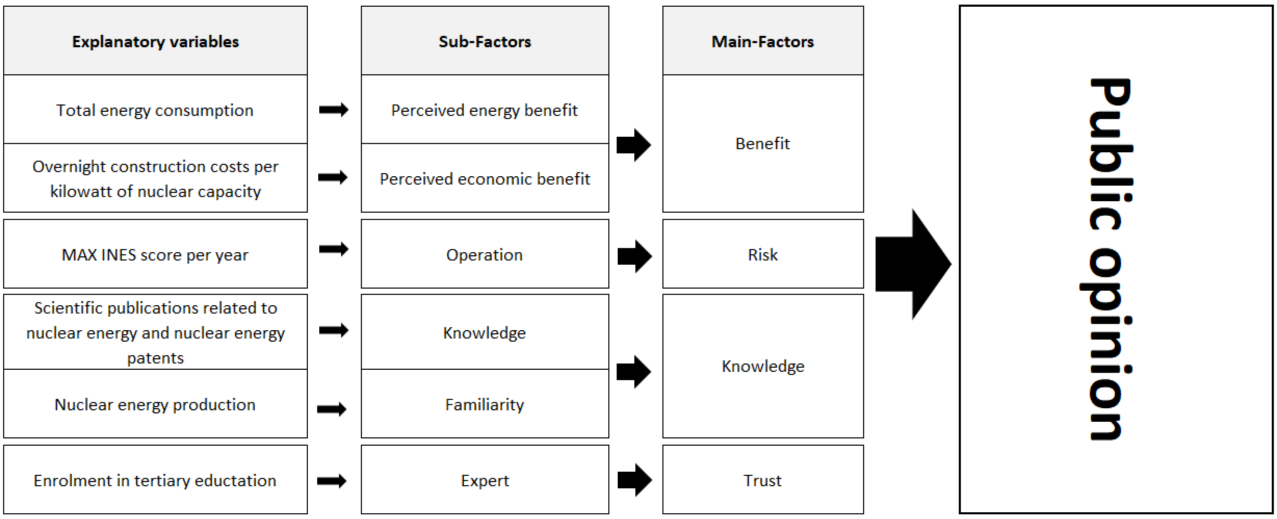

Figure 2: Overview of the hierarchy of influencing variables on the public opinion of nuclear energy

The explanatory variables have that will be used to explain the public opinion, have been specified in more detail per country in table 3. The purpose of this table is to provide a detailed overview of the explanatory variables in order prevent possible confusion. Note that there are 7 explanatory variables in total, in previous figure 2 the nuclear publications and patents were combined in one cell.

***Table 3**: detailed overview of explanatory variables*

Explanatory variable	Unit	Source
Total energy consumption	PJ	NL: (CBS, 2021) UK: (Department for business, energy & industrial strategy, 2020) DK: (Danish Energy Agency, 2018; Worldbank, 2021)
Overnight construction costs per kilowatt of nuclear capacity	$ per kilowatt	NL/UK/DK: (Lovering et al., 2016)
MAX INES score per year	Scale: 1-7	NL/UK/DK: (Ayoub, Stankovski, Kröger & Sornette, 2021)
Scientific publications related to nuclear energy	Total number of publications per year	NL/UK/DK: (Scopus, 2021)
Nuclear energy patents	Total number of patents per year	NL/UK/DK: (Espacenet, 2021)
Nuclear energy production	GWh	NL: (CBS, 2020) UK: (Department for Business, Energy & Industrial Strategy, 2013)
Enrolment in tertiary education	Total number of people enrolled in tertiary education, all programs, both sexes	NL/UK/DK: (UNESCO, 2013)

4 Results

Using the described methodology, a unique data set was constructed including over 20,000 news articles collected from 9 newspapers in The Netherlands, The United Kingdom and Denmark between 1970 – 2018. For this section, first an overview of the sentiment analysis is provided, illustrating the sentiment over time through the polarity and subjectivity scores of the news articles related to nuclear energy. Second, the descriptive statistics of the explanatory variables will be discussed to provide an overview of the differences between countries in the developing factors over time. Finally, a regression model per country is presented in which a possible relationship between the attention development, sentiment development and the explanatory variables will be examined.

4.1 Attention

The level of attention of nuclear energy in this study is measured by a frequency analysis of the news articles related to nuclear energy. More specifically, the level of attention is represented by the count of news articles related to nuclear energy per year for each country.

Figure 3 represents the count of news articles related to nuclear energy per year for each country. While the number of articles is different for each country, they do seem to follow a similar trend. There seems to be a steadily increase of articles every year from 1970 until 1979/1980, followed by a decline until 1986 in which there is a steep increase in the number of published articles. This increase stops in 1978, after which the number of published articles seems to have reached its lowest point for a long period of years. This period in where there are published relatively few news articles related to nuclear energy, continues until 2011-2012, in which especially The Netherlands publishes a large number of articles related to nuclear energy for a few years.

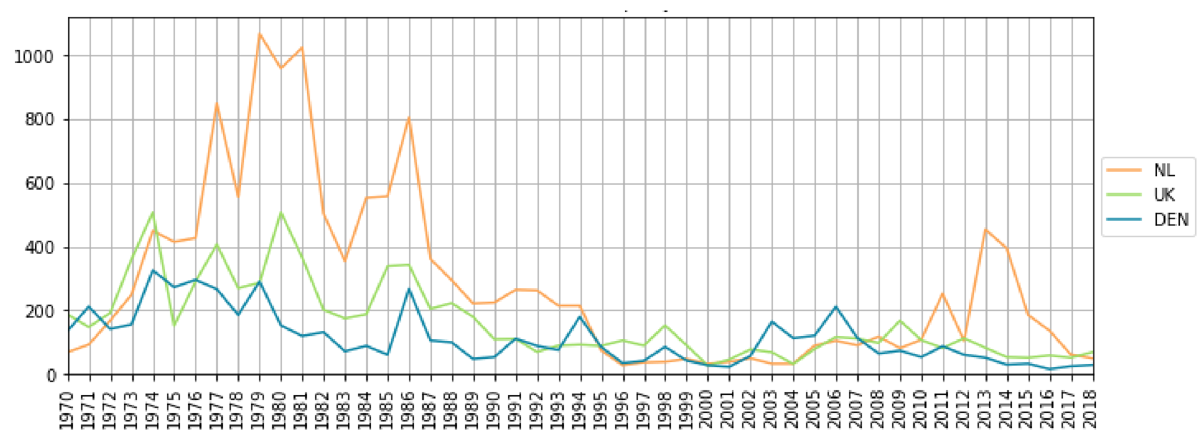

Figure 3*: number of articles per year for each country*

4.2 Sentiment analysis

Before we turn to the country sentiment analyses, we first examine the entire database and its individual datapoints. The polarity and subjectivity scores of all individual news articles of the three countries have been combined into a hexbin heatmap (figure 4) which represents the density of these scores. This figure shows that the polarity score of the news articles ranges from approximately – 0.28 to 0.47, and the subjectivity score ranges from 0.0 to 0.8. The highest polarity density lies approximately between the scores of 0.0 and 0.1, implying that the greater part of the news articles related to nuclear energy written during 1970 - 2018 contain a neutral or a somewhat positive sentiment, with respect to the scale of polarity ranges from -1, +1 in which -1 represents a negative sentiment and +1 a positive sentiment. The majority of the subjectivity scores in these news articles range between 0.3 – 0.5, indicating a balanced mix of opinions and facts present in the news articles, considering that the scale of subjectivity ranges from 0, +1, in which 0 represents a pure fact, and +1 a perfect personal opinion. Important for the original -1, +1 scale of the polarity and subjectivity is that, as mentioned in the method section, polarity seems to appear on a smaller scale in newspapers, ranging from -0.25, +0.50. Since there seems to be a different range for newspaper articles, compared to other types of text such as twitter tweets, it makes sense to apply a smaller range to visualise any differences in scores per year. For the coming sentiment analyses, we have chosen to apply a scale of -0.05, +0.15.

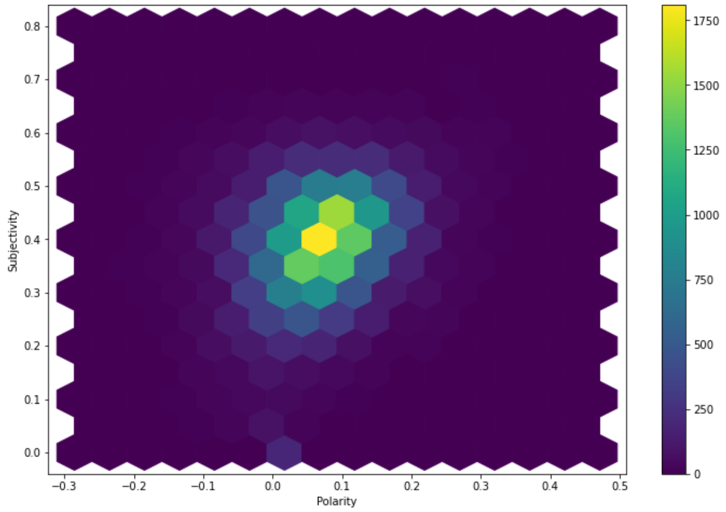

Figure 4: Subjectivity vs Polarity of all news articles 1970 2018 (NL/UK/DK)

The subjectivity and polarity scores in figure 4, represent the scores per individual news article related to nuclear energy. Considering that this study aims to find out what explains the differences in public opinion over time between EU countries, it is necessary to identify the average polarity and subjectivity scores per year per country. Doing so allows for the comparison of these scores between countries and per year, and to visualize the development of the average polarity score over time representing the public opinion.

4.2.1 Polarity scores

The first part of the sentiment analysis is the polarity score which detects the amount of positive or negative emotion contained in a text. The polarity score development of all three countries has been combined in figure 5, visualising the average polarity scores of all three national newspapers combined per year for each country, indicates a different development of polarity throughout period 1970 - 2018.

