UNIVERSITY OF TWENTE

Development of a Decision Support Tool Based on Fuzzy Cognitive Mapping for Energy Transition of District Heating Systems of Leeuwarden

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Acronyms

CAS: complex adaptive system

DHS: district heating system

ET: energy transition

FCM: fuzzy cognitive map

RE: renewable energy

TAM: technology adoption model

ABSTRACT

The Netherlands has targeted the reduction of CO2-eq emissions by approximately half by 2030. To achieve this ambitious goal, the energy transition has to be accelerated in various forms including heating. Geothermal energy is one of the major proven Dutch renewables, and in 2023, the first geothermal well is going to be operated to provide heating energy for industries in the first place and households afterward. As a niche, this new energy source will have to be supported to turn into the dominant regime, and the question is how? This research intends to provide a decision support tool based on a fuzzy cognitive map (FCM) with a focus on households as the users. The flow of this FCM is towards the residents' attitude towards the transition, and the data for the evaluation of the attitude has been collected from an online survey using the concept of the technology adoption model (TAM). There are also several non-social interconnected variables in the FCM that decision-makers can change to see the decision outputs, and the data to value the interconnections have been collected from another online survey spread among energy experts and scholars. Five scenarios have been analyzed using this tool to validate the FCM's outputs and demonstrate that it produces reasonable outputs. Based on the results of the scenarios, a few distinct recommendations have finally been made that are helpful when using this tool in decision-making processes.

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1. Introduction

1.1. Background

The Netherlands has the ambition to reduce CO2-eq emissions by roughly half by 2030, compared to the emitted amount in 1990. This reduction has been planned to hit the target of 95% by 2050 (Ministrie EZK, 2019); however, to achieve these ambitious goals, the pace of sustainable energy transition is required to become six times faster than the record of 2018. According to the master plan of geothermal energy in the Netherlands, 960 PJ, which is roughly 40% of the whole energy demand, was for heat. This resulted in 40% of emissions (71 megatons) in 2018. Geothermal energy itself has the potential to suffice 50 and 200+ PJ of energy in the years 2030 and 2050 respectively, which means a CO2-eq reduction of 3 and 12 megatons respectively (Stichting Platform Geothermie, 2018).

Based on Regional Energy Strategies (RES), some strategies have to be implemented to meet sustainable heat demands. Around 70% of a household's energy consumption is by heat demand. This makes the heating transition a complex, multi-sectoral challenge that has not only technical dimensions, but also components of governance, business models, and residents' adoption and participation. Since 2013, an alliance of companies has been working on a geothermal plant in industrial area De Zwette in Leeuwarden (Bouwgroep Dijkstra Draisma et al., 2022). In 2021, they drilled the first of the two wells. One difficulty that came up was the insufficient flow in this first well (Bouwgroep Dijkstra Draisma et al., 2022). So far, they have found solutions to increase the flow, and are optimistic about the geothermal plant delivering heat to companies and industries starting after the summer of 2023 and in the future also to households (Leeuwarder Courant, 2022).

Currently, there are two District Heating Systems (DHS) serving Leeuwarden, one in Techum and the other in Camminghaburen, which are shown in blue in Figure 2. The energy profile of the network in Techum includes a combination of natural gas and biogas, while in Camminghaburen; natural gas is the only energy resource (see Figure 1). The geothermal plant has been planned for the expansion of these systems as renewable energy (RE), and to make it economically feasible, at least 6000 households are required (Ennatuurlijk, 2021). Hence, if residents are meant to have the option to join this system, it is crucial for policy

makers and investors to know to what extent households in Leeuwarden are willing to adopt this plan.

Figure 1 Schematic of the current heat network in Camminghaburen (Ennatuurlijk, 2022)

Figure 2 Location of the two heat networks in Leeuwarden (Ennatuurlijk, 2022)

It needs to be noted that the dynamic nature of the energy market raises difficulties in the way of the judgment of the possibility of this change, especially in the context of ever-fast-changing geopolitics, energy price fluctuations, and other significant factors. For example, over the past year, the price of natural gas has almost tripled (see Figure 3), and as a result, less than 6000 households are required for this business case; however, the significance of the concept of technology adoption (TAM) is still valid in these new circumstances. This is because in this early stage where geothermal energy is in its infancy, as a niche technology it requires support from actors such as consumers to transform into a mainstream regime according to the concept of strategic niche management (Kern, 2012).

Figure 3 variation of natural gas price over a year until mid-June 2022 (Trading economics)

1.2. Geothermal energy as a renewable

Geothermal energy is a type of energy in the form of heat coming from hot geological strata. Quantitatively, this local energy source could be considered inexhaustible, which is not dependent on weather conditions and almost constant regardless of time. Below the ground surface, warm water exists in porous sandstone and limestone strata, and its heat originates deeper in the Earth's crust. This thermal conduction happens due to convection and radiation mechanisms in the outer crust of the Earth, which means within tens of kilometers deep in the Netherlands (Stichting Platform Geothermie, 2018).

The warm water flows through a doublet (see Figure 4), one production well for pumping warm water up from the aquifer to the heat exchanger and the other one, for injecting back the cooled water into the aquifer after serving the consumers. Depending on the location of the well, its depth varies from 500 m to over 4,000 m in the Netherlands, namely shallow to deep geothermal energy (Cousse et. al., 2021). According to the high depth of the bored well in Leeuwarden, which is approximately 2.5 km, it lies under the category of a deep geothermal well.

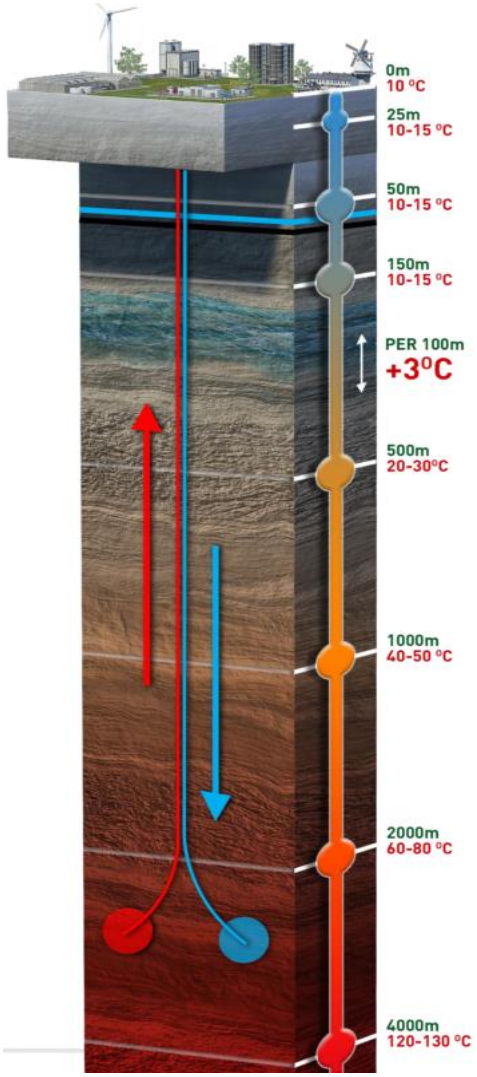


Figure 4 Schematic of a geothermal doublet (Stichting Platform Geothermie, 2018)

Among renewables for district heating, there is a focus on the potential for utilizing geothermal energy in the Netherlands. One advantage of this source of energy is that it is possible to be generated at a neighborhood level which could play a role as a sustainable element of a decentralized energy community. The potential of this local energy source in urban areas must be assessed by understanding its techniques as well as the identification of stakeholder groups within the energy landscape (Achilles et al., 2020).

A District heating system (DHS) is one of the efficient choices when it comes to energy supply systems. The concentration of heating demand in urban areas makes it more financially competitive to implement district heating, which is necessary for the integration of RE sources (Unternährer et al., 2017). As the population grows, the requirement for the expansion of this DHS is perceived more. On the other hand, the fluctuation of the

production of heaters running on non-permanent RE like solar and wind would decrease the reliability of the DHS, especially in peak loads, and then lead to residents' dissatisfaction. As geothermal energy is one of the unlimited and permanent renewable sources of energy, it can be added to the energy profile of DHS (Unternährer et al., 2017).

1.3. Research questions

Even though the government is making effort to have energy priced fairly, the actual price of all kinds of energy has followed the rate of natural gas. Thus, economic factors alongside other indicators play a key role in the residents' perception of the ET and then whether or not they will adopt it. Therefore, this research firstly is intended to investigate social concerns of the heat network in Leeuwarden through the analysis of the results of surveys. Secondly, from a technocratic point of view, some techno-economic factors are steering the indicators, which would vary in different scenarios.

To exemplify, residents might point to "in-home thermal comfort" as their most important concern about the upcoming DHS. This technical factor results from engineering inputs like grid efficiency and the mean quality of thermal insulation of households. Hence, efficiency itself leads to a different experience for the households ranging from the best to the poorest energy labels. If, for example, residents' concern is intended to decrease through an enhancement in in-home thermal comfort, more energy would be needed, which would reflect a rise in the customers' energy expenses. As a result, other concepts like energy prices see a change, and this consequence eventually leads to a growth in residents' concerns. That is to say, a strategy that is initially meant to address one concern would make the residents worried in another way after all.

Therefore, in the context of Leeuwarden, decision-makers in the field of ET of DHSs need to have a tool that represents such complex interactions and helps them to design policies and evaluate the possible outputs of their decisions. In this research, the main focus is going to be on how to develop decision-making support that connects techno-economic concepts to residents' concerns about technology. In the atmosphere of this key question, two sub-questions would be as below:

Main Question	What are the most important concerns of the residents of Leeuwarden, related to District Heating Systems (DHS)?
Sub-question 1	What techno-economic features of Leeuwarden's DHSs affect the residents' concerns and therefore should be taken into consideration?
Sub-question 2	Which changes in the techno-economic environment of Leeuwarden's DHS could enhance the residents' attitude toward geothermal energy?

1.4. Ethical statement

Since this research requires data gathering through surveys as mentioned above, it can raise ethical issues regarding the participants' personal information and privacy. The chosen online platform to store the data on is Microsoft Forms which is GDPR-compliant. At the beginning of the two surveys, the following consent form is situated and without this consent, it is not possible to proceed with the survey.

> *This questionnaire is by no means mandatory. You may stop filling it out at any stage by closing the browser. If you have any questions or remarks about the questionnaire beforehand, feel free to contact me via this email address:*
> *r.shahbazi@student.utwente.nl*
> *Your privacy will be protected because this questionnaire is anonymous. In this questionnaire, no personally identifiable information will be collected (e.g. your name, e-mail address, or phone number). In addition, only summaries and analyses of the data and no individual data will be shared with peers or professors. Only summaries and analyses can be published. The collected data of individual responses will be deleted after the completion of this research.*
>
> ◯ ***Hereby I say that I read the above consent form and agree with it.***

1.5. Reading guideline

This thesis is divided into eight sections. In the literature review section, firstly, the indicators used in this research will be reviewed. Secondly, the principles and definitions of fuzzy cognitive maps (FCMs) are provided. After section two, in the methods section, the elaboration of the research strategy will come first and then the methods of data collection and analysis are explained. Also, this section includes the elaboration of the two surveys (responded by residents and experts) as well as the generation steps of the FCM. Next, in the findings and discussion, data extracted from both surveys have been interpreted and

used to calculate the interrelation values of the FCM. To wrap up the findings in sections five, six, and seven, a summary of the findings and recommendations for them will be proposed and then limitations of this research and some advisory points for future research have been made.

2. Literature review

2.1. Energy trilemma and quadrilemma

The key concept in this research is the energy trilemma with three pillars of cost, security, and environment (Editorial Applied Energy, 2016). Some scholars have added another pillar to this concept, which transforms the concept of trilemma into a quadrilemma (see Figure 5). The adopted fourth pillar is the energy economy and job opportunities (Editorial Applied Energy, 2016). In this sense, ET is perceived as an opportunity to boost the job market and the economy, which could lead to citizens' satisfaction, especially the employed people.

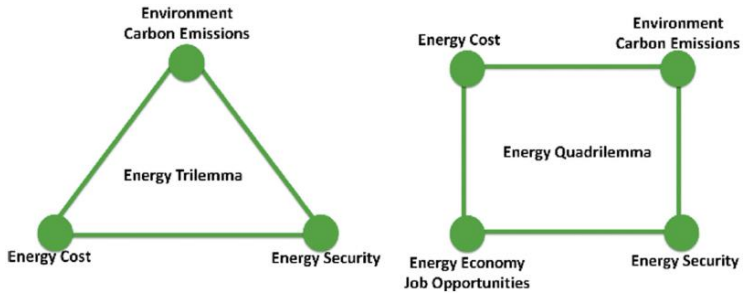


Figure 5 Energy trilemma versus quadrilemma (Editorial Applied Energy, 2016)

2.1.1. Trilemma-based indicators

To simplify the broad concept of public acceptance, in this research, consumers' attitude towards the transition is under attention, and this is in line with the theoretical framework of TAM elaborated in section 2.2. In general, the consumers could be divided into two groups of industries and residents, but it is the latter that has been selected as the target group of this research. To evaluate the residents' attitude towards this new technology, public concerns about the transition of DHS in Leeuwarden have been surveyed. It has then been assumed that residents' concerns have a reverse correlation with their intention to use technology, which means the more concerned the residents are, the lower the transition is likely to be accepted.

Preliminary consultations with local municipality officers made it clear that residents have complained about a number of issues, which have been included in this study's indicators. The main group of indicators has been derived from the pillars of the energy trilemma as follows, namely energy prices, environmental friendliness, and security.

2.1.2. Energy Prices

Aspects of energy prices (as introduced as a simple indicator by Savocool & Mukherjee (2011), are in this case study purchase costs of the needed installation, maintenance costs, and the monthly energy bill, as people tend to have different stands towards these investment costs and usage costs (Exadaktylos & van den Bergh, 2021). Some scholars have integrated some other concepts into costs such as energy equity or general fairness (Perlaviciute, 2018). This view emphasizes the fact that unfair decision-making processes such as unfair distribution of costs, profits, risks, etc. threaten the public's values, which eventually would evoke negative emotions in the way of energy projects (Perlaviciute, 2018).

However, this study excludes such details (e.g. equity and unfairness) of costs as a simplifying assumption and therefore take it as a general concept. In this sense, the purchase costs can be a first barrier to switching to the renewable heat grid depending on the actual pricing of the to-be-installed in-home system. The maintenance costs and monthly energy bill will be decisive factors to be considered by residents as the energy they use needs to be affordable. The importance of energy prices has therefore been measured because it influences the concern about the ET to geothermal energy.

2.1.3. Environmental Friendliness

This indicator is another pillar of the energy trilemma, and geothermal energy strives for a transition towards sustainability. For instance, this energy source has little chance to cause environmental issues because it has a small land footprint and little production of carbon dioxide thus it would be a renewable option for DHSs (Acheilas et al, 2020). Consequently, residents might find it important to accept the technology because of environmental friendliness. Despite this, it entails construction processes, land modifications, constant production of pollution just like any ongoing construction and operation activity, nuisance, and so on, which are indicators in the paper of Savocool & Mukherjee (2011). However,

compared to conventional ways of primary heat supply such as natural gas, it is more environmentally friendly as discussed in the introductory section.

The future work to implement the DHS and the building of the plant itself needs energy and therefore affects the environment. Well-informed residents know what to expect and therefore might accept it more easily. Therefore, this study also measures the importance of the transparency of technical changes in and around residents' homes.

2.1.4. Energy security

Import dependence, climate change, and earthquakes have effects on the feeling of energy security in The Netherlands. Savocool & Mukherjee (2011) used import dependence as a relevant indicator as well and in this case, the geothermal plant will produce energy locally, which will consequently reduce the energy dependency.

As well as the import dependence, the residents would be concerned about natural disasters due to the extraction of fossil fuels such as natural gas in Groningen. The public believes the contemporary and unprecedented ground shakings are related to the natural gas field in this city, and to address this issue, the gas valves have recently been closed (Chong et al., 2020). Owing to these beliefs, the level of this earthquake concern has also been measured.

2.2. Indicators from TAM

There is a wide range of extensions to the original TAM, all of which have been intended to understand the factors that influence consumers' acceptance of technology. The technology acceptance model created by Davis (1989) is one of the popular fundamental frameworks which have been employed in a number of research studies (Yang et al., 2021). It is a combination of the comprehensive theories of reasoned action (TRA) and planned behavior (TPB) (Yang et al., 2021). According to the technology acceptance model, an individual's attitude towards a technology type and their willingness to utilize it, as a result, are affected by their perception of usefulness as well as ease of the use of the technology (see Figure 6) (Yang et al., 2021).

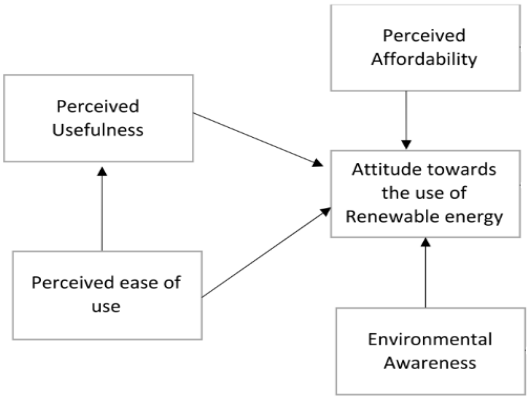


Figure 6 Theoretical framework of TAM (Yang et al., 2021)

In the case of Leeuwarden's DHS, as far as the functionality of this technology is concerned, the perception of usefulness relates to thermal comfort every household is predicting after having ET happened. Also, the ease of technology would be attributed to the ease of transition. That is, when the residents perceived this change as a vague and dissatisfactory one (in and out of their places), they would think of it as a difficult process and technology. Besides, the ease is not only limited to the process of transition itself but it could also be imagined while using the renewable DHS. For example, if consumers believed the maintenance and recycling of technology would be problematic, they would again perceive this process as uneasy too. Therefore, with the consideration of the usefulness and ease of use, we have chosen other indicators of this research, namely, in-home thermal comfort and openness as defined hereafter:

2.2.1. In-home comfort

In-home comfort is an indicator that is not discussed by energy trilemma but is added as a key indicator in this study because comfort temperature (Ponni & Baskar, 2015), and in-home view influences the concerns about heating systems. One aspect of this is in-home thermal comfort (sufficient heat and humidity), which can raise a concern in particular for residents with poorly insulated houses. This is because they are worried to lose their in-home thermal comfort as a result of the ET (de Wildt et al., 2021). Depending on the household's energy label, this concern can be justified and interpreted. In a city where a significant number of houses are still old and have poor heating insulation thus energy labels, the ET is most likely to face this challenge, also reported by other scholars in other cities (Hernández, 2015). For example, those who live close to the poverty line or elderlies who cannot renovate their houses can be categorized in this group who will probably

complain about having one or more uncomfortable cold days (Hernández, 2015). Another aspect is the appearance of the in-home devices to be installed, which may be a concern for the residents as comfort is also linked to the in-home view of the rooms, as mental health needs to be considered in all design processes (Barros et al., 2019).

2.2.2. Ease of switch between energy providers

Another key component of ET that is not discussed in the energy trilemma is openness. The prices of a heat grid are subject to sometimes disproportional high increases which resulted in a petition advocating affordable pricing (Otten, 2022). This might bring up concerns about future price fluctuations, making a monopoly less accepted. In addition, price equity among citizens might also be a concern as the households connected to such a heat grid cannot easily change to another provider, i.e., there is no open market for heat grids, but a monopoly market (Afonso et al., 2021). In addition, there might be a concern about the monopoly, as there is (1) no freedom to switch to another heating provider, and (2) there might be unexpected unaffordable price fluctuations. Another indicator is therefore openness of the DHS. We measure two aspects regarding the indicator openness, one being the possibility to switch, and the other being the possibility to opt for another system than a DHS. In addition, we added the transparency of the individual contract with the energy provider as a possible concern, as the residents require transparent information about all the terms of the contract with the energy provider for deciding their heating connection.

2.3. FCM

Complex systems are composed of many elements that interact with each other, which makes them extremely rich dynamical systems (Thurner et al, 2018). A social-economic political system can be an example of such a system that does not necessarily show a linear behavior (Özesmi & Özesmi, 2004). Complex adaptive systems (CAS) generally refer to open dynamical systems that can organize their structural configuration themselves with the benefit of the flow of information, energy, and other resources within their environment (Turner and Baker, 2019). In this sense, openness refers to the fact that the components might experience dynamic interactions and external forces in a new environment to which they learn how to adapt themselves. Having learned this, a CAS tends to update its state, and this is what in complexity literature is called emergence (Turner & Baker, 2019). One of

the key elements of CAS is this emergence which contributes to the unpredictability of the system. This feature in addition to other features such as self-organization, adaptation (evolution), feedback (history), and non-deterministic systems supports CAS. These specifications have made CAS theory the main tenet of sustainability science and are recommended for today's complexity in social science (Gaziulusoy, Brezet, 2015).

FCMs can represent such CASs, aiming to model a system with a variety of variables that have many interlinks and feedback loops (Özesmi & Özesmi, 2004). Despite the hardship of analyzing a complex system, the matrix algebra tools of graph theory make the analysis much easier. Also, visualizing the system via such a map makes it so understandable that having a glance at the map gives a quick understanding of the system, especially in terms of what concepts influence what and to what extent.

One of the applications of FCM is for the analysis of broad concepts like ET where dozens of concepts in terms of its three aspects of sustainability including environment, economy, and society, can causally be interconnected. Over the past years, some researchers have shown interest to propose decision support systems using FCM. This popularity comes from the fact that firstly, with the advanced but simple features of FCM, expert stakeholders can contribute to the generation of the mental landscape of a plan more easily. Secondly, it can incorporate uncertainty due to the fussiness of the concepts (Kokkinos et al., 2020).

To review some relevant examples of this application, in 2013, Szwed recommended the use of FCMs for analysis of the development of the academic units. He concludes that although this tool is a real facilitator, it tends to produce subjective outcomes (Szwed, 2023). This is because the process of FCM generation and giving value to interrelations require the contribution of experts and agents of the system who might not be neutral.

After that, Nikas et al. in the year 2018 made an effort to address the reasons why the Netherlands had not succeeded to reach the ET pace of European leaders with the benefit of FCM (Nikas, 2018). The focus of this research was on the Dutch solar sector, and it deployed a delayed-based approach to make FCMs consider the notion of time. It concluded that FCM cannot be used for a quantitative study. Though, policy-makers could apply their experience and expertise to the model which would give them insight by comparing the outputs of their policy strategies. The major finding of this research is that policy-makers

should concentrate on behavioral change-based measures rather than incentivize the transition process using pure economic instruments. Of course, the key to the success of this scenario is high societal participation; otherwise, this scheme would be less likely to reach its goals (Nikas, 2018).

Later in the year 2020, Guðlaugsson et al. used fuzzy logic to classify stakeholders of sustainable ET in Iceland (Guðlaugsson, 2020). This research combines fuzzy logic theory with a two-dimensional power-interest matrix to propose a three-dimensional decision surface to raise the accuracy of the assessment of stakeholders' salience. According to their results, decision-makers, industrial users, professional interest groups, and energy producers are the most influential stakeholder groups in decision-making (Guðlaugsson, 2020).

In the same year, Kokkinos et al. developed decision support systems (DSSs) to facilitate the shift toward a sustainable low-carbon environment via bio-based ET. This transition also aims to turn the challenge of the accumulation of bio-waste into an opportunity of replacing fossil fuels with biofuels (Kokkinos et al., 2020). Besides, this research includes several scenarios (the best and worst) of the FCM to assess the influence of the transition on the urbanization of a Greek case and vice versa. The concepts of the FCM were chosen so broadly that the map could be employed in other ET research. This feature is a major advantage of this research because it has provided a basis for future research like the current one.

2.3.1. FCM terminology

The concepts picked from a complex system are key characteristics of it, which can graphically be illustrated as nodes (C_i). Then each concept has a state of the node (a_i) which is a value between zero and one, denoting the state of the concept C_i (also known as node attribute). The nodes are interconnected using signed arcs/links, each of which has a value that is an entry/element in the adjacency matrix ($E=e_{ij}$). These weighted links represent the causal relationship that exists among the concepts. The sums of nodes are often weighted, and each sum is passed through a non-linear function known as a transfer function.

The transfer function normally has a sigmoid shape, but other nonlinear functions such as hyperbolic tangent have alternatively been used as well (Carvalho, 2013). The sigmoid threshold function ensures that the measured value of each concept lies in the interval of (0,1] (see Equation 1), while the hyperbolic function is used when the value is possible to be any real number from the interval of [-1,+1] (see Equation 2) (Kokkinos, 2020). In this research, the hyperbolic choice has been made because the causal relationships have been defined in a way that can be both negative and positive.

A matrix called "adjacency weighted matrix", which represents FCM consists of these values. Positive numbers indicate positive causalities whereas negative ones do the opposite. Positive causalities are interpreted as an increase of one concept when another connected concept increases, while negative causalities indicate that the connected concept decreases.

Equation 1: $\boldsymbol{f(x) = \frac{1}{1+e^{-\lambda x}}}$

Equation 2: $\boldsymbol{f(x) = tanh\, \lambda x}$

Having defined all the mentioned parameters of an FCM, new state vectors could be simulated and this update can be repeated infinitely. This step should be taken at least 2n (n = total number of concepts) times until the system converges to a fixed point, which is the essence to achieve the results of the desired scenario (Kok, 2009).

3. Methodological strategy and data collection

3.1. Research strategy

This study has extracted indicators from the energy trilemma as well as the TAM. These indicators have been employed in an empirical study using the survey method to measure the concern-based indicators of the residents of Leeuwarden. Initial desk research was also done to select socio-economic concepts that have an impact on the abovementioned concerns in the FCM (see Figure 9). After that, to establish the relationships between the chosen upstream concepts, it was initially meant to have interviews with the experts; however, due to limitations from the local interviewees' side, it did not happen, and alternatively, the second survey was designed.

The research strategy from the first to the last step is following the graph shown in Figure 7, which begins with background research and literature study. Then, the surveys were designed and distributed among the residents of Leeuwarden using printed and digital flyers (see section 8.1). Next, the collected data was utilized to analyze and calculate the weights of interrelations of the FCM. Having made the FCM in the Mental Modeler software (www.mentalmodeler.org), the scenarios were made using the same software to pave the way for presenting results, interpretations, and recommendations of the study. This software is web-based and has a user-friendly environment, which has been used in a number of participatory decision-making case projects (Gray et al., 2013).

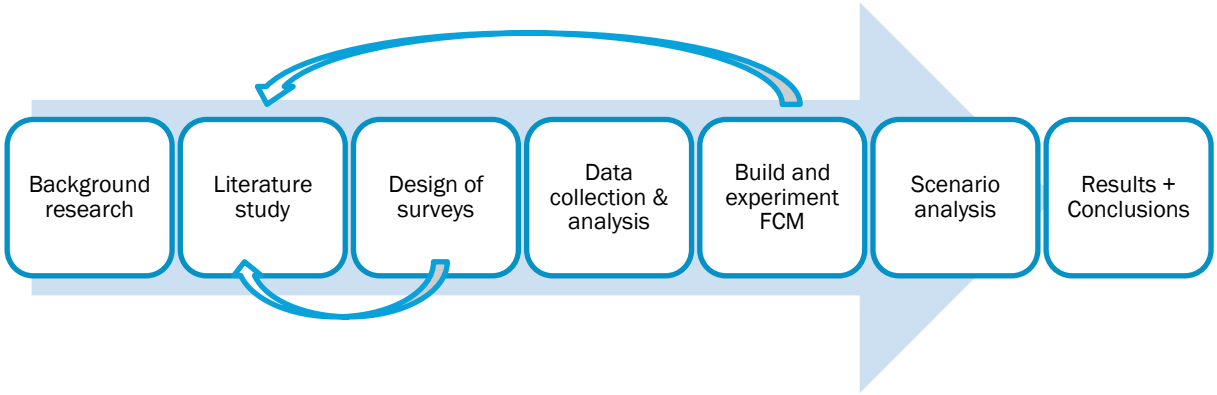


Figure 7 Research strategy

3.2. Surveys

3.2.1. Residents' survey

As mentioned, the selected strategy to investigate residents' opinions in this research is surveying, which has been used in a similar quantitative study on hydrogen energy (Molin, 2005). Survey has been chosen rather than interviews because many locals do not have sufficient English proficiency or tendency to be interviewed. Hence, to overcome language obstacles, a questionnaire in Dutch in our case project team was prepared to survey the residents' concerns about ET of DHSs. To reach out to as many residents (older than 18) as possible, all the possible means were employed including social media, distributing printed flyers, in-person persuasion, contacting local communities and associations, and so on. The link to an online survey, the text version of the survey, the flyers, and the contact info has been provided in the Appendix section.