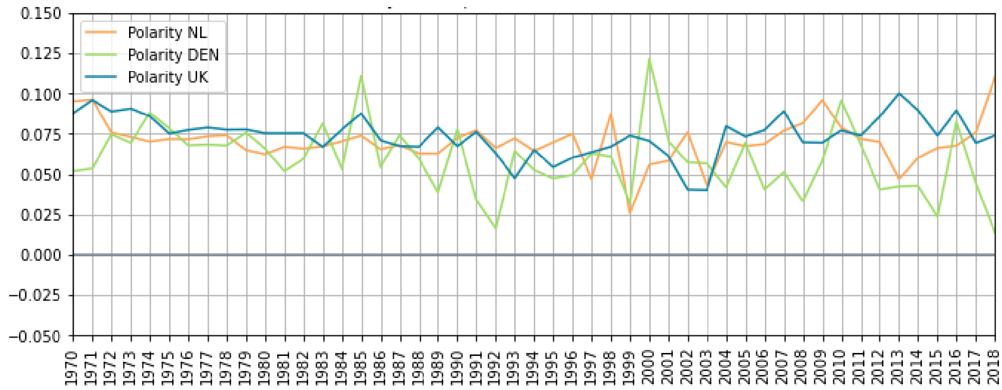

Figure 5: average polarity development per year for each country

The first country, The Netherlands, displays a rather stable average polarity development until 1997 in figure 5, after which short decrease and increase of polarity occurs. After 2003 the polarity score is gradually increasing up until 2009 after which it decreases again and rises again after 2013. These changes in average polarity scores between years may be explained by changes in the explanatory variables which will be discussed in the next paragraph.

Second, the polarity scores of The United Kingdom are visualised. Interesting is that similar to The Netherlands, the polarity score of The UK is relatively stable in the beginning but changes in the 90's as the score diverts more from 0.075.

Finally, as opposed to the other countries, Denmark displays a dynamic development of the polarity score throughout the full period 1970 -2018 as can be seen in figure 5. The polarity scores seem to be less centred around the 0.075 value and having more steep increases reaching the value 0.125, and more decreases almost reaching 0.0.

The polarity scores of all three countries ranges between 0.0 – 0.125 in which the first years of The Netherlands and The United Kingdom are linked to a stable polarity score of approximately 0.075. Both these countries display a firm change in the polarity score starting in the 1990's, after which the polarity score in the news articles seems to be much more divers. This could represent a relative stable positive sentiment towards nuclear energy in the beginning of the 1970 – 2018, which started to change after the 1990's. Compared to The Netherlands and The United Kingdom, the polarity score of Denmark seems to have a volatile character from the start in 1970. This could indicate that the sentiment towards nuclear energy in Denmark is ever changing, taking no real stance that holds for a longer period of time. The period in which all three countries seem to display to most similarities is the period 1970 – 1980, in which the polarity score centres around the value of 0.075, indicating a slight positive sentiment towards nuclear energy present in the news articles.

After 1980, the polarity scores start diverging from each other, with Denmark being the country with the most significant changes in polarity per year.

4.2.2 Subjectivity scores

The subjectivity score is the second and final part of the sentiment analysis and represents the ratio of subjectivity versus objectivity that is presence in a text. Figure 6 combines the average subjectivity scores per year for each country and illustrates the development throughout the period 1970 – 2018. Contrary to the reduced scale of polarity scores in the previous paragraph, necessary to visualise any differences in polarity between countries, the scale of subjectivity scores does not need to be reduced. The reason for this is that the average range of the subjectivity score 0.3 – 0.4, fits the journalistic (‘objective’) character of a newspaper, and we would only be interested in major increases or decreases from the expected standard. The range of 0.3 – 0.4 represents a fair balance between subjectivity and objectivity, leaning to an objective way of writing which is ultimately what is expected of newspapers when covering the news.

Both The Netherlands and The United Kingdom show a very similar development of the subjectivity scores over time. The subjectivity scores for each of these countries are centred almost perfectly around the value of 0.4, with slight deviations in 1999 and 2001.

The development of the Danish subjectivity scores seems to have a wider range in comparison with The Netherlands and The United Kingdom. The subjectivity scores of Denmark range between 0.3 – 0.4. This implies that the Danish news articles are more objective in character in the largest part of the period 1970 – 2018. However, the subjectivity score seems to change almost every year between approximately 0.3 and 0.4, which makes it hard to provide a solid explanation for this interaction between subjectivity and objectivity.

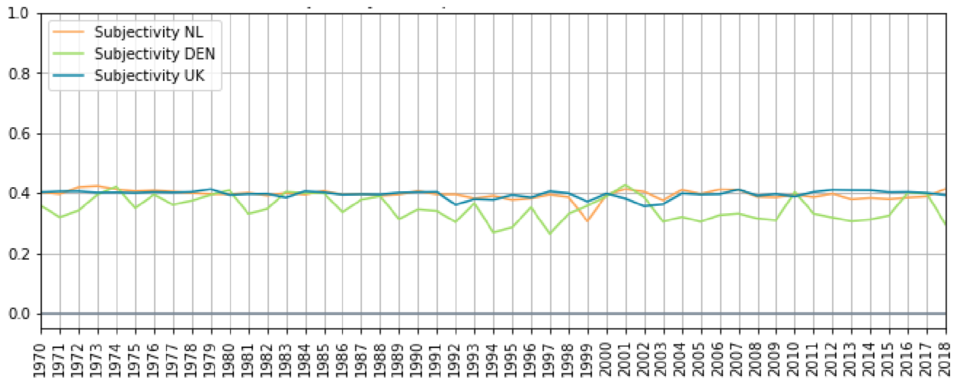

Figure 6: average subjectivity scores per year for each country

4.3 Descriptive statistics

The sentiment analysis per country is a descriptive statistic, and hence does not provide explanations for the differences in public opinion over time and across countries. Mentioned in the method section, seven explanatory variables will be used to try to explain the differences in public opinion over time.

This study includes seven explanatory variables and eventually measures its effect on the public opinion. Before the results of the regression models, the historical development of each explanatory variable will be displayed first.

4.3.1 Energy consumption in PJ

Energy consumption represents the effect of the perceived energy benefit on the public opinion of nuclear. Considering that each explanatory variable is destined to be included in a regression model, an average output per capita for comparison between countries is not relevant.

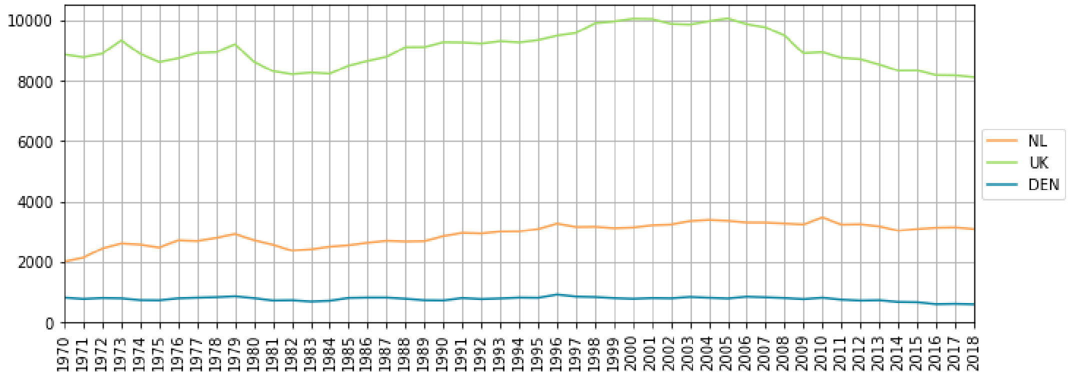

Figure 7: total energy consumption in PJ per year for each country

The energy consumption for especially The United Kingdom and Denmark shows a clear trend of declining consumption over the last years. The energy consumption in The Netherlands, however, displays a rather stable energy consumption over the last years.

4.3.2 Overnight Construction cost (OCC) per kilowatt of nuclear capacity

The OCC per kilowatt of installed nuclear capacity examines the effect of perceived economic benefit on the public opinion of nuclear energy.

Figure 8 shows the development of the OCC throughout the period 1970 – 2018, in which the costs seem to have developing rather dynamically with a steep increase in the last ten years. This could be possibly due to increased safety requirements after the Fukushima event.

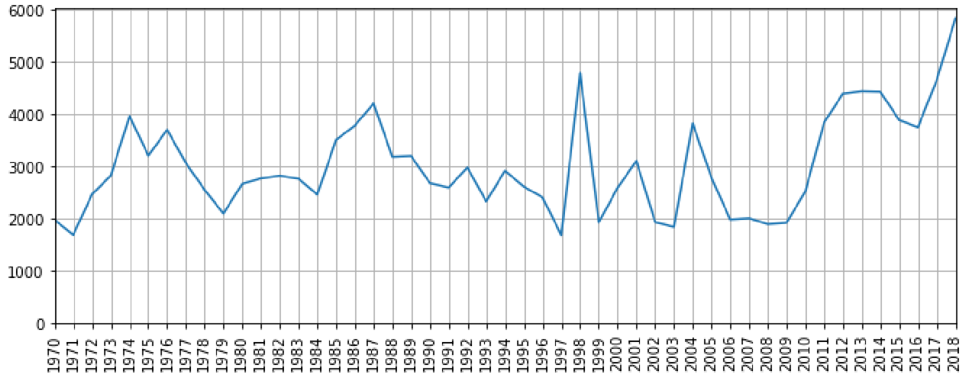

Figure 8: average overnight construction costs of nuclear energy in $ per kilowatt of capacity

4.3.3 Maximum INES score

Utilizing the ETHZ Curated Nuclear Events Database allows for the construction of a plot that visualises the maximum INES score per year.