The questionnaire starts with an introduction to the case project and the research intention, including affiliation. After that, the participants are asked to sign the consent form which contains statements about our research ethics. Then some demographic data have been asked such as neighborhood, age, gender, occupation status, and the gross yearly income of residents in questions 4-8. Then questions 9-12 are intended to inquire whether the respondent lives in an owner-occupied place or tenancy. This information is important to get since it is an owner in the Netherlands who has the right to choose the heating system of the place, while for a tenant, it is determined by the property owner.

Next, question 13 wants to know what they rather have between three options about the practicalities of the new heat grid; namely, the easiness to switch, the need for monitoring of the energy prices, and a possible preference for sustainable heat in any case. This makes sure the importance of energy prices, openness, and environmental friendliness has been asked. Following up on question 14, this is the main question of the survey targeting all the concerns of the residents. In this question, the residents are provided with choices to determine to what extent they would be concerned about various indicators mentioned earlier. The respondents were given four choices, which were “A lot,” “Somewhat,” “A little,” and “Not at all”. These four options were given to measure their attitudes toward the indicators. The option “neutral” was excluded from the choices to make people choose their real sides.

After that, in question 15, it was asked which factor they will compromise their preferences based on the topics of independence of imported natural gas, climate change, and earthquakes. The accountable news and rumors of ground motions due to underground activities (e.g., earthquake in Groningen), dependence on gas imports (e.g., Russian gas), and environmental risks of human activities are widespread and therefore relevant to consider. Furthermore, the choice of energy label has been given and whether they feel in-home thermal comfort would change, compared to the natural gas systems (questions 16-18). For energy monopolies, we ask about their reasons to be able to switch between energy providers (questions 19-20). Finally, there is question 21 to find information from the respondents about their overall feeling toward the connection to the renewable heat grid. There is also a place to enter issues that could be considered for future research. Overall, in

Table 1, the question numbers aiming to measure the indicators included in the survey could be followed.

Table 1 Question numbers for various indicators

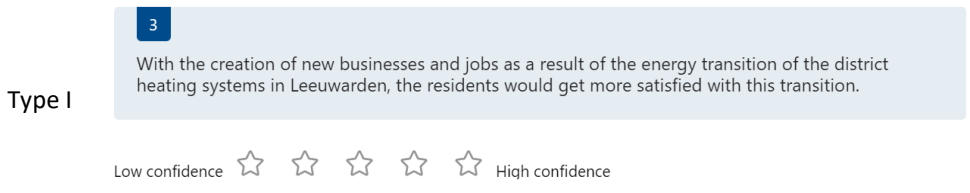
Indicators	Question numbers
Energy prices	13, 14
Openness	13, 14, 19,20
In-home thermal comfort	14, 16-18
Environmental friendliness	13-15

3.2.2. Experts' survey

As explained, the second survey was for enquiring the weights of the relationships between the 16 socio-techno-economic concepts which will be elaborated on in section 3.3. The link to this online questionnaire and the text version of it have been provided in the Appendix section. There are two advantages to this surveying strategy over interviewing in this case, one of which is that an online questionnaire gives flexibility to the respondents. This is because it can be responded to at the most comfortable place and time for the participants. Additionally, it can make it possible for experts to respond to questions in a quite anonymous way. This way could particularly be a smart approach when the topic is controversial and potential interviewees prefer to prevent conflicts with other stakeholders. This was the case when it come to this research since according to some stakeholders, the new law that is intended to limit the fluctuations of RE so that it does not follow natural gas, has already raised energy providers' concerns and opposition.

To elaborate this survey has 32 questions, most of which are required to be scored using the Likert scale. Having checked the consent form, the respondent needs to insert their job title which is the only demographical information taken from them to make the participation as anonymous as possible. After that, in every question, the relationship between every two concepts of the FCM was explained, and based on that, the respondent gave a score as to what extent they believe it is a true statement. In Figure 8, the two typical questions of the survey can be seen:

Figure 8 Typical questions of the experts' survey



Type II

7

After completing the statement below using the following items, to what extent do you think each item is likely?

Statement: To boost this transition, new investments are needed. These investments would ...

	not at all	a little	somewhat	a lot
grow businesses and jobs	○	○	○	○
rise the proportion of renewables to the whole	○	○	○	○

At the end of the survey, to make sure if the chosen techno-economic concepts are relevant, there is a field where the irrelevant concept can be inserted. Also, there is another field to recommend a significant relationship in the FCM that is missed. According to the responses, experts have determined neither irrelevant concepts nor recommendations.

3.3. FCM generation

Having known the concern-based indicators elaborated in sections 2.1.1 and 2.2, their connections to the concept of attitude toward the use of RE are the focus of this section. These concepts have been placed at the core of the FCM in blue color pointing at the attitude concept in purple, as shown in Figure 9. This map consists of 16 socio-techno-economic concepts listed in Table 2, which have been selected based on initial brainstorming and recommendations of the experts and literature (Kokkinos et al., 2020).

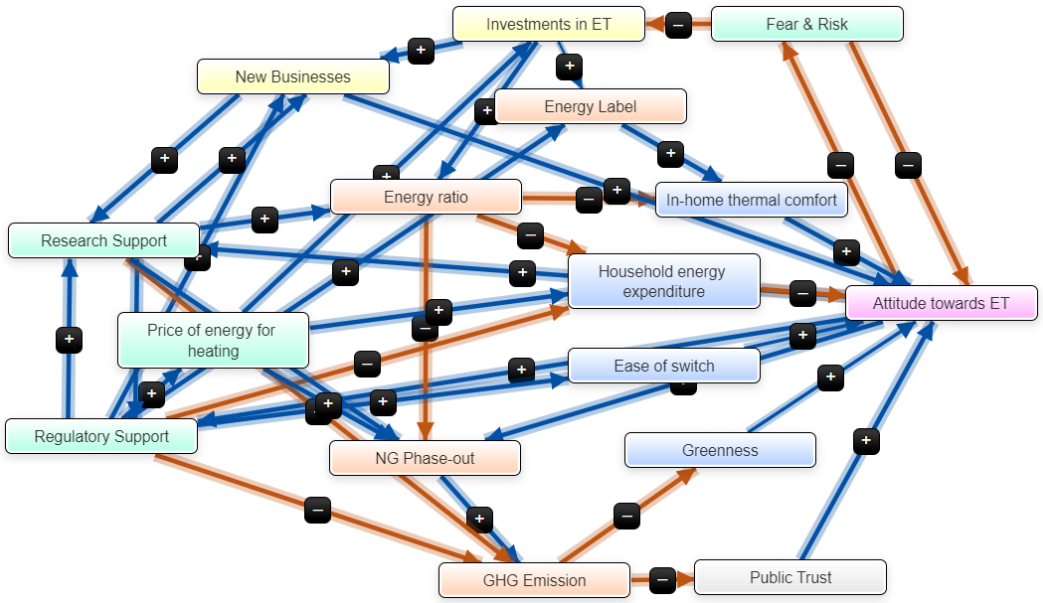


Figure 9 Initial ideas of the FCM for this research

Table 2 List of the concepts included in the FCM

Concept class	Concept number	Concept name
Social	C1	Attitude toward ET
Social	C2	Risks and fears of the transition
Social	C3	Public trust
Environmental	C4	Environmental friendliness
Environmental	C5	Greenhouse gas emissions
Environmental	C6	Natural gas phase-out
Environmental	C7	Energy ratio (renewable over total)
Technical	C8	Ease of switch between energy providers
Technical	C9	In-home thermal comfort
Technical	C10	The energy label of buildings
Technical	C11	Regulatory support
Technical	C12	Research support
Economics	C13	New businesses and jobs
Economics	C14	Investment in ET
Economics	C15	Household expenditure on energy
Economics	C16	Price of energy needed for heating

Energy label: The concern of in-home thermal comfort, as explained in section 2.2, is affected by the energy label of households. That is, the poorer the energy label of a household, the more worried its inhabitants become in terms of their thermal comfort. Besides, mostly the low-income live in old buildings where there is no valid information about this label; thus, the idea of this research is that knowing this important factor for the whole system requires funds, which could, for example, be supported by regulations with the benefit of subsidies on identification process of the energy label. Also, national building design codes have recently paid special attention to the minimum requirements of the insulation systems in residential buildings. Therefore, regulatory support ensures this knowledge in the future for to-be-built residential buildings.

Energy ratio: The energy ratio, with the given formula in **Equation 3**, is a key factor implying how renewable the source of energy utilized in the district systems is. This ratio will drop immediately in case there is any interruption in the geothermal plant because alternatively, natural gas will be added to the energy mix of the DHSs.

Equation 3: $$\text{energy ratio} = \frac{E\_renewables}{E\_total}$$

As explained, this ratio will be adjusted to maintain the thermal comfort of the users, but it will bring bigger numbers on the monthly energy bills of the residents because the natural gas rate is meant to be higher than renewables in the Netherlands. Additionally, growing gas in the energy profile of the system means less phase-out of natural gas and more carbon

emission as a result. This growth will eventually damage public trust as the residents have environmental concerns too (Kokkinos et al., 2020). Another alternative could be the improvement of the heating systems, which is in the need of research support and plenty of investment to put the proven research outcomes into practice.

New businesses: As explained in section 2.1, some scholars have added the fourth pillar to the energy trilemma to make a quadrilemma, energy economy, and job opportunities for instance. Adding a new energy source involves new businesses and this works as an economic motive. These new opportunities, however, require funds which often come when the risks of investment are low and the technology does not cause fear and serious concerns in public (Kokkinos et al., 2020). Researchers could provide solutions as to how to make these businesses sustainable and decrease risks and fears of the ET as well. It needs to be mentioned that these fears and risks could decline having improved the residents' attitude toward the ET.

Regulatory support: Regulations can undeniably pave the way for the transition in several ways. Firstly, regulatory support is meant to minimize monopoly because the energy market is supposed to be open. Even though energy supply prices are being monitored by the Authority Consumer and Market (ACM), unfortunately, under the current energy pricing regulations of heat energy, the prices are allowed to go up at the same rate as natural gas. Fortunately, the government is planning to enforce a new heat law to solve this problem. This law distinguishes namely between the different sources of energy to ensure fair pricing (Ministry of Economic Affairs and Climate Policy, 2022). This regulatory change is yet to be implemented, but the elaboration clearly shows how regulations could work in favor of prices as well as the openness of the market.

Secondly, with the development of rurban areas, energy demands increase as well, thus, permits are required for more energy production, and emissions produced in power plants must be limited. Regulations can play a key role in this ground in favor of the transition with the effective tools of permits and standards. Thirdly, future developments involve new residential buildings too whose energy label formerly mentioned influences thermal comfort. In this sense, construction standards could ensure insulation minimum standards and encourage constructors to identify the energy label of new buildings as well.

3.4. Importance of non-binary values

There might be an important question about what if the FCM of this research was generated using a binary mindset. Having experimented with various scenarios with extreme interrelation values (-1, 0, 1), it became clear that the leading concepts in each scenario would remain unchanged in ranking but different in percentage. However, there would be a considerable change both in the ranking of the following concepts after the leading concept and their percentages. Therefore, it can be concluded that using binary values would only give a holistic insight into the behavior of the FCM. This approach could especially be helpful before the design of the experts' survey to give the idea of whether or not the map has the minimum requirements to produce expected outputs. Though, making any final remark and conclusion requires real values calculated from the survey's outcome.

3.5. Data analysis

In total, 95 residents of Leeuwarden have responded to the residents' survey of this research. As explained earlier, this survey was initially designed to target both English and Dutch speakers; however, most of the English respondents were international students who had been experiencing the context of the case for half a year approximately. Not only this, but they are also all tenants whose opinions might be interesting to know but not as important as the place owners. This is because, in the Netherlands, it is normally the landlord who has the right to decide on the energy contract and signs it. Hence, the focus of the results has been decided to be only on the Dutch outputs (73 responses) since this group consisted of the majority of the property owners.

Although 73 is respectable sample size for the case study project, it is too small and does not provide enough degrees of freedom to run any inferential statistics. Also, it is less than 10% of the number of households in Leeuwarden, which means that this sample is not an ideal one that represents the population of the target group for quantitative research. In addition, some scholars recommend that there should be at least five respondents for each question of the survey. This calculation gives the minimum sample size of 135 and unfortunately, this criterion has not been met either; as a result, the results should be presented qualitatively; therefore, descriptive statistical analysis is the best method

available. For the ordinal-scale questions, for each aspect, a relevance score out of 100 (RS%) has been calculated using the following formula:

Equation 4: $RS\% = \frac{3*\%\ a\ lot+2*\%\ somewhat+1*\%\ a\ little}{3}$

This calculation is necessary to assign realistic weights to the relationships of the concepts in the FCM. Although the outputs of this research can only be indicative since internet surveys cannot be scientific samples, the probability of reaching a large sample is high as the survey will be spread via the world wide web (Bickman & Rog, 2014). As this research intended to stay independent from other stakeholders such as the municipality, the participants were asked to participate in an academic study with the consideration of ethical values using informed consent. The link to this online survey has been included in the Appendix section.

Figure 10 The job title of the respondents to the experts' survey

Shifting to the experts' survey, 11 energy experts filled out the questionnaire and Figure 10 illustrates the occupation status of these experts. By asking the experts to rate the links between the concepts using a Likert scale, it was then possible to translate the score to a [-1,+1] range to reflect the strength of interaction. For instance, for a link, if the calculated average of an RS equaled 78%, the value assigned in the map would be 0.78. This defuzzification process is a common method to calculate values for the links connecting every two concepts of a fuzzy map, which has been adopted by other scholars as well (Kokkinos et al., 2020).

4. Findings and discussion

As the input data of the FCM has been derived from the two surveys, in the first place, the results of the surveys come separately in this chapter, firstly, the results of the residents' survey and then the experts'.

4.1. Residents' survey

4.1.1. Demographics

The first demographic data is the neighborhood, inquired in question four, and 64 respondents (out of 73) declared that they did not live in the neighborhoods where the DHSs are going to be developed with geothermal energy first, namely Camminghaburen and Techum.

Shifting to the second demographic is age group; the questionnaire has been filled out by residents from all the defined age groups. As it can be seen in Figure 11, the graph peaks at around the age of 30 and show roughly equal contribution in age groups of 18-30, 41-50, and 51-60, while the ones older than 60 contributed the least. This distribution follows the trend of age distribution in the city of Leeuwarden, as shown in Figure 11 (Urbistat, 2022).