The scatterplot in figure 9 illustrates the maximum INES Score per year globally. What seems interesting in this figure are the relatively high INES scores between 1974 – 1986, and the lower INES scores per year following 1986 (with the exception of outlier 2011). This observation could refer to the learning curve associated with nuclear technology, claiming to make it a safer source of energy by learning from its mistakes (Kahouli, 2011).

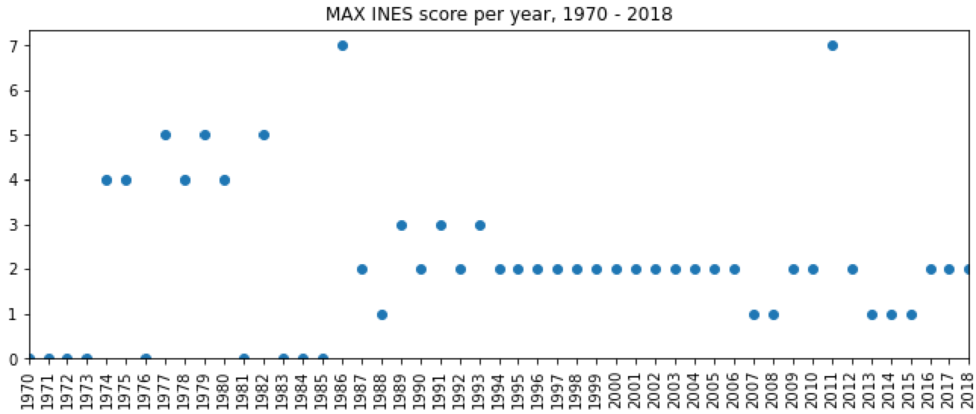

Figure 9: maximum global INES score per year

4.3.4 Nuclear energy production in GWh

Including the nuclear energy production allows for the examination of the effect of familiarity of nuclear energy on the public opinion. An important note is that Denmark is not included in figure 10 since Denmark did not adopt nuclear energy as an energy source until now, consequently no share of nuclear energy is present.

Figure 10 shows the difference in the production of the nuclear energy between The United Kingdom and The Netherlands. It is clear that The United Kingdom, having constructed 21 nuclear power plants, produces more nuclear energy than The Netherlands, having constructed 2 nuclear power plants. The construction of new power plants as from 1970 in The United Kingdom could explain the steep increase in energy production, and the closure of respectively 8 power plants in The United Kingdom, could explain the decrease in nuclear energy production after 1998. The two nuclear power plants in The Netherlands display a stable production of nuclear energy, with a small decrease in 1997 when one of the two plants was closed.

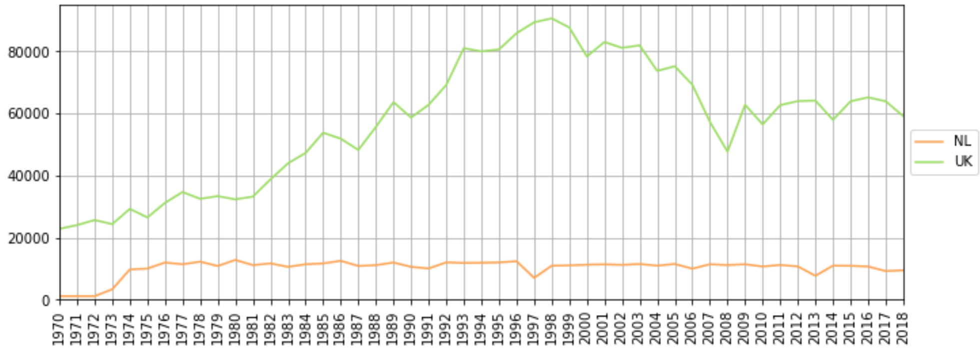

Figure 10: nuclear energy production in GWh per year for each country

4.3.5 Scientific publications related to nuclear energy

Publications related to nuclear energy are used to try to explain the knowledge of nuclear energy as a possible influence on the public opinion of nuclear energy.

Figure 10 shows the number of publications per year of all three countries. What seems interesting is that The United Kingdom seems to have the highest number of nuclear publications since the start of this period and was never caught up with, followed by The Netherlands and Denmark having the lowest number of publications. The relatively low number of publications of Denmark could be explained by the fact that Denmark did not adopt nuclear energy in the energy system.

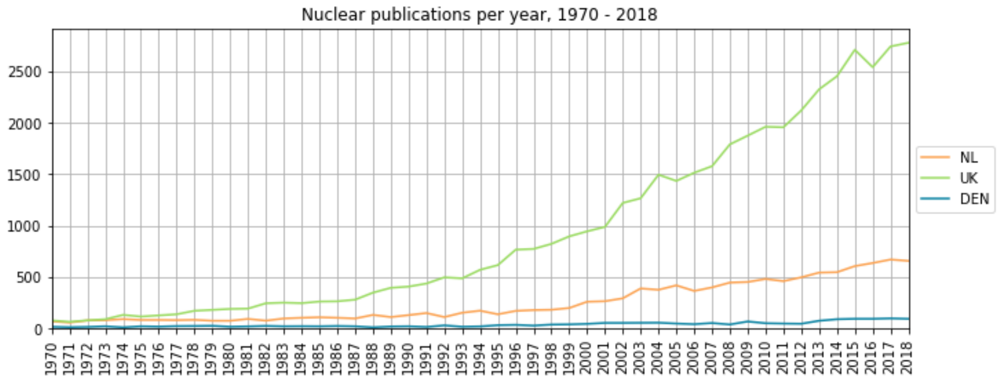

Figure 11: number of nuclear energy related publications per year for each country

4.3.6 Patents related to nuclear energy

The nuclear patents per year represents the knowledge associated to nuclear energy, similar to scientific publications but different in the practical application of knowledge. As can be seen in figure 12, Denmark is not present. This can be explained by the fact that there are no Danish nuclear patens available in the database of the European Patent Office (1998). What stands out in figure 12, is that the number of patents in The United Kingdom drops significantly after the year 1980. Further examination shows that for both The Netherlands and The United Kingdom, the highest number of patents were published between 1975 – 1980. This steep increase in patents is followed by a decline after 1980 for both countries, after which the number of patents did not reach the same number of patents as 1975 – 1980.

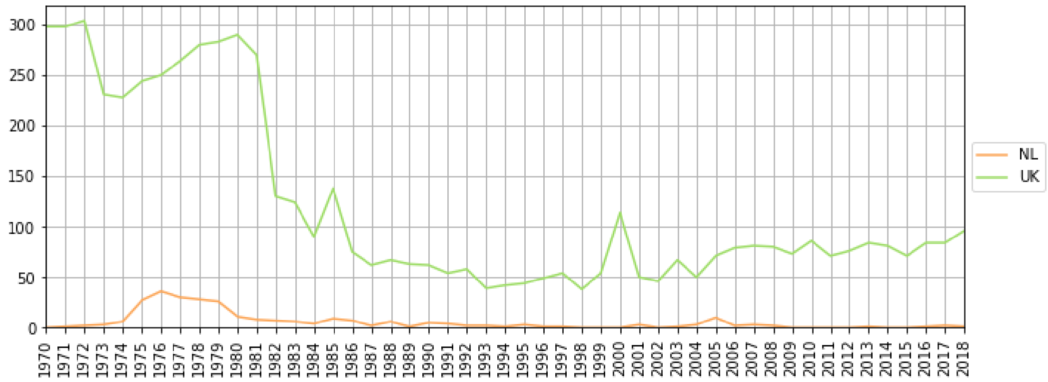

Figure 12: number of nuclear energy related patents per year for each country

4.3.7 Enrolment in tertiary education

To measure the level of trust in the scientific community and its experts, the number of people that enrolled in tertiary education was collected per country. In this study, the tertiary education is defined as higher education leading to the award of an academic degree.

Figure 13 shows that the enrolment number in tertiary education per year has increased gradually over the years. As mentioned before, average numbers could be better by means of comparison, but the goal of these variables is to examine the correlation with polarity.

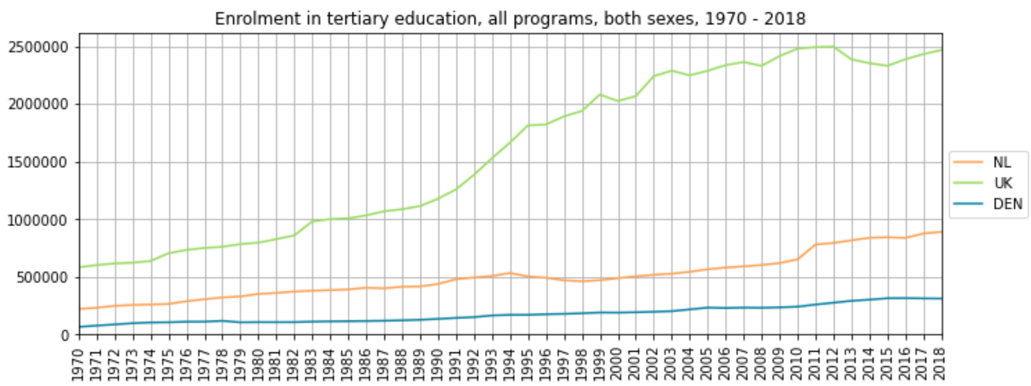

Figure 13: number of enrolled people in tertiary education per year for each country

4.4 Regression

The research question of this study is concerned with explaining the differences in public opinion in Europe over time. Having identified the public opinion by calculating the polarity and subjectivity scores over years, as an outcome of a collective process of debate in society as reflected in (mass) media with respect to the study of Glynn and Huge (2008), the next step is to explain these differences. As mentioned in the sentiment analysis chapter, both the polarity and subjectivity scores are centred around a stable value for the largest part of the period 1970 – 2018. This phenomenon provides a rather difficult starting ground for the success of a regression model, considering that a dynamic increase or decrease in values improves the probability of identifying a significant regression between variables. Nonetheless, this section builds upon the theory of linear regression in which the shape of the regression is the result of the ordinary least square method. Provided in the chapter descriptive statistics, there are six explanatory variables which take on the role of independent variables in the regression models. Furthermore, it was mentioned that that two of the explanatory variables could not be applied to Denmark because of the absence of such factors in the Danish economy.

4.4.1 Significance of differences between years

The relative stable development of the polarity scores per year for all three countries raised the question whether the scores are significantly different from each other, can these scores indeed be used in the regression model? In order to verify this, a significance test was employed by means of executing a one-way ANOVA on the polarity and subjectivity scores per country. The one-way ANOVA significance tests the statistical differences among two or more groups, but the data is required to be normally distributed. Therefore, a visualisation of the polarity and subjectivity score distribution per year and country was required to determine whether the data was normally distributed. To remind you of the construction of the polarity and subjectivity score data: each year contains a collection of polarity and subjectivity scores that are calculated from news articles published in that specific year, finally the mean of these scores is calculated to get the mean score per year. The histogram plots demonstrated that the polarity and subjectivity scores per year were indeed normally distributed, therefore the one-way ANOVA could be employed.

The hypotheses that were being tested for the polarity scores of all countries in the one-way ANOVA, were as follows:

- *Fail to Reject H_0: There is no difference between the polarity means in the period 1970 -2018.*
- *Reject H_0: There is a difference between the polarity means of one or more years in the period 1970 - 2018.*

The hypotheses that were being tested for the subjectivity scores of all countries in the one-way ANOVA, were as follows:

- *Fail to Reject H_0: There is no difference between the subjectivity means in the period 1970 -2018.*
- *Reject H_0: There is a difference between the subjectivity means of one or more years in the period 1970 - 2018.*

Examining the results from the one-way ANOVA test per country in table 4, demonstrates the significant differences between polarity and subjectivity scores per year for each country.

Table 4: table of one-way ANOVA polarity score results for each country

	The Netherlands	*United Kingdom*	*Denmark*
P-Value	**3.91e-19**	**1.09e-31**	**6.59e-05**
F Statistic	**4.02**	**5.58**	**1.98**
Critical F Value	**1.356**	**1.356**	**1.356**

Table 5: table of one-way ANOVA subjectivity score results for each country

	The Netherlands	*United Kingdom*	*Denmark*
P-Value	**2.88e-04**	**1.778e-03**	**0.0036**
F Statistic	**3.23**	**2.36**	**1.66**
Critical F Value	**1.356**	**1.356**	**1.356**

The differences between the years are significant if the p-value is < 0.05, and the F statistic is < the critical F value. For all countries, the results meet the requirements to reject the 0 hypothesis and therefore assume that there is a difference between the polarity means of one or more years in the period 1970 – 2018.

4.4.2 Correlations and multicollinearity

For each variable in each country that will be included in the regression model, the correlation with the dependent and independent variables has been examined using a correlation matrix (see appendix A). The correlation matrix illustrates any possible correlation between an independent variable and dependent variable, but also reveals what independent variables might correlate with each other which could lead to multicollinearity. Multicollinearity is the phenomenon of high correlations between two or more independent variables in a multiple regression model. Consequently, this could lead to false results because of wider confidence intervals that produce less reliable probabilities.

The correlation matrix in appendix A, B and C of each country indicates that almost certainly are independent variables correlating with each other, instead of exclusively correlating with the dependent variable. Therefore, it is necessary to further investigate the correlation between independent variables to exclude any multicollinearity present in the model. To measure the amount of multicollinearity in the set of independent variables per country, the variance inflation factor (VIF) was calculated with the dependent variable polarity. The VIF ratio for each independent variable is equal to the ratio of the overall model variance versus the variance of a model that only includes that single independent variable. A

VIF ratio larger than 4 indicates that the associated independent variable is highly collinear with the other independent variables in the regression model, causing multicollinearity.

Table 6: VIF values of the independent explanatory variables for each country

	The Netherlands	*United Kingdom*	*Denmark*
Total energy consumption PJ (VIF)	**39.1**	**3.5**	**13.3**
Nuclear electricity production (VIF)	**29**	**8**	**N /A**
Nuclear patents (VIF)	**2.5**	**5**	**N/A**
Nuclear publications (VIF)	**28.7**	**30**	**27.7**
Max INES score (VIF)	**3.3**	**1.1**	**2.8**
Enrolment in tertiary education (VIF)	**133.4**	**42.5**	**48.3**
OCC in $ per kilowatt of capacity (VIF)	**15.7**	**1.9**	**12.3**

The VIF ratios in table 6 indicate the presence of multicollinearity among a large number of independent variables for all three countries. Considering that VIF ratios larger than 4 indicate multicollinearity, it is evident that the largest share of the independent variables for each country are multi-collinear. Correcting multicollinearity can be done in different ways such as combining variables, performing LASSO regression, or removing some of the highly correlated independent variables. In light of the research question that is concerned with explaining the differences in public opinion, polarity scores, it is necessary to examine the effect of each independent variable on the polarity scores. Therefore, it is not possible exclude variables from the model, combine variables. Employing a LASSO regression could be possible but complex solution, the best solution for dealing with multicollinearity in this context is to conduct univariate regressions for each individual independent variable. The construction of a univariate regression per individual variable excludes the possibility of multicollinearity, is fairly simple and still allows for the examination of the effect of that variable on the polarity score.

4.4.3 Univariate regression Polarity score

For every individual independent variable, a univariate regression was employed to measure the effect on the dependent variable polarity score. To summarize the results of the univariate regression models for each individual independent variable, table 7, 8 and 9 were constructed using the P-value, Coefficient, and R^2 of each model. The univariate regression was calculated using the ordinary least squared error (OLS) method because then the outputs of the regression (coefficients) are unbiased estimators of the real values of alpha and beta. To determine the significance of the model, the confidence level, α, was set to 0.05.

Important to note is that for Denmark only 5 individual univariate regression models could be constructed because 2 independent variables (Nuclear electricity production & Nuclear patents) are not present in the Danish economy. For each table, the bold P-values indicate a value that is $< \alpha$ 0.05 and thus are significant.

Table 7: Univariate Regression results for polarity score, The Netherlands

Independent variable (/10.000)*	*P-Value*	*Coefficient*	*R²*
Total energy consumption in PJ	0.169	-0.077	0.040
Nuclear electricity production in GWh	**0.045**	-0.014	0.083
Nuclear patents	0.975	0.072	0.000
Nuclear publications	0.636	0.049	0.005
MAX INES score	0.431	-0.0009	0.013
Enrolment in tertiary education	0.921	-0.000010	0.000
OCC in $ per kilowatt of capacity	0.307	0.021	0.022

Table 8: Univariate Regression results for polarity score, The United Kingdom

Independent variable (/10.000)	*P-Value*	*Coefficient*	*R²*
Total energy consumption in PJ	**0.004**	-0.08	0.163
Nuclear electricity production in GWh	**0.000**	-0.0035	0.319
Nuclear patents	**0.001**	0.66	0.222
Nuclear publications	0.697	0.0083	0.003
MAX INES score	0.231	-0.0013	0.030
Enrolment in tertiary education	0.144	-0.000037	0.045
OCC in $ per kilowatt of capacity	0.093	0.032	0.059

Table 9: Univariate Regression results for polarity score, Denmark

Independent variable (/10.000)	*P-Value*	*Coefficient*	*R²*
Total energy consumption in PJ	0.266	0.5287	0.026
Nuclear publications	0.697	-2.5589	0.003
MAX INES score	0.231	-0.0013	0.030
Enrolment in tertiary education	0.144	-0.0010	0.045
OCC in $ per kilowatt of capacity	0.093	-0.0308	0.059

**All independent variables, with the exception of MAX INES Score per year, have been divided by 10,000 to normalize the coefficient values.*

Table 7 shows that there is only one possible statistically significant relationship between an independent variable and polarity score for The Netherlands: *Nuclear electricity production in GWh*. This P-value of this variable is less than then the confidence level of 0.05, indicating that there is a statistically significant relationship between the term and the response. The associated coefficient of nuclear electricity production implies that with one unit increase in nuclear electricity production in GWh, the expected value of polarity score decreases by -0.014. The small size of this coefficient is explained by the fact that the range of the dependent variable polarity score is centred around 0.075 as visualised in the sentiment analysis. The associated R^2 value is relatively low, representing a model that explains 8% of the variation in the polarity score around the mean.

The P-values of univariate regression model for The United Kingdom in table 8 show that out of the 7 tested independent variables, there are 3 that indicate a significant relationship with dependent variable polarity score. The first independent variable indicating a significant relationship with polarity score is *Total energy consumption in PJ*, having a p-vale of 0.04. The associated coefficient of total energy consumption implies that with one unit increase in total energy consumption in PJ, the expected value of polarity score decreases by -0.08. The R^2 of the total energy consumption univariate regression model indicates that 16.3% of the variation in the polarity score can be explained by the total energy consumption in PJ. Considering the research context, this value can be interpreted as acceptable. In conclusions: these findings present an acceptable, negative significant relationship between the total energy consumption in PJ and polarity score in The United Kingdom.

The second variable showing a significant relationship with polarity score, is *Nuclear electricity production* in GWh, having a P-value of 0.000. As for the case of the Netherlands, there is negative significant relationship between the nuclear electricity production in GWh and polarity score in The United Kingdom, where one unit increase in nuclear electricity production in GWh, decreases the expected value of polarity score by -0.0035.

Finally, it shows that the variable *Nuclear patents* has a significant relationship with polarity score with a P-value of 0.001. To sum up the findings of the univariate regression model of the nuclear patens in The United Kingdom: there is an positive significant relationship between the number of patents and the polarity score in The United Kingdom, indicating that with one unit increase in nuclear patents, the expected value of polarity score increases by 0.66.