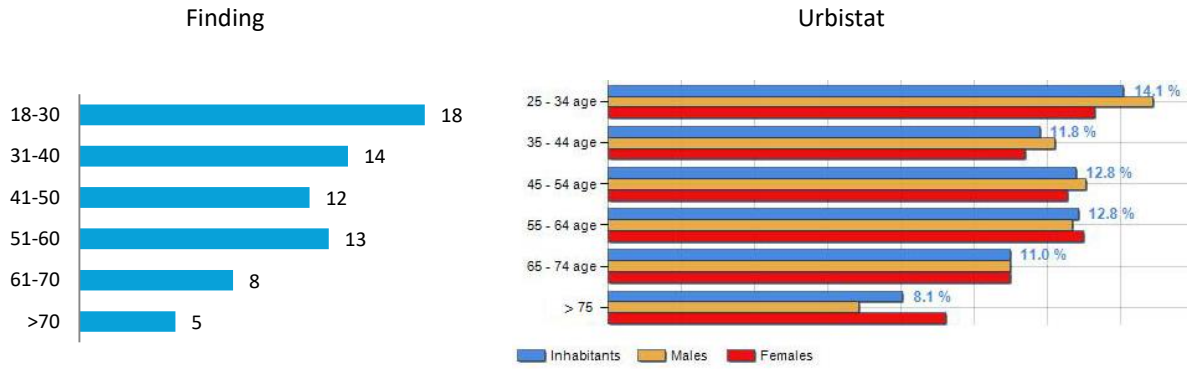


Figure 11 Distribution of respondents in six age groups based on the finding of this research (left) and the online age statistics of the residents of Leeuwarden (right) (Urbistat, 2022)

There is a striking point regarding the top participation age group, 18-30, which is that few of them have their property at the time of surveying; therefore, they do not have the legal right to influence the decision of this transition. However, in the future, their ownership status will probably change from tenant to owner. Next, the third demographic data targets the gender of respondents. According to the responses, the number of females is less than half of the male ones, with the numbers of 22 and 50 respectively.

According to Figure 11, even though the male and female population in Leeuwarden approximately seems equal, this wide gap between the participation of females and males cannot surely be interpreted with the city's population data. This is because firstly, the gender of the owners of the surveyed households was not asked. Secondly, the survey did

not ask the respondent to be just the owner property. Hence, the respondent is more of a random family member who participated on behalf of the owner. On contrary, in 2019, Clancy and Feenstra pointed out that decision-making, business, and some other aspects of ET in the Netherlands were male-dominated. Besides, in females' view, environmental issues were more important than males' who mainly emphasized economics more than females (Clancy & Feenstra, 2019). Hence, more females' contributions to this research could have increased the importance and therefore weight of environmental concerns rather than the financial.

The following categorizing criterion is the status of occupation. The answers could be categorized into six groups, employed, student, retired, unemployed, and unspecified. As is illustrated in Figure 12, approximately 70% of the responses are from the employed category. In comparison to the employment rate of the province, which is 75% (Friesland, 2022), it can be concluded that the survey has reached out to a sample whose employment rate roughly follows the province's rate.

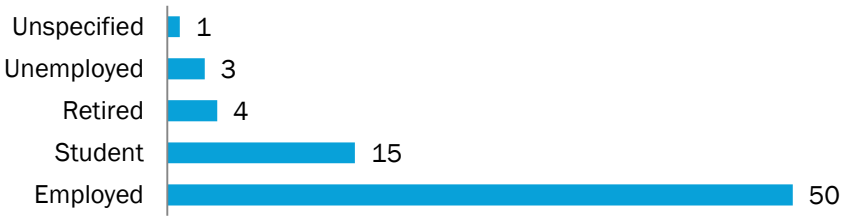


Figure 12 Respondents' employment status

With regards to the income of the ones who have been identified as "employed", as is shown in Figure 13, most of them have opted for the range of 50-100K Euros.

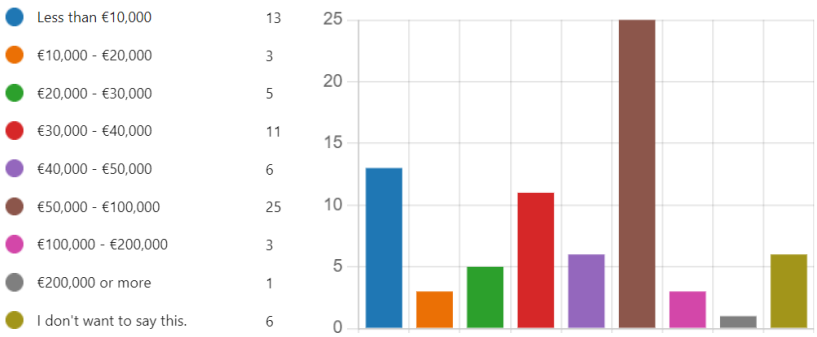


Figure 13 Distribution of the declaration of income

Next, as the pie chart of Figure 14 shows, the highest share belongs to natural gas with a share of 74%, which is at the same rank as the dominant energy source of heating systems in Leeuwarden. Among those five people who selected “other” to specify their energy source themselves, one stated that their place is using geothermal energy in combination with electricity which might indicate a heat pump and electric radiators, and this had not been identified as a common heating system in this research.

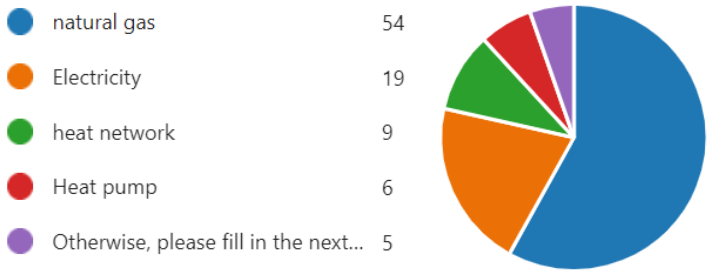


Figure 14 Diversity of energy sources of heating systems

After that, the number of property owners and tenants was intended to measure, and according to the responses, the numbers are 52 for the former and 17 for the latter. This dominance of the owners satisfied this research’s interest because tenants do not have the right to switch their energy providers. There is one unpredicted answer which is living in a tent and this resident is one of the ones who burn wood to warm themselves.

4.1.2. Residents’ prior knowledge

Most respondents knew about DH (47 out of 73), but only around half of the participants declared having prior knowledge of the upcoming DHS in Leeuwarden. No matter why around a quarter of the residents did not have the idea of collective, this group has the potential of being exposed to information about the concept through information campaigns or any other proven effective tool.

4.1.3. Indicators from the first survey

4.1.3.1. Household expenditure on energy

As the actual cost of the transition is the combination of three elements that are paid in different stages, the residents’ survey inquires them separately. The monthly energy bill ranks first amongst the cost composition with the RS% of 85% (see Equation 4). The other two could be ranked second with a narrow gap as can be seen in Figure 15, 75% for purchase and installation and 73% for the maintenance costs. Therefore, it is clear that the

monthly energy bill is leading the energy price concerns. In addition, it was anticipated the well-paid population (monthly income more than 50k) would be far less concerned about primary costs than monthly costs, but the results made it clear that even this class is as much worried about the primary costs as the monthly costs.

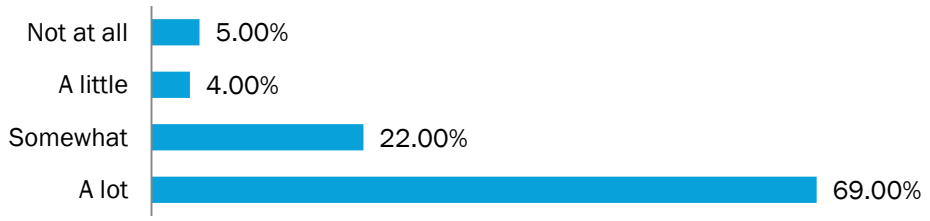


Figure 15 Level of concern about monthly energy bills

Later in the next question, it was asked why it is important to have the option of switching energy providers. This time, the respondents had the chance to check one or more items from a given list. For this reason, the total number of various options does not have to be equal to our sample size. Based on the results given in Figure 16, the choice related to the variation of charges has been the most often picked with 55 times. Following price, sustainability, and functionality of the DHS are situated in the second and third places with 29 and 22 times of selection respectively. This rather high prioritization of sustainability provides proof of the fact that the residents do not want cheaper energy at any cost. The other reasons, whether it was given as a choice or not, were not popular.

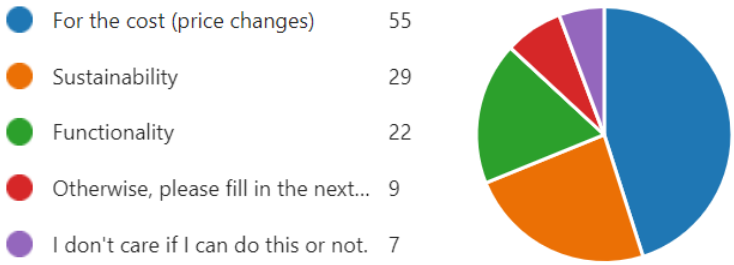


Figure 16 Reasons why it is important to have the choice of switching energy providers

4.1.3.2. In-home thermal comfort

This indicator has been evaluated in two different ways. Given the order of outputs in Figure 17, the most important item with regards to comfort is in-home thermal comfort. This is because with a high emphasis on the Likert scale of “a lot”, the RS% became 85%. This high score implies thermal comfort would leave the highest impact on the decision to connect/disconnect the DHS. The level of this concern has been so high that no one selected

"not at all" for this item, while in the most of other items; it has been chosen at least once. Another aspect of in-home comfort could be the appearance of the changes around the house; however, the residents believed that this item would not be a relevant concern as 46.5% of RS% for this factor was the least amongst all indicators.

Figure 17 Reaction to in-home thermal comfort

Consideration of the energy label of buildings: This label technically plays a key role in the success of the ET of DHS. According to the results, it is only 50% of the respondents know the energy label of their places. Also, while owners contribute to 89% of the ones who know their energy labels, this contribution falls to 50% when it comes to the group who has no idea about this label. This high number of property owners that have no information about the energy label would be an obstacle in the way of ET of DHSs because they might complain about the transition, while their poor energy label was more to blame rather than the functionality of the network. This is the case according to the responses because the majority of the ones who stated thermal comfort after the ET would not me as much as now live in the buildings with the energy label of poorer than C.

As households with poor energy labels must normally pay much higher monthly energy bills to have the same thermal comfort as the top-energy-label ones, this research anticipates receiving more concerns on the future of indoor thermal comfort and energy bills from poor labels areas. Proportions given in Table 3 satisfy our anticipation. Besides, the comparison of the shares of the two inquired qualities makes it clear that apart from the energy label, those who already know their energy labels would be more worried about their monthly energy expenses rather than in-home thermal comfort.

Table 3 Comparison of the concerns of poor energy label households with top labels

Energy label class	RS	
	In-home thermal comfort	Energy bill
Poorer than C	96%	96%
Better than C	86%	83%

Having asked for the energy labels, the respondent has been requested to imagine if their house would have a satisfactory thermal performance after the transition. The number of those who were optimistic about this quality is the same as the number of the ones who do not have any idea about it. Therefore, policy makers should put different measures on their agenda to persuade those with “no” and “don’t know” choices (see Figure 18).

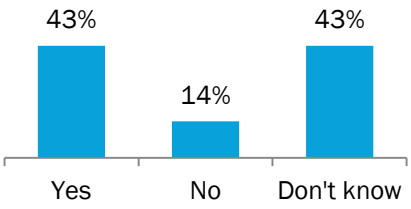


Figure 18 Self-evaluation of the performance of houses with the consideration of energy label

4.1.3.3. Ease of switch between energy providers

One aspect of this ease could be related to the terms of the contract between energy providers and households. With the RS% of 81%, residents have stated that this would be one source of their concerns in the future. The following items are the individual right to switch the source of energy as well as ease of switch between energy providers, which earned 68% and 72% of RSs respectively. Therefore, to the residents, the terms of their energy contract with the energy providers would worry them more than the ability to switch between energy providers themselves.

4.1.3.4. Environmental friendliness

First of all, as explained in 4.1.3.1, the choice of sustainability could roughly give the idea of how important environmental concerns are in the context of Leeuwarden, compared to the ease of switch or monopoly in the energy market. Besides, about 50% of the respondents expressed their preference for consuming sustainable energy sources no matter if they have the option of switching or not.

Secondly, respondents later on the questionnaire had the chance to choose their environmental concerns. As can be seen in Figure 19, the two items had the RS% of 82% and 79.5%, which means the residents would be significantly concerned about the environmental effects of DHS (running on geothermal energy) and climate change, and this

shows that the public needs to be assured that the advantages of this transition would outweigh the negative impacts in terms of the environment.

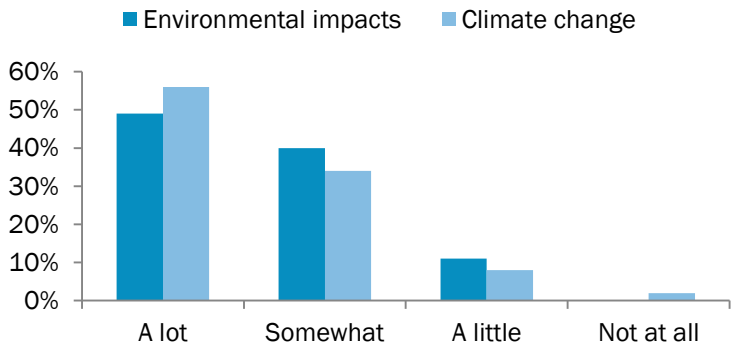


Figure 19 Comparison of responses in terms of the environment

Finally, an anthropocentric view might give high priority to living places and neighborhoods when it comes to the environment. Hence, there is another item in the questionnaire targeting this group with the question of to what extent having clear information about future indoor and outdoor changes will influence the decision of the connection to the DHS. The RS% of 64% emphasizes that this factor is much less relevant, compared to the other two environmental items.

4.1.4. Summary of the 1st survey

Before making concluding remarks on the first survey, it would be relevant to mention that in the 1st survey, one of the last questions generally inquired about whether the residents would be connected to the DHSs after the transition. According to the responses, 31 households (out of 73) chose “Yes”, while 11 of the respondents opted for “No” (see Figure 20). That 43% of the respondents have a positive attitude already is a promising sign of the future. Persuasion of the undecided residents would be much less effort than the ones who know that they will not connect to the DHSs. Thus, less work needs to be done to persuade the pessimists to become optimistic.

Figure 20 Residents’ decision on the choice of being connected to the DHSs after the transition

Having discussed the results of the first survey in detail, Table 4 gives the overview of the selected values from this survey, applied to the inter-connections of the FCM towards the concept named the residents' attitude. The comparison of the percentages in the table makes it clear that the four indicators have almost the same shares in the residents' view.

Table 4: Summary of the findings of the 1st survey

Indicator	Total
Households' expenditure on energy	85%
In-home thermal comfort	85%
Environmental friendliness	82%
Ease of switch between energy providers	81%

In case the residents participated fully and provided an ideal sample size, different outputs would probably come out, compared to the shares in Table 4. This is because firstly, as discussed in 4.1.1, with more females' participation, the environmental concern would see a higher percentage, which would even overtake the concern of expenditure which is more of a masculine concern. Secondly, in one of the few pieces of research on the social acceptance of geothermal energy in the Netherlands, it was pointed out that the main prevailing concern was the sufficiency of this resource in the first and environmental friendliness in the second place (Auf, 2010). However, this recent soaring energy price, as a powerful driver, must have shifted the top concern towards expenses, too. Therefore, making a comparison between the findings of the current survey with the old ones especially the ones dated older than the war in Ukraine would be invalid.

4.2. Experts' survey and interlinks

Having collected the data from respondents of the second survey, the level of interrelations between each pair of the connected concepts in the FCM has been calculated as in Table 5. The values in this table have labeled as "Ci,Cj"; i and j represent the concept numbers given in Table 7. Take "C1,C2" as an example, its value is the weight applied to the arrow going out of C1 into C2.

According to the values given in Table 7, the weakest relationship, from the experts' view, is that with the growth of RE contribution to total heating energy, the household expenditure would rise. This is also what the local governors desire to be after the transition because the residents' most important concern would be heating energy expenses after the transition.

On the other hand, the biggest weight in the causality table belongs to the link implying that the government supports the plan in favor of the reduction of greenhouse gas emissions. This would boost the public trust, eventually leading to an enhancement in the residents' attitude toward the ET. Since this improvement is making several other improvements in the system as the map illustrates, this is another promising result, which will be discussed more in the scenarios.

Table 5 FCM causalities

C1,C6	0.72	C7,C6	0.7	C11,C13	0.67	C12,C6	0.67
C1,C11	0.58	C5,C4	-0.75	C11,C12	0.55	C12,C11	0.73
C1,C12	0.58	C5,C3	-0.75	C11,C16	-0.7	C12,C13	0.61
C1,C2	-0.57	C6,C5	-0.75	C14,C7	0.73	C2,C1	-0.78
C9,C1	0.85	C10,C9	0.71	C14,C10	0.64	C2,C14	-0.48
C15,C1	-0.85	C3,C1	0.75	C14,C13	0.67	C11,C15	0.5
C8,C1	0.81	C11,C15	-0.76	C13,C1	0.62	C11,C12	0.67
C4,C1	0.82	C11,C8	0.7	C13,C12	0.61	C11,C16	0.75
C7,C9	-0.71	C11,C5	-0.88	C12,C7	0.75		
C7,C15	-0.4	C11,C10	0.78	C12,C5	-0.67		

After the weight assignment to the map, FCM statistics and metrics can be derived from the FCM, which could be followed below in Table 6 and Table 7. As Table 6 illustrates, in total, 38 links connect the 16 concepts of the FCM, which gives 2.375 connections per component on average. Additionally, the map has neither transmitter component, nor receivers but all the concepts are ordinary. A transmitter variable is a concept that influences at least one of the other concepts, while it does not receive any influence from any of the others. Unlike transmitters, receivers do not influence others but just get influenced.

Table 6 FCM statistics

FCM properties	Value
Total components	16
Total connections	38
Density	0.16
Connections per component	2.375
Number of driver components	0
Number of receiver components	0
Number of ordinary components	16
Complexity score	-

Since there is no receiver variable in the mental landscape, the index of complexity has become zero. Also, that there is no transmitter forcing the functions of the system gives stakeholders the idea that there is no variable out of their control or no variable of significantly more driving influence than the rest, and this is in a sense a feature of a

democratic system. In fact, in a hierarchical system, there must be at least one transmitter representing the top-down influences.

It needs to be mentioned that in a fully connected system composed of 16 concepts, the highest number of interrelations equals 240 (see Equation 5); however, the map of this research has only 38 of them, and this results in the low value of density in the statistics. FCM with higher density displays a greater degree of complexity in the relationships, and thus offer a greater number of options (Gray et al., 2014). Also, aside from exceeding the scope of this research, at least one question per connection would have to be there in the survey, which would make the survey too time-consuming.

Equation 5: Clustering coefficient $(\mathrm{D}) = N\ (N-1)$; $where\ N\ is\ the\ number\ of\ nodes\ in\ a\ graph$

Table 7 FCM metrics

Concept	Name	In-degrees	Out-degrees	Centrality	Type
C1	Attitude toward ET	5.482	2.45	7.93	ordinary
C2	Risks and fears of the transition	0.57	1.26	1.83	ordinary
C3	Public trust	0.75	0.75	1.5	ordinary
C4	Environmental friendliness	0.75	0.82	1.57	ordinary
C5	Greenhouse gas emissions	2.3	1.5	3.8	ordinary
C6	Natural gas phase-out	2.76	0.75	3.51	ordinary
C7	Energy ratio (renewable over total)	1.48	1.81	3.29	ordinary
C8	Ease of switch between energy providers	0.7	0.81	1.51	ordinary
C9	In-home thermal comfort	1.42	0.85	2.27	ordinary
C10	The energy label of buildings	1.42	0.71	2.13	ordinary
C11	Regulatory support	1.31	5.04	6.35	ordinary
C12	Research support	1.74	3.43	5.17	ordinary
C13	New businesses and jobs	1.95	1.23	3.18	ordinary
C14	Investment in ET	1.23	2.04	3.27	ordinary
C15	Household expenditure on energy	1.66	0.85	2.51	ordinary
C16	Price of energy needed for heating	0.7	1.92	2.62	ordinary

Comparing the value of the FCM metrics in Table 7, it becomes clear that the attitude toward ET has the highest centrality. This peak relates to the high connectedness of this concept to the whole system, which is in line with the main flow of the first survey and the final goal of the TAM. As it has much more in-degree value than out-degree, it seems a better idea to make it more of the goal of the scenarios. Considering the following top central concepts after the attitude, it is anticipated that regulatory and research support, as well as environmental concepts, make the highest difference in the system.

4.3. Scenario analysis

Having prepared the FCM, it can be employed in a variety of ways for decision-making purposes, the main of which is scenario analysis. A scenario is a hypothetical condition in which the FCM is intended to give the outputs before the condition happens in reality. Thus, as there is no limitation in the number of WHAT-IF scenarios, this research focuses on five selected ones to give the idea of how differently the system would behave when the conditions change from the worst to the best-case scenarios. The purpose of the scenario section of this thesis is two-fold. Firstly, to validate the decision support tool, demonstrating its usefulness and ensuring that its outcomes are reasonable. Secondly, to simulate and interpret a few key scenarios upon which key recommendations can be made on the ET of the DHSs in Leeuwarden.

Table 8 summarizes the features of every scenario from scenario one to scenario five. Scenario one is intended to investigate what would have to happen if the current upward trend of the rate of natural gas experienced a sudden sharp increase. In this democratic ecosystem, the goal is to boost the residents' attitude because the transition needs more public support and to achieve that, research centers were mobilized to give effective solutions to manage this critical condition.

Moving on to scenario two which aims to highlight the role of regulatory support and good government by increasing them to the highest level with keeping the same hypotheses as scenario one. In contrast to the previous scenario, scenario three bolds the unpleasant outputs of scenario one where regulatory support and governing were at the poorest level.

The fourth scenario is focused to evaluate the latest passed law for collective heat grids in the Netherlands. The consultation period of this law finished in August 2020, and it is currently being enforced (Ministry of Economic Affairs and Climate Policy, 2022). It has been included in the law to give municipalities more control options to promote DHSs and better safeguard public interests altogether. Local and state governments have the highest motivation to make this new law work. The recommendations of research centers have been collected in addition to the stakeholders' opinions. There is also a significant emphasis on the environmental friendliness of the solutions and initiatives. However, some stakeholders from the supply side believe this new law threatens their investments and the

risks of it have risen. Thus, this scenario tries to figure this factor out what if new investments got frozen as a result of the high perceived risks. Unlike this scenario, the next scenario has been run to give an understanding of what if these concerns and risks were addressed successfully.

Table 8 What if scenarios

Scenario	Conditions
S1	• The sharp rise in natural gas price • Improvement of residents' attitude toward ET • Heavy support for the transition from research centers
S2	• Scenario one + regulatory support and good governing
S3	• Scenario one + bad regulatory support and bad governing
S4	• Strong regulatory and research support • High risks of new investments • Ensuring the reduction of GHG emissions
S5	• Scenario four with minimizing the risks of new investments

4.3.1. Scenario one

This scenario involves a sharp rise in the natural gas rate, which is needed to boil water for heating. This increase would act as a catalyst for the ET and raise the energy ratio (E_ren/E_tot) as a result. This is because renewable business cases would become more feasible financially as burning natural gas becomes less economical. However, currently, the price of renewable heating energy follows the natural gas rate, which can raise residents' concerns as well. Therefore, the result of the scenario could give the resultant idea of this contradiction, which can be followed in Figure 21.

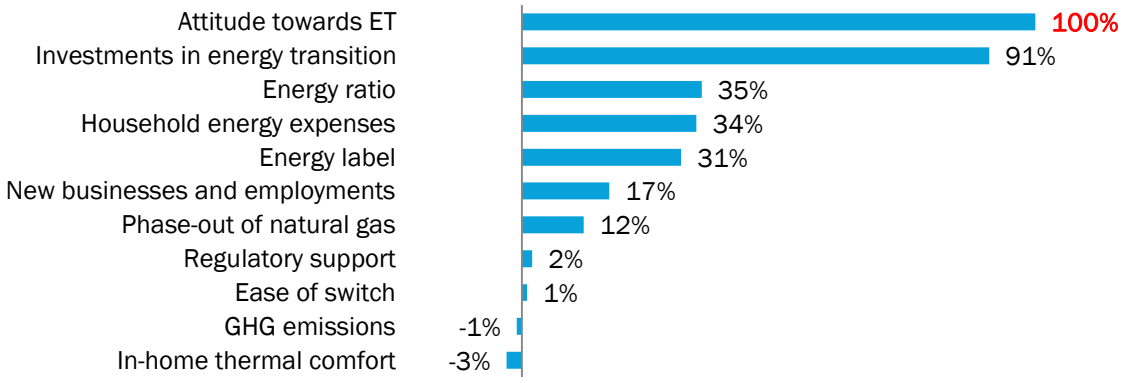


Figure 21 Output of scenario one (with hyperbolic tangent)

According to the above bar chart, in a scenario where a considerable improvement in the residents' attitude toward the ET happened, new funds would have to be invested in the ET

(91%). These new investments would partly lead to a rise in the contribution of RE (by 35%). Another part of these new funds would have to be allocated to the upgrade of the energy labels of residential buildings. Besides, new investments could boom new businesses and create job opportunities, which finally end up in a better residential attitude.

It is an interesting point that this attitude enhancement would come true despite a 34% rise in household energy expenses. This mostly results from the positive environmental impact of RE in addition to the ease of switching between energy providers, which finally makes a better attitude. The shares of other possible changes in this scenario are negligible; however, one would think of the effect of the decline in in-home thermal comfort by 3%. Since this scenario would require a considerable improvement in the energy labels of the buildings, this little concern could be ignored.

4.3.2. Scenario two

In this scenario, it can be analyzed how the outputs of the first scenario would change if regulatory support was mobilized to facilitate the ET. The comparison of Figure 22 with Figure 21 illustrates that with focused regulatory support, the same high new investment would have to be absorbed in the transition; however, with a higher contribution of funds to energy labels of the buildings, households' energy expenses would go up less and in-home thermal comfort would remain unchanged. Also, the following figure shows that with the regulatory support the ease of switch would rise from 1% in scenario one to 7% in scenario two, and in the end, by 2% GHG emissions would go down.

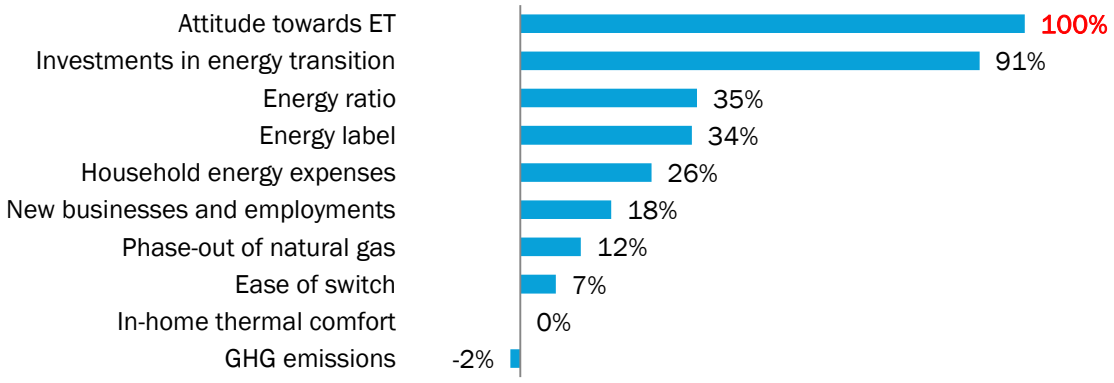


Figure 22 Output of scenario two (with hyperbolic tangent)

4.3.3. Scenario three

Unlike scenario 2, if the government and regulations failed to support the ET effectively, dissatisfactory outputs would appear. These outputs would come out although the effort seems to be made in favor of the residents' attitude toward the transition. An example of this bad governing could be a combination of incorrect measures including:

- Discouraging the ease of switch through monopolizing the market
- Downgrading environmental standards of energy plants to reduce costs
- Issuing permits for poor energy label buildings as an affordable housing scheme
- Ignoring research findings and researchers' recommendations

Although each of the above-mentioned ways could be taken as a solution for a specific case, however, for the case of Leeuwarden, the combination of them would bring about the worst scenario outputs as shown in Figure 23. In this scenario, household energy expenses would grow sharply (+153%), and to address this problem, policies would focus on making compensations for financially harmed residents like affordable housing that are poor energy-labeled (-80%). This measure would not only deteriorate in-home thermal comfort (-67%) but also end up in high growth of GHG emissions (+48%), which would damage public trust (-27%) because the residents have access to the statistics on air pollution thus they would notify the downgrade of air quality. This fall in the public trust would worsen the residents' attitude and as a result, perceived risks and fears of transition would rise. Consequently, investors would participate in the transition less while this scenario needs so many new funds (91%). Therefore, the level of consequences of the chain of causal relationships in the FCM can be analyzed in this way.