The P-values of Denmark in table 9 show that there are no independent variables having a significant relationship with polarity score in Denmark. This is the only country of all three, in which there is no single independent variable having a significant relationship with the polarity score.

4.4.4 Univariate regression Subjectivity score

Besides examining the possible relationships between the explanatory variables and the polarity scores, we will also look into the possible relationships between the explanatory variables and the subjectivity scores. Doing so will allow us the find out whether there are any explanatory variables within our set, that are able to significantly influence the ratio between subjectivity and objectivity presence in a news article. Similar to the univariate regression models for polarity score, we have constructed individual univariate regressions in order to prevent multicollinearity from influencing the results. To determine the significance of the model, the confidence level, α, was set to 0.05.

Table 10: Univariate Regression results for subjectivity score, The Netherlands

Independent variable (/10.000)*	*P-Value*	*Coefficient*	*R^2*
Total energy consumption in PJ	0.068	-0.1288	0.069
Nuclear electricity production in GWh	0.072	-0.0159	0.067
Nuclear patents	0.089	4.8343	0.060
Nuclear publications	0.247	-0.1515	0.028
MAX INES score	0.538	-9.1294	0.008
Enrolment in tertiary education	0.062	-0.0002	0.072
OCC in $ per kilowatt of capacity	0.406	0.0221	0.015

Table 11: Univariate Regression results for subjectivity score, The United Kingdom

Independent variable (/10.000)*	*P-Value*	*Coefficient*	*R^2*
Total energy consumption in PJ	**0.007**	-0.0823	0.144
Nuclear electricity production in GWh	**0.001**	-0.0029	0.205
Nuclear patents	**0.011**	0.5149	0.130
Nuclear publications	0.758	0.0067	0.002
MAX INES score	0.980	-0.2778	0.000
Enrolment in tertiary education	0.200	-0.000033	0.035
OCC in $ per kilowatt of capacity	0.071	0.0353	0.068

Table 12: Univariate Regression results for subjectivity score, Denmark

Independent variable (/10.000)*	*P-Value*	*Coefficient*	*R^2*
Total energy consumption in PJ	0.665	-0.4043	0.004
Nuclear publications	0.253	-2.8304	0.028
MAX INES score	0.994	0.2495	0.000
Enrolment in tertiary education	**0.041**	-0.0017	0.086
OCC in $ per kilowatt of capacity	0.937	0.0052	0.000

The table 10 provides the most important results from the univariate regression models for The Netherlands. What stands out is that there are no explanatory variables that seem to significantly influence the dependent variable subjectivity score. In other words: the ratio between subjectivity and objectivity presence in the collected news articles related to nuclear energy in The Netherlands, is not influenced significantly by any of these 7 explanatory variables.

The results of the univariate regression models for The United Kingdom can be found in table 11. Contrary to The Netherlands, there are in fact 3 explanatory variables that seem to significantly influence the ratio of subjectivity and objectivity presence in the news articles related to nuclear energy in The United Kingdom. The first explanatory variable with a significant relationship with the subjectivity score is *Total energy consumption in PJ*, with a P-value of 0.007 which is < 0.05. The associated coefficient is -0.0823 which, taking the division of 10.000 for normalization of the coefficient values into account, implies that for every 10.000 increase in total energy consumption in PJ, the polarity score decreases with -0.0823. The R^2 of the total energy consumption univariate regression model indicates that 16.3% of the variation in the subjectivity score can be explained by the total energy consumption in PJ. Considering the research context, this value can be interpreted as acceptable. In conclusions: these findings present an acceptable, negative significant relationship between the total energy consumption in PJ and subjectivity score in The United Kingdom.

The second explanatory with a significant relationship with the subjectivity score is the *Nuclear electricity production in GWh*, with a P-value of 0.001 which is <0.05. The associated coefficient implies that for every 10.000 increase in nuclear electricity production in GWh, the subjectivity score decreases with -0.0029. The associated R^2 value of 0.205, indicates that 20.5% of the variation in the subjectivity score can be explained by the nuclear electricity production in GWh. Considering the research context, this value can be interpreted as acceptable. All findings of this explanatory variable combined seem to present an acceptable, negative significant relationship between the nuclear electricity production in GWh, and the subjectivity score.

The final significant relationship between an explanatory variable and the subjectivity score in The United Kingdom is *Nuclear patents*, with a P-value of 0.011 that is < 0.05. The associated coefficient implies that for every 10.000 increase in number of patents, the subjectivity score increases with 0.5149. The R^2 value of this relationship indicates 13% of the variation in the polarity score can be explained by the number of patents. Considering the research context, this is an acceptable percentage. To sum: there is a positive, significant relationship between the number of patents and the subjectivity score.

Finally, table 12 shows that for Denmark there is 1 explanatory variable indicating a significant relationship with the subjectivity score. The relationship between *Enrolment in tertiary education* and the subjectivity score is significant with a P-value of 0.041 which is < 0.05. The associated coefficient is -0.0017, implying that for every 10.000 increase in number of enrolled people in tertiary education, the subjectivity score decreases with -0.0017. The R^2 however, implies a poor and unacceptable explanation of the variance in subjectivity by the enrolment in tertiary education: 0.086. Therefore, this negative signification relationship between enrolment in tertiary education and subjectivity score will be regarded as unacceptable because of the low R² score of 8.6%.

4.4.5 Univariate regression number of news articles

Apart from the sentiment scores, we can also look at the total number of newspaper articles devoted to nuclear energy in each year and in each country. This variable indicates the intensity of the public debate. To summarize the results of the univariate regression models for each country, a table was constructed using the P-value, Coefficient, and R² of each model. The univariate regression was calculated using the ordinary least squared error (OLS) method because then the outputs of the regression (coefficients) are unbiased estimators of the real values of alpha and beta. To determine the significance of the model, the confidence level, α, was set to 0.05.

Important to note is that for Denmark only 5 univariate regression models could be constructed because 2 independent variables (Nuclear electricity production & Nuclear patents) are not present in the Danish economy.

Having examined the trend of the number of publications of nuclear energy related news articles, a univariate regression per independent variable and number of articles as dependent variable will be conducted. Choosing a univariate regression per independent variable over constructing a multiple regression models is motivated by the continued presence of multicollinearity.

Table 13: Univariate Regression results for number of articles, The Netherlands

Independent variable	*P-Value*	*Coefficient*	*R²*
Total energy consumption in PJ	**0.001**	-0.3649	0.212
Nuclear electricity production in GWh	0.124	0.0220	0.050
Nuclear patents	**0.000**	19.2723	0.367
Nuclear publications	**0.002**	-0.6329	0.190
MAX INES score	**0.015**	56.7832	0.120
Enrolment in tertiary education	**0.007**	-0.0006	0.144
OCC in $ per kilowatt of capacity	0.690	0.0172	0.003

Table 14: Univariate Regression results for number of articles, The United Kingdom

Independent variable	*P-Value*	*Coefficient*	*R²*
Total energy consumption in PJ	**0.037**	-0.0611	0.090
Nuclear electricity production in GWh	**0.000**	-0.0040	0.457
Nuclear patents	**0.000**	0.9028	0.449
Nuclear publications	**0.000**	-0.0845	0.367
MAX INES score	0.164	14.3708	0.041
Enrolment in tertiary education	**0.000**	-0.0001	0.533
OCC in $ per kilowatt of capacity	0.951	-0.0012	0.000

Table 15: Univariate Regression results for number of articles, Denmark

Independent variable	*P-Value*	*Coefficient*	*R²*
Total energy consumption in PJ	**0.024**	0.4042	0.104
Nuclear publications	**0.000**	-1.7519	0.274
MAX INES score	**0.014**	16.8772	0.121
Enrolment in tertiary education	**0.000**	-0.0006	0.324
OCC in $ per kilowatt of capacity	0.372	-0.0114	0.017

Table 13 shows that there are 5 independent variables in The Netherlands of which there seems to be a significant relationship with the dependent variable number of articles. First, there is the *Total energy consumption in PJ* with a p-value of 0.001. The associated coefficient is -0.3649, implying that with one unit increase in total energy consumption in PJ, the expected value of number of news articles related to nuclear energy decreases by -0.3649. The R^2 of this univariate regression model has a value of 0.212, indicating that 21.2% of the variation in the number of news articles related to nuclear energy can be explained by the total energy consumption in PJ. Considering the research context, this is an acceptable value.

The second significant independent variable is the *Nuclear patents* with a P-value of lower than 0.000, indicating a strong significance. The associated coefficient value is 19.2723, implying that with one unit increase in nuclear patents, the expected value of number of news articles related to nuclear energy increases by 19.2723. The R^2 of this univariate regression model has a value of 0.367, indicating that 36.7% of the variation in the number of news articles related to nuclear energy can be explained by the total energy consumption in PJ. Considering the research context, this is an acceptable value.

The third significant independent variable is *Nuclear publications*, with a P-value of 0.002. The associated coefficient value is -0.6329, implying that with one unit increase in nuclear patents, the expected value of number of news articles related to nuclear energy decreases by -0.6329. The R^2 of this univariate regression model has a value of 0.190, indicating that 19% of the variation in the number of news articles related to nuclear energy can be explained by the nuclear publications. Considering the research context, this is an acceptable value.

The fourth significant independent variable is the *MAX INES score per year*, with a P-value of 0.015. The associated coefficient value is 56.7832, implying that with one unit increase in nuclear patents, the expected value of number of news articles related to nuclear energy increases by 56.7832. The R^2 of this univariate regression model has a value of 0.120, indicating that 12% of the variation in the number of news articles related to nuclear energy can be explained by the MAX INES score per year. Considering the research context, this is an acceptable value.