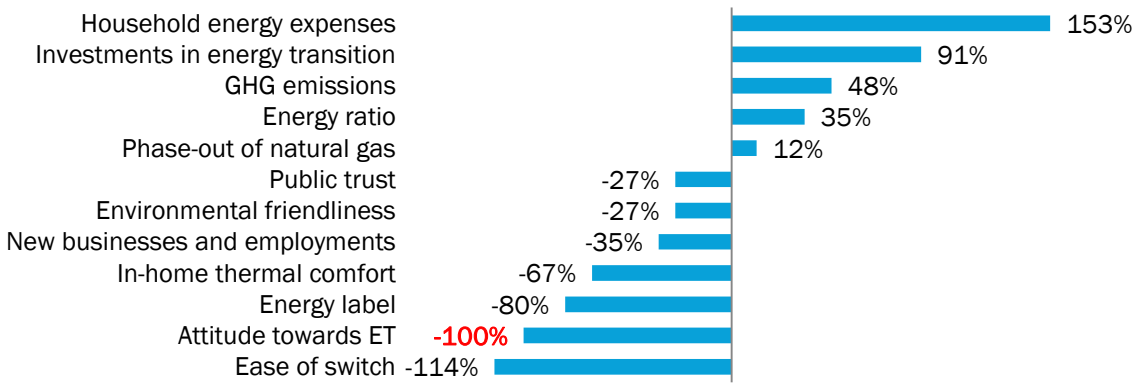


Figure 23 Output of scenario three (with hyperbolic tangent)

4.3.4. Scenario four

This scenario is intended to evaluate the recently passed Dutch law, named Collective Heat Supply Act (CHSA). As included in the law, the new tariff system will be more cost-based to eventually ensure the consumers will be charged fairly. One conservative view from the supply side would be that this new law would threaten their profits, and the risk of investment has increased therefore they would communicate opposed to the change.

Having been introduced to this law, the initial discussions with the governors during the design of the first survey approved these opposing reactions. Hence, it would be a practical scenario in which the risk of investment increased, and investors were less encouraged to develop this market owing to a cut-down on their profits.

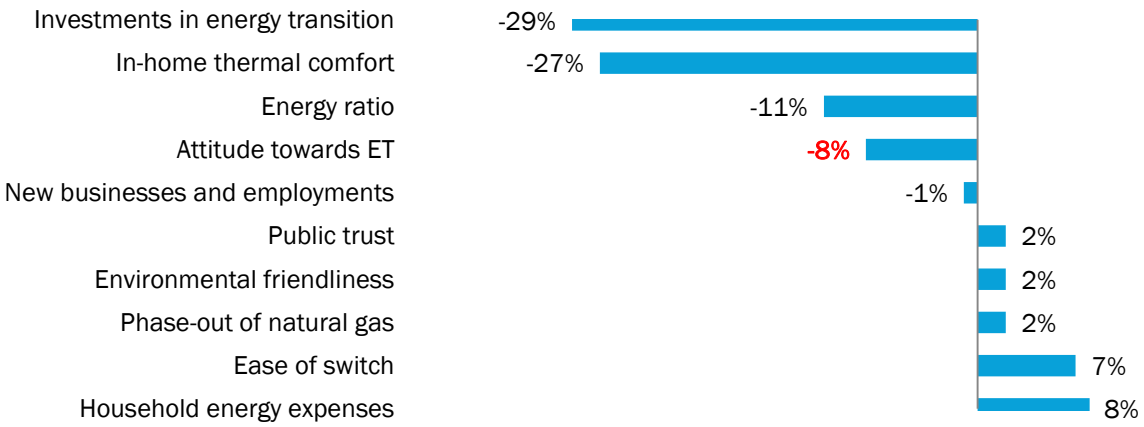


Figure 24 Output of scenario four (with hyperbolic tangent)

As Figure 24 Shows, despite all the efforts made to regulate the district heating market better, new investments would fall by roughly a third due to high perceived risks. This decline would raise the residents' concerns in several ways. This is because the investments would be allocated to three concepts, namely the upgrade of the energy labels, the growth of new businesses, and the boost of energy ratio. Thus, the lack of investments, in the end, would affect the residents' attitude adversely by 8%. This is a logical result since experts also believe ET of DHS from 3rd generation to the 4th would cause a decrease in the temperature of water in the heating doublet (see Figure 25).

In addition, the balance in this scenario has reached a negative change in energy ratio, which means that the boost of energy ratio would be such difficult that to make the energy

mix environmentally friendly, other methods like carbon capturing and emission filtrations would come to the agenda again. This is not a favorable output for this scenario because the delay of ET would be extended again.

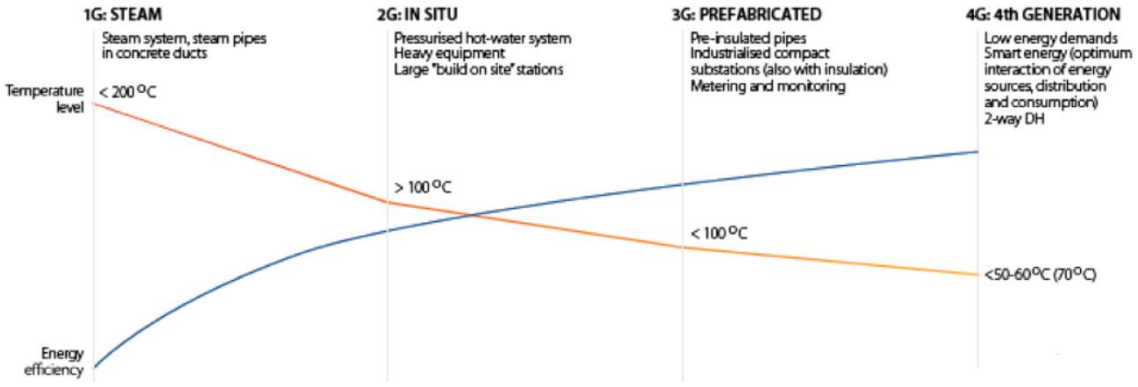


Figure 25 Illustration of the concept of 4th Generation District Heating in comparison to the previous generations (Lund et al., 2014)

4.3.5. Scenario five

In contrast to scenario four, if the new law for DHSs communicated the stakeholders of the supply-side well and addressed the risks of new investments in the transition, rewarding results would come out. As it can be seen in Figure 24, with no change in the residents' attitude toward the transition, the policy would achieve its targets as the energy ratio would rise by 12%. Besides, in comparison to the 4th scenario, the phase-out would triple and the financial burden on households would drop by half.

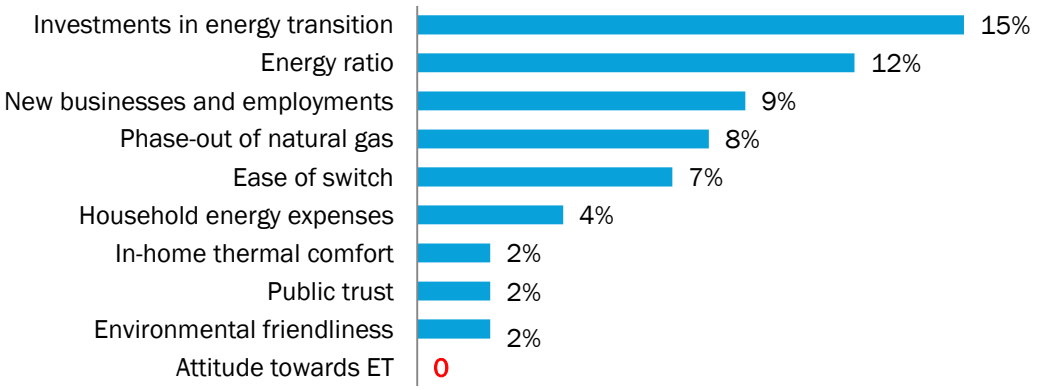


Figure 26 Output of scenario five (with hyperbolic tangent)

4.3.6. Summary of the scenarios

In the previous section, the five scenarios made to experiment with the functionality of the FCM were discussed from the viewpoint of the resulting percentage changes in the system's components. Though, it should again be noted that the mentioned numbers are only intended to facilitate qualitative comparisons and any quantitative conclusions from these numbers should never be drawn. Qualitative summaries from the results could be produced for different purposes. For instance, one could only want to know how different the trend of some of the variables would be in various scenarios as shown in Table 9. In these tables, the trends can be compared and seen the influence on the residents' attitude towards the ET. These results could also be inputs of a multi-criteria decision-making model (MCDM) to make another comparison method as well. As it is observable, the positive trends are green and the negative ones are red.

Table 9 Trend of changes in five variables derived from energy quadrilemma (Editorial Applied Energy, 2016)

Scenario	Residents Attitude	New businesses	Energy expenditure	Thermal comfort	Ease of switch	Environmental friendliness
S1	↑↑↑↑	↑	↑↑	↓	↑	UC
S2	↑↑↑↑	↑	↑↑	UC	↑	UC
S3	↓↓↓↓	↓↓	↑↑↑↑↑↑	↓↓↓	↓↓↓↓	↓↓
S4	↓	↓	↑	↓↓	↑	↑
S5	UC	↑	↑	↑	↑	↑

*UC: unchanged

Another way of comparing the results of various scenarios could be the ranking of a number of top changed variables in each scenario and prioritizing the different concepts in policymaking processes. For instance, when it is observable that new investments receive the highest changes in nearly all scenarios, it can be concluded that the system is more economics-oriented than environmental-oriented for example.

Table 10 Ranking of changes in various variables

Scenario	Rank 1	Rank 2	Rank 3	Rank 4	Attitude
S1	New investments	Energy ratio	Household expenses	Energy label	↑↑↑↑
S2	New investments	Energy ratio	Energy label	Household expenses	↑↑↑↑
S3	Household expenses	Ease of switch	New investments	Energy label	↓↓↓↓
S4	New investments	Thermal comfort	Energy ratio	Household expenses	↓
S5	New investments	Energy ratio	New businesses	Ease of switch	UC

*UC: unchanged

Also, in all scenarios, the outputs show that the FCM enables policy-makers to consider the impact of non-social concepts on the residents' attitude towards the ET. This knowledge

would be so beneficial especially when the prerequisite of a scenario is the participation of the residents, and the user can see if this quality is likely to achieve in each case.

5. Recommendations and limitations

5.1. Recommendations

Finding 1: according to the 1st survey, a quarter of the participants did not have prior knowledge about the future development of DHSs, and most of them had not decided if they would be connected to the DHSs (if given this chance).

Recommendation: holding information campaigns targeting these residents seems essential; otherwise, they might conservatively refuse to join the ET scheme, and consequently, the business cases become less financially feasible. These campaigns should address at least four important concepts of finding 2.

Finding 2: according to the 1st survey, the residents have almost equal concerns about what would happen to these concepts after the transition: their energy expenses, in-home thermal comfort, environmental friendliness of heating energy, and ease of switching between energy providers. While the given order of the four concerns is from the most to the least important, in the two poor FCM scenarios, the first two concerns experienced adverse changes the most.

Recommendation: decision-making models of the ET should include these four important concerns, and the weight of each of the concepts should be adjusted based on the level of concerns derived from the residents' survey. The order of the concerns is better to be considered when making decisions about the priorities of policies; however, as the FCM outputs signify, in poor scenario making, the first two concerns worsen the most. This indicates that addressing expenditure and thermal comfort should be prioritized highly.

Finding 3: according to the 1st survey, most residents expect their energy contracts with energy providers to be transparent about their concerns.

Recommendation: The contract should cover all aspects clearly, especially with the residents' concerns mentioned in finding 2. As introduced, the new Dutch law for DHSs is

price-oriented and wants the municipalities to ensure the fairness of prices; however, the composition of the prices is useful information the residents are curious to have. In-home thermal comfort additionally needs to be guaranteed for example by setting a clear range of temperature at the inlet of the houses. Besides, new investments should diversify the market in favor of competition between energy providers, and having this option should be included in heating energy contracts. Last but not least, the environmental friendliness of the energy mix consumed for heating should never be sacrificed for the sake of other concepts.

Finding 4: having compared the scenario results, new investments seem to be the top non-social influencer concept of the FCM when a scenario targets the prevention of a fall in the residents' attitude towards the ET.

Recommendation: since new investments should not raise the residents' key concerns, these new investments should partly be allocated to diversify the RE market not only to achieve this goal but also to help the second leading concept, ease of switch between energy providers. Also, as the upgrade of DHSs means lower grid temperatures, energy labels of the buildings should be upgraded as well, which needs other funds.

Finding 5: according to the 1st survey, half of the respondents do not know the energy label of their buildings. The behavior of the FCM highlights its importance so that its knowledge ought to prevail among the residents.

Recommendation: even though new policies have made the labeling process mandatory for to-be-built housing, most of the concerns do not come from these buildings but the already-occupied ones. This necessity needs urgent plans because the energy label was one of the top influencing concepts in the three scenarios which did not decrease the residents' attitude. If this is neglected, dissatisfaction and complaints due to the low temperature of the heat grid after the transition would work as a barrier on the way of the transition process.

Finding 6: according to the FCM scenarios, the accuracy of the values applied to the interrelations has more impact on the variables that rank after the 1st in the list of changed variables.

Recommendation: the interpretation of the concepts placed after the top variable should be done conservatively and if they are so important, more reliable measurements should be taken. One of the effective tools could be the participatory method with the collaboration of a focused expert group. Also, these experts had better contribute to the development of the FCM actively.

Finding 7: according to the 2nd survey, experts believe that an increase in RE contribution to the heating energy profile would not much result in a household's higher energy expenditure, while the residents are more concerned about this possible change.

Recommendation: with assuming the correctness of the experts' insight, informing residents about the composition of their energy expenses in all stages of the ET seems necessary. If this information has already been provided, informative public debates with the participation of the representatives of residential areas would help the clarity of the scheme.

Finding 8: according to the scenarios, regardless of the attitude level, this ET necessitates new investments that ought to be incentivized to hit multi targets.

Recommendation: new funds should firstly target increasing the ease of switch, and this had better be regulated in favor of quality and price. Secondly, as an inseparable element of the plan, improvement of the energy label of buildings should be pursued and accelerated alongside its promotion, especially to unaware residents. Thirdly, new investments would lead local businesses to flourish, which would bring residents' support not only for the financial profits but for the reduction of GHG emissions which is a common interest of the residents and the government.

Finding 9: according to the scenarios, even though the rising natural gas rate is making the heating energy more expensive, the residents' attitude would not necessarily worsen after the ET. This clearly shows the nonlinear behavior of this complex system.