The final significant independent variable for The Netherlands is *Enrolment in tertiary education*, with a P-value of 0.007. The associated coefficient value is -0.0006, implying that with one unit increase in nuclear patents, the expected value of number of news articles related to nuclear energy increases by -0.0006. The R^2 of this univariate regression model has a value of 0.144, indicating that 14.4% of the variation in the number of news articles related to nuclear energy can be explained by the enrolment in tertiary education. Considering the research context, this is an acceptable value.

Table 14 shows that, similar to The Netherlands, there are 5 independent variables in which there seems to be a significant relationship with the dependent variable number of articles. First, there is the *Total energy consumption in PJ* with a p-value of 0.037. The associated coefficient is -0.0611, implying that with one unit increase in total energy consumption in PJ, the expected value of number of news articles related to nuclear energy decreases by -0.0611. The R^2 of this univariate regression model has a value of 0.090, indicating that 9% of the variation in the number of news articles related to nuclear energy can be explained by the total energy consumption in PJ. Considering the low value of < 10% this is considered to be insufficient to be an acceptable value of R^2.

The second significant independent variable is the *Nuclear electricity production in GWh* with a P-value lower than 0.000, indicating a strong significance. The associated coefficient value is -0.0040, implying that with one unit increase in nuclear electricity production in GWh, the expected value of number of news articles related to nuclear energy decreases by –0.0040. The R^2 of this univariate regression model has a value of 0.457, indicating that 45.7% of the variation in the number of news articles related to nuclear energy can be explained by the nuclear electricity production in GWh. Considering the research context, this is an acceptable value.

The third significant independent variable is the *Nuclear patents*, also having a P-value lower than 0.000, indicating a strong significance. The associated coefficient value is 0.9028, implying that with one unit increase in nuclear patents, the expected value of number of news articles related to nuclear energy increases by 0.9028. The R^2 of this univariate regression model has a value of 0.449, indicating that 49.9% of the variation in the number of news articles related to nuclear energy can be explained by the nuclear patents. Considering the research context, this is an acceptable value.

The fourth significant independent variable is the *Nuclear publications*, also having a P-value lower than 0.000, indicating a strong significance. The associated coefficient value is -0.0845, implying that with one unit increase in nuclear patents, the expected value of number of news articles related to nuclear energy decreases by -0.0845. The R^2 of this univariate regression model has a value of 0.367, indicating that 36.7% of the variation in the number of news articles related to nuclear energy can be explained by the nuclear publications. Considering the research context, this is an acceptable value.

The final significant independent variable for The United Kingdom is *Enrolment in tertiary education*, also having a P-value lower than 0.000, indicating a strong significance. The associated coefficient value is -0.0001, implying that with one unit increase in enrolment in tertiary education, the expected value of number of news articles related to nuclear energy decreases by –0.0001. The R^2 of this univariate regression model has a value of 0.533, indicating that 53.3% of the variation in the number of news articles related to nuclear energy can be explained by the enrolment in tertiary education. Considering the research context, this is an acceptable value.

Table 15 shows that for Denmark there are 4 independent variables in which there seems to be a significant relationship with the dependent variable number of articles. First, there is the *Total energy consumption* in PJ with a p-value of 0.024. The associated coefficient is 0.4042, implying that with one unit increase in total energy consumption in PJ, the expected value of number of news articles related to nuclear energy increases by 0.4042. The R^2 of this univariate regression model has a value of 0.104, indicating that 10.4% of the variation in the number of news articles related to nuclear energy can be explained by the total energy consumption in PJ. Considering the research context, this is an acceptable value.

The second significant independent variable is *Nuclear publications* with a P-value lower than 0.000, indicating a strong significance. The associated coefficient value is -1.7519, implying that with one unit increase in nuclear publications, the expected value of number of news articles related to nuclear energy decreases by –1.7519. The R^2 of this univariate regression model has a value of 0.274, indicating that 27.4% of the variation in the number of news articles related to nuclear energy can be explained by the nuclear publications. Considering the research context, this is an acceptable value.

The third significant independent variable is *MAX INES score per year*, having a P-value of 0.014. The associated coefficient value is 16.8772, implying that with one unit increase in nuclear patents, the expected value of number of news articles related to nuclear energy increases by 16.8772. The R^2 of this univariate regression model has a value of 0.121, indicating that 12.1% of the variation in the number of news articles related to nuclear energy can be explained by the MAX INES score. Considering the research context, this is an acceptable value.

The final significant independent variable for Denmark is *Enrolment in tertiary education*, also having a P-value lower than 0.000, indicating a strong significance. The associated coefficient value is -0.0006, implying that with one unit increase in enrolment in tertiary education, the expected value of number of news articles related to nuclear energy decreases by –0.0006. The R^2 of this univariate regression model has a value of 0.324, indicating that 32.4% of the variation in the number of news articles related to nuclear energy can be explained by the enrolment in tertiary education. Considering the research context, this is an acceptable value.

In all, compared to results of the univariate regression models that have been constructed for the polarity and subjectivity scores, there seem to be far more significant relationships between the explanatory variables and number of news articles related to nuclear energy per year as dependent variable. What stands out is that the explanatory variable MAX INES score per year has a positive significant relationship with the number of news articles related to nuclear energy in both The Netherlands and Denmark, but not in The United Kingdom. This difference between the two countries, which both adopted nuclear energy technology albeit to a different extent, is particularly interesting. We reflect on this finding below.

5 Conclusion

This study identified and explained the differences in public opinion on nuclear energy in The Netherlands, The United Kingdom and Denmark between 1970 - 2018. We considered the public opinion not as an aggregate of privately held opinions, but as the outcome of a social process among different groups in the media. The assumption that public opinion would serve as a possible predictor for the public acceptance and government decision to adopt nuclear energy, was built upon the theoretical notion that public acceptance is the outcome of a collective process of debate in society as reflected in mass media. The public opinion on nuclear energy in these three countries was examined by the quantification of three important aspects of public opinion: emotion, subjectivity/objectivity and the level of attention addressed to the topic nuclear energy.

Contrary to expectations, the polarity values representing the positive and negative emotions present in the news articles, displayed a rather stable development over the period 1970 – 2018. The polarity scores of these three countries varied from 0.0 to 0.125, which represents only a small part of the entire polarity scale, -1/+1, used to indicate a positive or negative emotion in a text. This may be interpreted such that the average emotions related to nuclear energy in the period 1970 – 2018 tend to be neutral or slightly positive, but a more likely assumption is that newspapers in general are very neutral in emotion when reporting the news. The overall neutral polarity score as found in newspapers, was also discovered in studies on other topics that employed sentiment analysis on newspaper articles. This stable and neutral development of the polarity score for each country, makes it more difficult to find any significant relationships between the explanatory variables of public opinion and the polarity scores related to the public opinion. Despite the stable neutral/slightly positive development of the polarity scores in this period, one finding stood out: *Nuclear electricity production* proved to have a significant relationship with the polarity scores in the two countries (The Netherlands and UK) that actually adopted nuclear energy technology (this variable could thus not be included in the analysis for Denmark). As opposed to a previous study (Eiser & Pligt, 1979) about the positive relationship of familiarity with nuclear energy and the emotion attached to nuclear energy, the univariate regression models for both The Netherlands and The United Kingdom returned a negative relationship between this explanatory variable representing familiarity, nuclear electricity production, and the polarity score. This implies that as a country produces more nuclear electricity and therefore becomes more familiar with the nuclear energy technology, the public seems to display a more negative emotion to nuclear energy. The notion of 'Not In My Backyard' (NIMBY) by Dear (1992) could provide a possible explanation for this outcome. The NIMBY theory describes the protectionists attitudes of community groups facing an unwanted development in their neighbourhood such as a nuclear facility. In the context of the negative relationship between nuclear electricity production and the polarity score, it could well be that the increase of nuclear energy production and the associated new nuclear power plants are regarded as a possible threat for the neighbourhood of community groups, resulting in a negative attitude towards nuclear energy.

The second aspect of public opinion that was examined, is the subjectivity/objectivity ratio contained in the news articles related to nuclear energy. While the subjectivity score for all three countries proved to be even more stable than the polarity scores during the period 1970 – 2018, there were nevertheless three explanatory variables, in The United Kingdom, having a significant relationship with the subjectivity score. Interestingly, the significant variables for subjectivity are identical to the significant variables for polarity with corresponding negative and positive relationships: total energy consumption (negative), nuclear electricity production (negative), and nuclear patents (positive). It is expected that the explanation for the type of relationship for each significant explanatory variable for subjectivity, is similar to the variables for polarity. However, to clarify that explanation for this context, it seems that explanatory variables (total energy consumption, nuclear electricity production) which were linked to negative emotions in the previous polarity section, in the subjectivity section are expected to provoke more objectivity. On the other hand, the explanatory variable (nuclear patent) that was linked to positive emotions in the polarity section, in the subjectivity section is expected to provoke more subjectivity. This information tells us that in The United Kingdom, both the positive emotion and subjectivity attached to public opinion on nuclear energy increases with a rise in the number of nuclear patents.