Recommendation: this upward trend is making RE business cases more financially feasible in the first place, which would absorb new investments as a key to the success of the ET; however, comprehensive laws and monitoring systems are required to steer this process well. The price-based CHS act has the potential to succeed in this regard, but it needs to

communicate with current and potential energy providers effectively to address their perceived risks of investment. Otherwise, the ET process might end up in the deterioration of the residents' attitude towards the ET because new investments would freeze due to high perceived risks.

5.2. Limitations

First of all, as mentioned, the residential survey suffered from a small sample size. In other words, 73 responses are still far from the ideal sample size of 1000 households. According to these small contributions, it can be stated that finding an effective way to persuade residents is one of the biggest challenges this study encountered. Although this survey invited all genders to participate, females participated much less than was expected. Hence, overall, the results of this survey could only be considered indicative and are not generalizable, especially because online surveys are not the best means to produce perfect samples. Secondly, the time plan of the research was tough; otherwise, the continuation of approaching people in person would have provided more participation despite some refusals.

Thirdly, both surveys might have an underrepresentation of elderlies and technophobes that normally use social media less than others, and this is because the data was collected online. Fourthly, the respondents might not have entirely read long texts in the survey or got tired on have way through and therefore they have not chosen their real opinions from the provided choices. Fifthly, the FCM could have been generated with a participatory method among more varied experts and stakeholders who refused to collaborate in this independent research. Sixthly, having the chance of interviewing both groups would have considerably worked to the advantage of the reliability of the data. Seventhly, to avoid lengthy questionnaires, the least questions were asked to measure each desired concept, while with more questions, not only would more reliable output have been produced but the consistency of results could have been checked. Eighthly, this study would be more complete with the consideration of more indicators such as energy equity. The inclusion of such indicators might have led this research to draw different conclusions. Finally, to make this research feasible in this short period, industries were excluded from energy consumers and their interaction with this system would have made different results.

6. Conclusions and future research

6.1. Conclusions

As the ET process in Leeuwarden needs to be accelerated to meet the upstream goals of the nation, this research focused on the provision of a decision support tool for the ET of DHSs in Leeuwarden. The chosen platform was an FCM customized in a way that the emphasis was on the residents' attitudes based on the TAM. According to the results of an online survey spread among the residents, four major residential concerns including household energy expenses, in-home thermal comfort, environmental friendliness, and ease of switch were chosen to steer the attitude in the FCM.

In addition to the abovementioned core of the map, several non-social variables were selected to be included in the FCM, namely regulatory support, research support, price of energy required for heating, the contribution of RE, energy label of buildings, new investment in the ET, risks of new investments, fears of the transition, new businesses/jobs, phase-out of natural gas, GHG emissions, and public trust. These variables were interconnected themselves and influenced the residential concerns with different levels of impact as well. Another online survey was spread among local energy experts and scholars to understand these levels. Having completed the FCM, it was tested in five different scenarios, and its results were interpreted. Having analyzed the five scenarios, it was concluded that the FCM would enable decision-makers to evaluate their upcoming policies before experiencing their real results in reality. This way, decisions could be modified and the outputs could also be compared in different hypothetical scenarios. According to the comparisons of the outputs of the scenarios, the results had better be used qualitatively because the reliability of the results of the surveys cannot be ensured 100%. However, the FCM has a great ability to show the trends and identification of the top changed concepts defined in the mental landscape.

In the atmosphere of the generated FCM, growth in the price of natural gas, needed for heating, would not threaten the ET but has the potential to work as a catalyst. Because it will convince more investments to accelerate ET; however, the accumulation of new investments in limited options would discourage the ease of switch and then raise the residents' concerns. As the ET would cause a fall in the temperature of the heat network, to

prevent thermal discomforts, awareness/enhancement of the energy label of residential buildings is the key to the success of the ET, and this does need new investments. Besides, any price-based law e.g. the CHS Act, which is intended to regulate energy pricing fairly, needs to communicate with all stakeholders well. In this sense, addressing the investors' concerns is as significant as the residents'. Furthermore, the structural analysis of the FCM identified this system as democratic; however, more effort needs to be made to prove that it is still democratic even though this new law empowers municipalities to intervene more.

In the analysis of CAS, FCM could support decision-making more effectively than pure theoretical frameworks e.g. TAM and energy trilemma. This is because firstly, some indicators of these two have numerous complicated aspects. For instance, affordability as one of the most frequently used indicators could be measured using over 300 sub-indicators, according to Savocool & Mukherjee (2011). This would make the use of TAM and trilemma complex. On the contrary, in the FCM, which breaks down CAS into simple concepts, the desired aspects of indicators are clear and their inter-relations are easy to follow as well. Secondly, TAM misses some steering contextual concepts and has not established key inter-connections of indicators influencing attitudes. In reality, indicators are not only interwoven but also variable from one context to another. For instance, the evaluation of the CHS Act showed that there are some concepts connecting indicators, yet not included in the TAM, which impact attitudes considerably. This is also the case when it comes to energy trilemma. In the example of CHS, the act could improve the system based on the energy trilemma, while it was demonstrated that the policy would result in contradictory outcomes in different circumstances which the trilemma is not able to consider. Finally, compared to TAM and energy trilemma, FCM visualized a CAS as more understandable, and a short structural analysis of the system can give very helpful insight into the behavior of CAS in different scenarios. This scenario-making is a feature with whom TAM has not been developed to assist yet.

6.2. Future research

This research hopes to provide a basis for a qualitative study that will provide an in-depth insight into the residents' concerns and attitudes towards this particular ET in the future. Besides, a comparison of the results of future interviews will evaluate the reliability of the

results of the two surveys of this research. Also, another important aspect to study more in-depth is the use of a multi-level perspective theory as the geothermal heat transition, the main source of future RE for DHSs in Leeuwarden, is a niche among the heating technologies which can more concepts to the FCM and help the accuracy of the results. Finally, local experts could be involved in a participatory method to customize the FCM not just giving weights to the links.

7. References

Acheilas, I., Hooimeijer, F., & Ersoy, A. (2020). *A decision support tool for implementing district heating in existing cities, focusing on using a geothermal source*. Energies, 13(11). https://doi.org/10.3390/en13112750

Afonso, T. L., Marques, A. C., & Fuinhas, J. A. (2021). *Does energy efficiency and trade openness matter for the energy transition? Empirical evidence for countries in the Organization for Economic Co-operation and Development*. Environment, Development, and Sustainability, 23(9), 13569–13589. https://doi.org/10.1007/s10668-021-01228-z

Age classes by genderMunicipality of LEEUWARDEN, old-age index, and the average age of residents. (2022). Retrieved June 17, 2022, from https://ugeo.urbistat.com/AdminStat/en/nl/demografia/eta/leeuwarden/23055904/4

Auf, G. (2010). A communication strategy for striking social acceptance of geothermal energy in the Netherlands. Master thesis Report – MSc Science Communication, TU Delft University. Retrieved on August 7th, 2022 from https://repository.tudelft.nl/islandora/object/uuid%3Abb2b536e-114c-4d66-a759-0178e6f315d1

Barros, P., Ng Fat, L., Garcia, L. M. T., Slovic, A. D., Thomopoulos, N., de Sá, T. H., Morais, P., & Mindell, J. S. (2019). *Social consequences and mental health outcomes of living in high-rise residential buildings and the influence of planning, urban design and architectural decisions: A systematic review*. Cities, 93(June 2019), 263–272. https://doi.org/10.1016/j.cities.2019.05.015

Bickman, L., & Rog, D. (2014). *The SAGE Handbook of Applied Social Research Methods*. The SAGE Handbook of Applied Social Research Methods, 413–434. https://doi.org/10.4135/9781483348858

Bouwgroep Dijkstra Draisma, Ennatuurlijk, Energie Beheer Nederland, & Shell. (2022). *Warmte van Leeuwarden home page*. Retrieved February 28, 2022, from https://warmtevanleeuwarden.nl/

Cousse, J., Trutnevyte, E., & Hahnel, U. J. J. (2021). Tell me how you feel about geothermal energy: Affect as a revealing factor of the role of seismic risk on public acceptance. *Energy Policy*, *158*, 112547. https://doi.org/10.1016/J.ENPOL.2021.112547

Carvalho, J. P. (2013). On the semantics and the use of fuzzy cognitive maps and dynamic cognitive maps in social sciences. *Fuzzy Sets and Systems*, *214*, 6–19. https://doi.org/10.1016/J.FSS.2011.12.009

Clancy, J., & Feenstra, M. (2019). *Women, Gender Equality and the Energy Transition in the EU*. EU policy Department for Citizens' Rights and Constitutional Affairs. PE 608.867. http://www.europarl.europa.eu/supporting-analyses

de Wildt, T. E., Boijmans, A. R., Chappin, E. J. L., & Herder, P. M. (2021). *An ex-ante assessment of value conflicts and social acceptance of sustainable heating systems: An agent-based modeling approach*. Energy Policy, 153. https://doi.org/10.1016/j.enpol.2021.112265

Editorial Applied Energy. (2016). *Energy quadrilemma and the future of renewable energy.* Applied Energy, 108, 1–6. https://doi.org/10.1016/j.energy.2016.07.145

Ennatuurlijk. (2021). *Warmtetransitie Midden*. Retrieved from https://youtu.be/AKWJ2Q7Itgs?t=2170

Ennatuurlijk. (2022). *Heat in Leeuwarden in 2030 and 2040*. Retrieved from https://ennatuurlijk.nl/warmtenetten/leeuwarden/warmte-in-leeuwarden-in-2030-en-2040

Exadaktylos, F., & van den Bergh, J. (2021). *Energy-related behavior rebounds when rationality, self-interest, and willpower are limited*. Nature Energy, 6(12), 1104–1113. https://doi.org/10.1038/s41560-021-00889-4

Gray, S. A., Gray, S., Cox, L. J., & Henly-Shepard, S. (2013). Mental Modeler: A fuzzy-logic cognitive mapping modeling tool for adaptive environmental management. *Proceedings of the Annual Hawaii International Conference on System Sciences*, 965–973. https://doi.org/10.1109/HICSS.2013.399

Gaziulusoy, A. I., & Brezet, H. (2015). Design for system innovations and transitions: a conceptual framework integrating insights from sustainability science and theories of system innovations and transitions. *Journal of Cleaner Production*, *108*, 558–568. https://doi.org/10.1016/J.JCLEPRO.2015.06.066

Guðlaugsson, B., Fazeli, R., Gunnarsdóttir, I., Davidsdottir, B., & Stefansson, G. (2020). Classification of stakeholders of sustainable energy development in Iceland: Utilizing a power-interest matrix and fuzzy logic theory. *Energy for Sustainable Development*, *57*, 168–188. https://doi.org/10.1016/J.ESD.2020.06.006

Hernández, D. (2015). *Sacrifice Along the Energy Continuum: A Call for Energy Justice HHS Public Access Author manuscript. Environmental Justice*, 8(4), 151–156. https://doi.org/10.1089/env.2015.0015.Sacrifice

Kok, K. (2009). The potential of Fuzzy Cognitive Maps for semi-quantitative scenario development, with an example from Brazil. *Global Environmental Change*, *19*(1), 122–133. https://doi.org/10.1016/J.GLOENVCHA.2008.08.003

Kern, F. (2012). *Using the multi-level perspective on socio-technical transitions to assess innovation policy*. Technological Forecasting and Social Change, 79(2), 298–310. https://doi.org/10.1016/j.techfore.2011.07.004

Friesland - Netherlands | Data, and Statistics - knoema.com. (2022). Retrieved June 17, 2022, from https://knoema.com/atlas/Netherlands/Friesland

Kokkinos, K., Karayannis, V., & Moustakas, K. (2020). Circular bio-economy via energy transition supported by Fuzzy Cognitive Map modeling towards the sustainable low-carbon environment. *Science of The Total Environment*, *721*, 137754. https://doi.org/10.1016/J.SCITOTENV.2020.137754

Leeuwarder Courant. (2022). *Optimisme over slagen geothermie Leeuwarden*. *Leeuwarder Courant*. https://warmtevanleeuwarden.nl/wp-content/uploads/2022/02/Artikel-LC-19-februari.png

Ponni, M., & Baskar, R. (2015). *A study on comfort temperature and thermal efficiency of buildings*. International Journal of Engineering and Technology, 7(4), 1469–1477.

Ministry of Economic Affairs and Climate Policy. (2022). *Toelichting Wet collectieve warmtevoorziening internetconsultatie.* https://www.internetconsultatie.nl/warmtewet2/document/5930

Ministerie EZK. (2019). *Climate policy*. https://www.government.nl/topics/climate-change/climate-policy

Molin, E. (2005). *Causal Analysis of Hydrogen Acceptance*. Transportation Research Record: Journal of the Transportation Research Board, 1941(1), 115–121. https://doi.org/10.1177/0361198105194100114

Nikas, A., Doukas, H., van der Gaast, W., & Szendrei, K. (2018). Expert views on low-carbon transition strategies for the Dutch solar sector: A delay-based fuzzy cognitive mapping approach. *IFAC-PapersOnLine*, *51*(30), 715–720. https://doi.org/10.1016/J.IFACOL.2018.11.208

Otten, R. (2022). *De tariefverhogingen van Ennatuurlijk zijn onacceptabel*. https://vrijestadsverwarmingmarkt.petities.nl/

Özesmi, U., & Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecological Modelling*, *176*(1–2), 43–64. https://doi.org/10.1016/J.ECOLMODEL.2003.10.027

Perlaviciute, G., Steg, L., Contzen, N., Roeser, S., & Huijts, N. (2018). Emotional Responses to Energy Projects: Insights for Responsible Decision Making in a Sustainable Energy Transition. *Sustainability 2018, Vol. 10, Page 2526*, *10*(7), 2526. https://doi.org/10.3390/SU10072526

Sovacool, B. K., & Mukherjee, I. (2011). *Conceptualizing and measuring energy security: A synthesized approach*. Energy, 36(8), 5343–5355. https://doi.org/10.1016/j.energy.2011.06.043

Stichting Platform Geothermie. (2018). *Master Plan Geothermal Energy in the Netherlands*. *May*. www.geothermie.nl

Szwed, P. (2013). *Application of Fuzzy Cognitive Maps to Analysis of Development Scenarios for Academic Units*. *17*(2). https://doi.org/10.7494/automat.2013.17.2.229

Thurner, S., Klimek, P., & Hanel, R. (2018). *Introduction to the Theory of Complex Systems*. *1*. https://doi.org/10.1093/OSO/9780198821939.001.0001

Trading economics. (2022). *Natural gas*. Retrieved from https://tradingeconomics.com/commodity/natural-gas

Unternährer, J., Moret, S., Joost, S., & Maréchal, F. (2017). *Spatial clustering for district heating integration in urban energy systems: Application to geothermal energy*. Applied Energy, 190, 749–763. https://doi.org/10.1016/j.apenergy.2016.12.136

Yang, L., Danwana, S. B., & Yassaanah, F. L. I. (2021). An Empirical Study of Renewable Energy Technology Acceptance in Ghana Using an Extended Technology Acceptance Model. *Sustainability 2021, Vol. 13, Page 10791*, *13*(19), 10791. https://doi.org/10.3390/SU131910791

8. Appendix

8.1. The flyer of the first survey

8.2. The English version of the 1st survey:

Link to the online version: residents' survey

ENERGY CASE STUDY - SOCIAL ACCEPTANCE OF GEOTHERMAL HEAT GRID

Important: This questionnaire is meant for the residents of Leeuwarden and individuals 18 years old or older.