The third and final examined aspect of public opinion on nuclear energy is the attention addressed to nuclear energy, measured by the number of news articles related to nuclear energy. Contrary to the polarity and subjectivity scores, the number of nuclear energy related articles per country varied considerably per year in the period 1970-2018. Consequently, the possibility of significant linear relationships between explanatory variables and the dependent variable increased. This was reflected in the results of the univariate regressions, which showed that for each country, at least four explanatory variables correlated significantly with the number of articles related to nuclear energy. Since there are so my significant explanatory variables, only the most important results will be discussed. While there seems to be an ongoing debate in the scientific community about the costs of nuclear energy, there is no evidence in this study that the costs of nuclear energy has any influence on the attention of nuclear energy in the newspapers. The results of the univariate regressions return no significant relationship between the construction costs of nuclear energy plants and the number of nuclear energy related news articles for any of the three countries. In the meanwhile, there is one explanatory variable that has shown to have a significant relationship with the number of articles in two countries and simultaneously has obtained the largest coefficient value: *MAX INES score per year*. The associated coefficient was 19.27 in The Netherlands, and 16.87 in Denmark, meaning that for every increase in INES score, the number of articles increase with respectively 19 and 16 in a year. Since for both The Netherlands and Denmark this is the explanatory variable with the greatest coefficient value, we can say that the associated significance of nuclear events according to the INES scale, has the largest influence on the attention that is addressed to nuclear energy in newspapers. However, what remains to be explained is the fact that the MAX INES score per year does not have a significant relationship with attention in The United Kingdom. A possible explanation for this phenomenon could be that the public opinion is not influenced significantly in The United Kingdom, because of its favourable attitude towards nuclear energy since 1970. Where Denmark and The Netherlands each can be seen as respectively an opponent and doubter of nuclear energy, The United Kingdom has been and still is, a supporter of nuclear energy. Consequently, an already convinced supporter of nuclear energy, is less prone to the public insecurities that come with the occurrence of nuclear events. On the other hand, the public aversion against nuclear energy will only grow stronger if nuclear energy proves to be faulty by the occurrence of a nuclear event. The same principle goes for the doubting attitude of The Netherlands: if a nuclear event occurs, it seems reasonable that such a country is more likely to give up on nuclear energy instead of promoting it.

This brings us to the final part of the conclusion of this study. We have seen that the emotion of all three countries in the news articles, as represented by the polarity score, tends to be neutral or slightly positive in the full period 1970 – 2018. No major increases or decreases in polarity scores were displayed for any of the three countries, while in the meantime, it was expected at the start of this study that the polarity scores between countries would illustrate significant differences in the emotional aspect of public opinion on nuclear energy between these three countries. The same result was revealed for the subjectivity scores between countries: it proved to be a relative stable score throughout the complete period 1970 – 2018. Until now there were no insights that explained the differences in public opinion between these three countries. That was until we examined the results of the univariate regression models including the number of articles per year as a dependent variable. The MAX INES scores per year which is linked to the perceived risks of nuclear energy, uncovered that the higher the impact of a nuclear event on society, the more news articles related to nuclear energy are published. So much even that there is a gap between the coefficient value of MAX INES score per year and the second largest significant variable in Denmark, of 13 articles. Considering that the MAX INES score per year has a significant relationship with the number of nuclear energy related news articles in both Denmark and The Netherlands but not in The United Kingdom, brings us to final conclusion of this study: it is not the emotion or level of subjectivity that influences the public opinion on nuclear energy, but the topic of the news articles, and especially the topics related to the perceived risks of nuclear energy. To clarify: if a higher MAX INES score means that considerably more nuclear energy related news articles are published, we can safely assume that those published news articles cover the associated nuclear events. And if primarily news articles covering the dangerous nuclear events are published, it is no surprise that for opposing and doubting countries, such as Denmark and The Netherlands, it is very hard to completely accept nuclear energy due to the higher sensitivity for perceived risks of nuclear energy. On the other hand, the public opinion of supporting countries of nuclear energy such as The United Kingdom, are less likely to be affected by the perceived risks of nuclear energy and compromise the existing public acceptance of nuclear energy.

6 Discussion

6.1 Theoretical implications

This study contributes to the literature on nuclear energy policy and innovation by examining the differences in public opinion on nuclear energy and explain how these differences could help understand the contrast in public acceptance of nuclear energy in Europe. First, we identified the existing theories that examined the public acceptance of nuclear energy and found that there are many different theories in the scientific community, but no consensus. The multitude of research efforts to understand the concept of public acceptance illustrated the complex nature of this phenomenon and led to the construction of a framework that combined the best practises of the public opinion and acceptance theories. We identified that public acceptance in the context of nuclear energy, can best be considered as an aggregate of the perceived positive changes to the living standards of individuals in a community because of the introduction of nuclear energy. Second, we have designed a framework that explained the formation of public acceptance. We found that public opinion and public acceptance are inextricably connected, in which the public opinion influences each of the three dimensions of public acceptance (*socio-political acceptance, market acceptance and community acceptance*) via 4 main factors of public opinion. The first main factor being the *perceived benefits of nuclear energy*, which refers to the perception of consequences that are associated with a recommended course of action. This main factor in turn, is composed of 2 sub-factors: *perceived energy benefits; perceived economic benefits*. The second main factor influencing public acceptance is the *perceived risks of nuclear energy*, explaining the perception of the safety of nuclear energy. This main factor includes one sub-factor: *perceived operation risks*. The third main factor influencing the public acceptance is the *perceived knowledge* of nuclear energy and refers to the public understanding of nuclear energy and has two sub-factors: *perceived understanding of nuclear energy* and *self-assessed familiarity with nuclear energy*. The final main factor in the framework of public opinion and acceptance of nuclear energy, is the *perceived trust in the parties associated with nuclear energy projects*. This main factor consists of the sub-factor *perceived trust* in nuclear experts.

This framework allows for the examination of public opinion, and consequently public acceptance, using a method that does not include any surveys. This is of value because the traditional method of examining public opinion and public acceptance was almost exclusively addressed by employing surveys. However, surveys provide a static and individualistic impression of the attitude towards a topic, while public opinion is the outcome of a collective process of a debate in society as reflected in mass media and thus dynamic.

The final theoretical contribution of this research is concerned with the semantic analysis on more than 20,000 news articles related to nuclear energy that represented the public opinion between 1970 – 2018. Based on the existing energy policy and innovation literature, it can be said that the public opinion and public acceptance of nuclear energy has not yet been examined via such an extensive semantic analysis over such a long time period. Doing so, allowed us to discover that it is not so much the sentiment in mass media that influences the public opinion and acceptance of nuclear energy, but the habit of the media to significantly publish more news articles as soon as nuclear events have occurred, in which also the intensity of the nuclear event plays an important role. Furthermore, this analysis found that because of this phenomenon, it seems almost impossible for countries that never obtained sufficient public acceptance of nuclear energy, to increase the level of public acceptance so much that adoption or considerable expansion of nuclear could become reality. Although not directly derived from this research, related to policy implications, this insight could indicate that European countries desperately wanting to increase their nuclear energy program but do not have sufficient public acceptance to do so, are better off to find different means of energy production because chances are that the public will turn against those nuclear plans as soon as sufficient nuclear events with a high INES score occur.

6.2 Limitations

In this research, a unique data set was constructed which enabled the analysis of the public opinion and acceptance between 1970 – 2018 for three European countries. However, some caution should be taken with the interpretation of the polarity and subjectivity scores. While the large data set of such an extensive period is unique, it also has its disadvantages when it comes to data quality. When it comes to cleaning and verifying the collected news articles for their relatedness with nuclear energy, it had to be done via algorithms that treated all the news articles the same way. However, in a data set with more than 20,000 articles, it could be that some articles are not caught via the cleaning algorithms and thus contaminate the polarity and subjectivity scores. Consequently, it could be that the average polarity or subjectivity score for a specific year, is calculated using unrelated and corrupted news articles, returning a polarity or subjectivity score that does not represent the true sentiment in that year.

Related to this, is the limitation of the available national newspapers per country with a searchable news article archive with full availability of all years 1970 – 2018. Because we were forced to select the newspapers per country that had such an archive, the selected newspapers do not represent the full political spectrum. Consequently, the results of this study do not represent the complete society and therefore the results are less generalizable.

Similar limitation is concerned with the selection of the European countries in this study. While The Netherlands, The United Kingdom and Denmark are an accurate representation of the possible participants in the European nuclear energy debate, we still were limited to these three countries because of the availability of the required newspaper archives per country. Countries such as France or Germany did not have the required collection of newspaper articles to conduct a sensible sentiment analysis on. Since only 3 of the 27 European Union member states were examined, the generalizability towards Europe is lower than expected.

Another limitation of this study is the calculation of the polarity and subjectivity scores representing the public opinion. The "*TextBlob*" algorithm was used for the calculation of the polarity and subjectivity scores, while this is an advanced lexicon-based algorithm for sentiment analysis, it has its limitations. These limitations concern the concept of sentiment analysis and the fact that these algorithms are computer programs and not humans. Algorithms like this have problems recognizing concepts like sarcasms and irony, negations, jokes and exaggerations, things a human would have little trouble identifying.

Failing to identify these concepts can skew the results, resulting in polarity and subjectivity scores that are a not an accurate reflection of the reality and thus causing poor external validity.

The final limitation of this study is that it is the first study that utilizes the relative new method of sentiment analysis to research the public opinion and public acceptance of a topic. Therefore, it was difficult to verify the results of this study with results from other studies. Despite conducting an extensive literature research in which the most relevant existing studies concerned with public opinion, public acceptance and sentiment analyses were examined, misinterpretation of data and concepts might have occurred in this study.

6.3 Suggestions for further research

This study revealed the possibility of examining the concepts of public opinion and public acceptance of a controversial technology in a dynamic way via sentiment analysis, rather than the static and the traditional method of employing surveys. While not perfect, sentiment analysis allows for the examination of the public opinion of any technology, in any given time, as long as there is sufficient text available to be analysed. However, as this study has shown, it is difficult to collect a news articles from a large number of newspapers and countries. Therefore, future research on the topic of public opinion of nuclear energy, could benefit from a more diverse collection of news articles collected from more than three countries. Including countries such as France, Germany or Belgium is expected to further support the findings of this research, in which it is suggested that the topic of news articles is more important than the sentiment when influencing the public opinion of nuclear energy. France for example is a country in which nuclear energy has a share of 70% in the total energy production, which could provide insights the process of forming a public opinion, in a country that is an extreme supporter of nuclear energy.