Heating transition

Currently, Dutch regional governments are developing their Regional Energy Strategies (RES) for dealing with sustainable heat demand to make a way to phase out natural gas in the heating system.

Collective heat grids in Leeuwarden

Besides the national natural gas grid, there are already two collective heat grids operating in Leeuwarden. A collective heat grid is a central heat plant connected to a group of households. In part of Camminghaburen, the plant is powered by 100% natural gas and in Techum the plant is powered by both biogas and natural gas. This questionnaire is about

your opinion about the possible upcoming expansion of the heat grid, which is going to be powered by geothermal energy too.

Why this questionnaire?

I am a master's student in environmental and energy management from the University of Twente. For my master's thesis, I have been focusing on the management of the energy transition of DHSs in Leeuwarden. I would like you to participate in this independent survey about the attitude of residents in Leeuwarden towards the upcoming heat network or the current ones. I do appreciate your participation in advance.

For more information about the geothermal heat grid in Leeuwarden, you can get more information on the below websites:

https://ennatuurlijk.nl/warmtenetten/leeuwarden/aardwarmte-in-leeuwarden

https://warmtevanleeuwarden.nl/

Consent form

This questionnaire is by no means mandatory. You may stop filling it out anytime by closing the browser. If you have any questions or remarks about the questionnaire beforehand, feel free to email me via: r.shahbazi@student.utwente.nl

Your privacy will stay protected because this questionnaire is anonymous. In this questionnaire, no personally identifiable information will be collected. There are no questions that will ask for things such as your name, e-mail address, or phone number. In addition, only summaries and analyses of the data and no individual data will be shared with peers or professors. Only summaries and analyses can be published. The collected data of individual responses will be deleted after the completion of this research.

1. Hereby I say that I have read the above consent form and agreed with it.

◯ Yes

◯ No (do not fill this out)

2. Before reading the introduction of this questionnaire, did you hear about the existing collective heat grid in Leeuwarden?

◯ Yes

◯ No

3. Before reading the introduction of this questionnaire, were you aware that the heat grid is going to be expanded?

◯ Yes

◯ No

4. Do you live in Techum, Camminghaburen, or somewhere else in Leeuwarden?

◯ Techum

◯ Camminghaburen

◯ Somewhere else

5. What is your age:

◯ 18-30

◯ 31-40

◯ 41-50

◯ 51-60

◯ 61-70

◯ Older than 70

6. What is your gender?

◯ Male

◯ Female

◯ Other

◯ Prefer not to say

7. What is your occupation? (Job/Study)

Enter your answer …

8. What is your annual gross income (in Euro)? If you're unemployed, skip this question.

◯ Less than 10000

◯ 10000-20000

◯ 20000-30000

◯ 30000-40000

◯ 40000-50000

◯ 50000-100000

◯ 100000-200000

◯ Over 200000

◯ I don't wish to provide this answer

9. What is your heat connection/what source do you use for heating? (more options are possible)
   - ◯ Natural gas
   - ◯ Electricity
   - ◯ Collective heat grid
   - ◯ Other, please specify
10. If you chose "other" for the previous question, please specify your energy source below.

    Enter your answer ...

11. Do you live in an owner-occupied house or are you a tenant?
    - ◯ Owner-occupied
    - ◯ Tenant
    - ◯ Other, please specify
12. If you chose "other" for the previous question, please specify your living situation below.

    Enter your answer ...

13. After the transition to the new heat grid or in case you are already connected to the heat grid, what would you rather have?
    - ◯ Being able to switch between energy providers easily
    - ◯ Not being able to switch given that the energy provider is monitored closely by legislation
    - ◯ The possibility to switch doesn't matter as long as the provided heat is sustainable
14. How much do the following points influence your decision to connect or to stay connected to a collective (geothermal) heat grid?

	A lot	Somewhat	A little	Not at all
Cost of purchasing and installation	◯	◯	◯	◯
Maintenance Cost	◯	◯	◯	◯
Monthly energy bill	◯	◯	◯	◯
Info about upcoming changes within your property	◯	◯	◯	◯
Transparency of your contract with energy providers	◯	◯	◯	◯
In-home thermal comfort	◯	◯	◯	◯
The appearance of to-be-installed home devices	◯	◯	◯	◯
Individual legal right to choose a heat technology, such as solar boiler, electrical boiler, gas boiler, heat pump, etc	◯	◯	◯	◯

Ease of switching to other energy providers	◯	◯	◯	◯
Effect of the renewable heat grid on the local environment	◯	◯	◯	◯
Climate change	◯	◯	◯	◯

15. To what extent would you compromise on the preferences you filled out in the previous question (Q14) for the sake of the following topics?

	A lot	Somewhat	A little	Not at all
Independence of natural gas imports	◯	◯	◯	◯
Climate change	◯	◯	◯	◯
Earthquakes	◯	◯	◯	◯

16. Do you know the energy label of your house?

- ◯ Yes, please specify it in the next item.
- ◯ No

17. If you know the energy label, please specify below:

Enter your answer …

18. Based on your energy label, do you think the heat grid will function as good as the heat of natural gas (would work) in your house?

- ◯ Yes
- ◯ No
- ◯ I don’t know

A collective heat grid has the attribute to give one energy provider an energy monopoly and make it difficult for house-owners to switch to another energy provider.

Note: In The Netherlands, Autoriteit Consument & Markt is monitoring the energy price of energy providers closely.

19. Why do you think it is important to be able to switch to another energy provider? (You can choose more than one item)

- ◯ It does not matter to me to be able to do so
- ◯ For the sake of costs (fluctuations)
- ◯ To opt for a more sustainable one
- ◯ Functionality
- ◯ The change itself
- ◯ Other, please specify in the next item.

20. If you chose "other" for the previous question, please specify your reason(s) below.

Enter your answer …

Almost there …

21. If your house can connect your house to the geothermal heat grid, would you choose to do so?

◯ Yes

◯ No

◯ I don't know

22. Do you have any remarks or any other related issues/topics we should know about?

Enter your answer …

8.3. Text format of the 2nd survey:

Link to the online version: experts' survey

FUZZY DECISION SUPPORT TOOL FOR ENERGY TRANSITION OF DISTRICT HEATING SYSTEM IN LEEUWARDEN

The residential attitude towards the transition

With the benefit of a public survey that has been online since April 2022, the households of Leeuwarden have been asked to share their concerns about various concerns related to the energy transition of the district heating systems (DHSs) in Leeuwarden (LWD). This online questionnaire, which is in Dutch, has been designed using the Microsoft Form platform. The address is as follows:

https://lnkd.in/eVfgBXST

Based on the residents' measured worries, their attitude toward this change is being evaluated with the application of the technology adoption model (TAM). According to the results so far, the residents have pointed to four concerning concepts as the most important ones; namely, in-home thermal comfort, household expenditure on heating energy, ease of

switch between various heating energy providers, and environmental friendliness of heating energy. In my fuzzy cognitive map (FCM), each of these concerns directly connects to the residents' attitude toward the energy transition. If this attitude goes up, public acceptance follows as well; however, the evaluation of the public acceptance itself is not the intention of my research but it is intended to know how various factors would affect the residential attitude.

Why your kind opinion?

After initial brainstorming and desk research, 11 concepts have been identified relevant to the abovementioned four indicators. This questionnaire is intended to survey your opinion about the strength of the bonds between these relevant concepts. You will kindly determine the strength/score of every relationship via either the star scoring tool or the Likert tool used in the questionnaire. A high score means that the relationship/concept is highly relevant according to your experience/knowledge.
I gratefully appreciate your time and contribution to this survey. Good luck with it!

Consent form

This questionnaire is by no means mandatory. You may stop filling it out at any time by closing the browser. If you have any questions or remarks about the questionnaire beforehand, feel free to contact the researcher. The email address is: r.shahbazi@student.utwente.nl

Your privacy will be protected because this questionnaire is anonymous. In this questionnaire, no personally identifiable information will be collected. There are no questions that will ask for things such as your name, e-mail address, and phone number. In addition, only summaries and analyses of the data will be shared and published.

1. Hereby I say that I have read the above consent form and agreed with it.
   ◯ I consent.
2. What is your profession?
   Enter your answer …

For each question below, choose the assigned scoring tool.

3. With the creation of new businesses and jobs as a result of the energy transition of the district heating systems in Leeuwarden, the residents would get more satisfied with this transition.

Low confidence ☆☆☆☆☆ High confidence

4. There is a chance that some local businesses related to fossil fuels get discouraged due to this energy transition. However, the residents of Leeuwarden would not find it significant but also they would demand it highly.

Low confidence ☆☆☆☆☆ High confidence

5. Some individuals resist changes when they are afraid of the possible dissatisfactory results, which similarly causes a bad attitude in them toward the energy transition of the district heating systems in Leeuwarden.

Low confidence ☆☆☆☆☆ High confidence

6. Amongst all the investors in the energy transition of the district heating systems in Leeuwarden, there are the ones who are reluctant to invest in this transition in the belief of high risks of investment.

Low confidence ☆☆☆☆☆ High confidence

7. After completing the statement below using the following items, to what extent do you think each item is likely?

Statement: To boost this transition, new investments are needed. These investments would ...

	A lot	Somewhat	A little	Not at all
grow businesses and jobs	○	○	○	○
rise the proportion of renewables to the whole	○	○	○	○
drop since the residents have fear of the change	○	○	○	○
decline as the risk of investment exists	○	○	○	○
enhance the energy label of buildings	○	○	○	○

8. The energy label of buildings influences the feeling of in-home thermal comfort which itself influences the consumers' satisfaction with the energy transition of the district heating systems in Leeuwarden.

Low confidence ☆☆☆☆☆ High confidence

9. Research centers are supposed to investigate and introduce effective solutions for how to increase the contribution of renewables to the whole energy profile of the district heating systems in Leeuwarden.
10. The residents have access to the statistics on air pollution while the transition process of the district heating systems in Leeuwarden is making a progress. Therefore, they would notice a boost in air quality during the process of the energy transition, which would work to the advantage of public trust.

Low confidence ☆☆☆☆☆ High confidence

11. After completing the statement below using the following items, to what extent do you think each item is likely?

Statement: Within this transition, if the ratio of renewable energy to the total energy (E_ren/E_tot) for heating goes up, ...

	A lot	Somewhat	A little	Not at all
the temperature of the heating network goes down	○	○	○	○
phase-out of natural gas will be accelerated	○	○	○	○
households' expenditure on energy will rise	○	○	○	○

12. To what extent do you think research support has the potential to work in favor of the following concepts?

	A lot	Somewhat	A little	Not at all
maturing regulations and laws of the transition	○	○	○	○
making new businesses and job	○	○	○	○
addressing greenhouse gas emissions	○	○	○	○

13. Regulatory support has been leading to an enhancement in the energy label of buildings connected to the district heating systems in Leeuwarden.
14. To what extent do you think regulatory and/or governmental support can work in favor of the following concepts?

	A lot	Somewhat	A little	Not at all
quality and quantity of research on the transition	○	○	○	○
control of greenhouse gas emissions	○	○	○	○
the ease of switching between energy providers	○	○	○	○
reduction in the financial burden on residents	○	○	○	○
national energy price for heating	○	○	○	○
residential energy labels	○	○	○	○

new businesses and/or jobs	○	○	○	○

15. After completing the statement below using the following items, to what extent do you think each item is likely?

Statement: with an increase in the residents' attitude toward this heating energy transition, ...

	A lot	Somewhat	A little	Not at all
they would drop their fears of change	○	○	○	○
they would do/ask for more research on the transition	○	○	○	○
more regulatory support would come to help the transition	○	○	○	○

16. Did you find any irrelevant concepts in this questionnaire? If so, specify, please.

Enter your answer ...

17. Is there any other key concept other than the ones that this research has focused on? If so, specify, please.

Enter your answer ...

8.4. List of neighborhood associations and email addresses

Neighborhood associations

Wijkpanel Aldlân (oud)
Wijkpanel Aldlân (nieuw)
Wijkpanel Achter de Hoven
Wijkpanel Bilgaard en Havankpark
Wijkpanel Vlietzone
Wijkpanel Huizum West
Wijkpanel Zuiderburen
Wijkpanel Nylân
Wijkpanel Binnenstad
Wijkpanel Muziek, Transvaal en Vogelwijk
Wijkpanel Westeinde
Wijkpanel de Zuidlanden
Bewonersplatvorm Valeriuskwartier
Wijkpanel Vrijheidswijk
Wijkpanel Heegterp Schieringen
Wijkpanel Camminghaburen
Wijkpanel Wielenpolle
Dorpsbelang Goutum
Dorpsbelang Hempens Teerns
Dorpsbelang Wirdum Swichum
Dorpsbelang Wytgaard
Wijkpanel "De Vrijheidswijk"
Wijkpanel Rengerspark
Wijkpanel Oranjewijk

Wijkpanel Vosseparkwijk
Buurthuis welgelegen
Stichting Westenkwartier
Jongerenwerk Leeuwarden
Wijkscentrum 't knooppunt
Wijkcommité Schepenbuurt
Wijkvereniging de Blokkendoos
Buurthuis kobbekooi
Wijk-en speeltuinvereniging KIO
Wijk en Speeltuin vereniging Gerard Dou/Huizum West
Bestuur Stichting Wijk
Wijkpanel Camminghaburen
St. Leefbaarheid Camminghaburen
MFC Beheerstichting (Camminghastins)
Websiteredactie
Publicatie's dienen uitsluitend digitaal te worden aangeleverd.
Administratie donateurs MFC
Beheerder MFC Camminghastins

Political parties

Groenlinks
D66

Others

Green Office Van Hall Larenstein