Another suggestion would be to include more news media that contain different levels of subjectivity, and consequently polarity. People tend to be exposed to more types of media than exclusively newspaper articles, one might expect that including a more complete range of news media, would reveal a different development of public opinion of nuclear energy. For example, as demonstrated in this study, newspapers are relatively objective in character when portraying the news. However, other types of media might be more subjective in character when portraying the news, in particular social media like Twitter, which in turn could influence the public opinion in a different way then we have expected, shedding a new light on the conclusion of subject over sentiment in this study. Obviously, using social media data would mean that the only a relatively short period of time can be investigated given that social media only emerged around the mid-2000s.

The final suggestion for further research is a more technical one. The current sentiment analysis builds upon a pre-built python sentiment library called "*TextBlob". This library builds upon the constructs of traditional sentiment analysis, which returns the overall sentiment of a whole text document. This is a relatively simple method of calculating the sentiment for a text and can be applied on almost any text but is not very accurate. The news articles related to nuclear energy in this study were selected based on required presence of the words 'nuclear-energy', however, the "*Textblob"* algorithm does not calculate the sentiment towards the words ‘nuclear-energy’ specifically. Consequently, it could be that a calculated polarity score for a score is not necessarily related to the topic of nuclear energy, but instead to a different topic in which nuclear energy plays a minor role. Analysing the sentiment towards a specific target within a text can be done with a variant of normal sentiment analysis, known as *targeted sentiment analysis*. Targeted sentiment analysis takes a text and a given entity within that text, and predicts the sentiment reflected on the text towards that specific entity. This method provides a more accurate calculation of the polarity score towards a subject of choice, but also has its disadvantages. The targeted sentiment analysis is a complex technique, making it harder for researchers to verify the results of the algorithm and come to the right conclusion. Second, this technique is well suited for short texts such as Tweets, but less suited for large texts because of the complex contextual construction of such a text in which the role of the targeted subject is hard to interpret for the algorithm.

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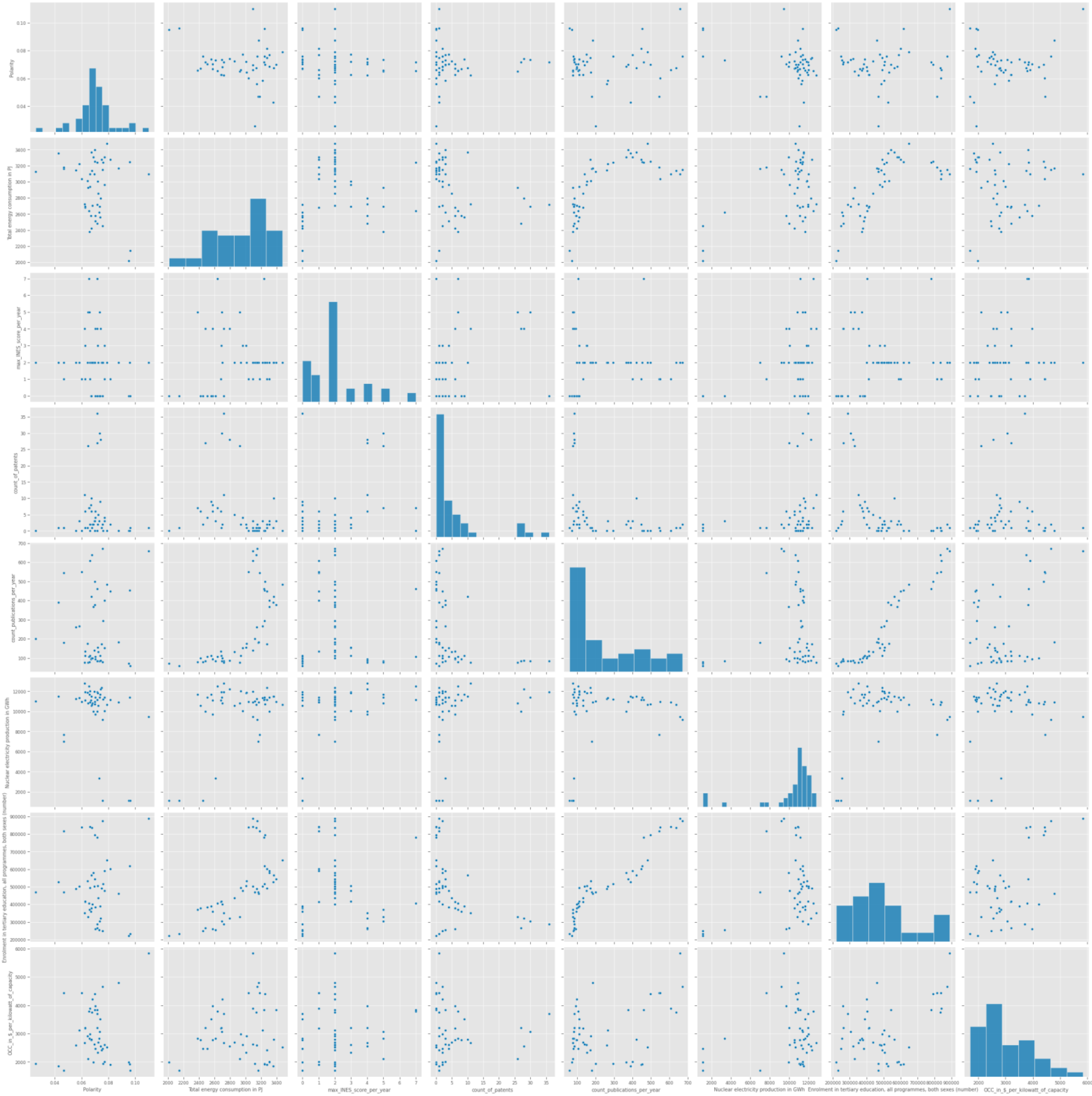
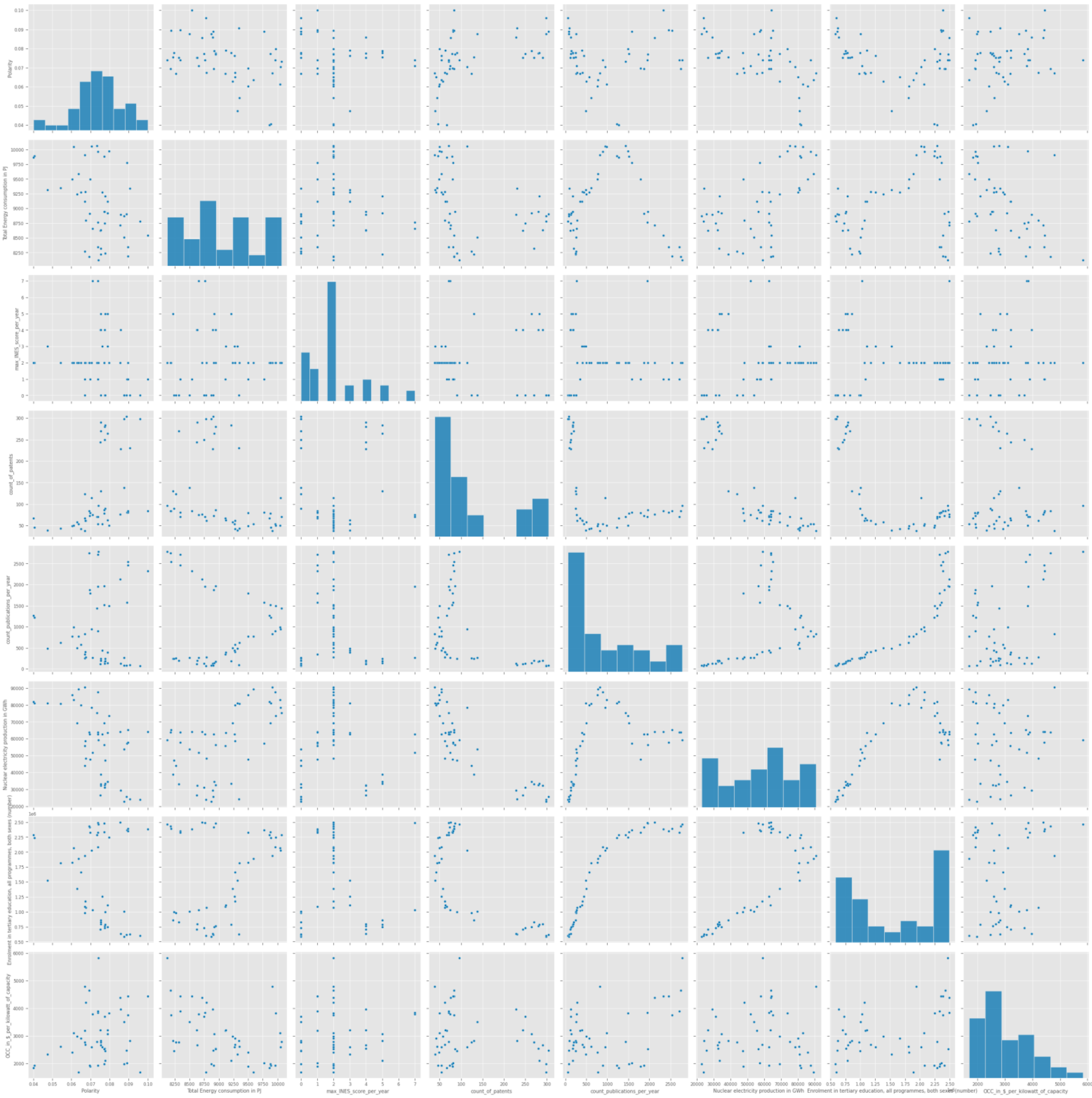
Appendix

Appendix A (Correlation matrix Polarity The Netherlands)



Appendix B (Correlation matrix Polarity The United Kingdom)



Appendix C (Correlation matrix Polarity Denmark)