The adoption of infrared heating from a quadruple helix perspective

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Preface

Before presenting you my master thesis 'The Adoption of Infrared Heating from a Quadruple Helix Perspective', I would like to thank some people. In the first place, I want to thank my supervisor, Eugen Popa, for always providing very helpful feedback and supporting me during this period. The enthusiasm and pleasant social interactions encouraged me to work hard. Further, my acknowledgement goes to my second reader, Vincent Blok, for providing critical and useful feedback. Also, I would like to thank the participants of the interviews for providing interesting insights about how and what barriers hinder infrared heating from being adopted. Further, I want to thank my fellow students for the in-depth discussions. Finally, I want to thank my family for the moral support.

Abstract

Infrared heating looks promising, however, parties that can potentially benefit from this technology are reluctant in adopting it. According to the quadruple helix theory, the adoption of new technologies depends on the contribution of four different actors: civil society, policy makers, scholars and the industry. These actors represent major parties that are crucial in innovation. The underlying reasons of the reluctant adoption of infrared heating by these different actors are unclear. Therefore, the research question has been constructed as follows: why is infrared heating not adopted yet as mainstream innovation according to the quadruple helix theory? The aim of this research is to understand what barriers and how barriers hinder infrared heating from being adopted by using a quadruple helix approach. To gain insights in the different perspectives interviews will be conducted with the four quadruple helix actors. From the interviews it resulted that civil society turned out to be unfamiliar with the technology and therefore it was not considered as an apparent option as heating method. Furthermore, consumers are not sure if infrared heating contributes to the environment. If consumers do think it is a sustainable technology, they only want to switch if it benefits them financially. Policy makers and scholars currently set full focus on finding alternative sources of energy instead of focusing on infrared heating, which is a technology that can potentially provide energy savings. The industry has a difficult time in spreading the awareness of their product and especially the sustainable responsiveness. These factors form in a nutshell the underlying reasons why infrared heating is not yet adopted as mainstream innovation.

Keywords; infrared heating, quadruple helix, barriers, adoption

Table of contents

1. Introduction

Many buildings in the Western world are heated via a central heating system. Most of the energy used is generated from non-renewable sources, such as natural gas (International Renewable Energies Agency, 2015). With a central heating system all parts of a building are heated simultaneously, while some parts of the building are used to a lesser extent or not used at the same time. Furthermore, during the night most offices and during the day most houses are heated while they are not used. To reduce the impact of this problem smart thermostats allow the heating system to switch on a couple of hours before people enter. Smart thermostats initiate the process to get the atmosphere at the pleasant temperature at the right time (Consumentenbond, 2019). To reach the pleasant atmosphere temperature in a more energy efficient and sustainable way, in comparison to other heating methods, the application infrared heating is a promising technology.

Infrared heating devices convert electricity to infrared radiation which provide heat at a specific location (Munguia et al., 2015). Infrared heating is transmitted as a wave that penetrates the object and the wave is then converted to heat (Sakai & Hanzawa, 1994). Infrared radiation primarily heats objects or persons which then emits heat to the atmosphere. The best-known infrared heating sources are fire and the sun (White, 2012). In contrast to this, convection heating heats the atmosphere, which subsequently heats the object. An example of convection heating are rooms in buildings where people feel warmth because of the high air temperature (The Green Age, 2015). Selective infrared heating is realized by the placement of panels on the walls or on the ceiling, which emits heat to objects and persons in the direction that they are facing. A wired electricity connection has to provide the energy for the panels. The claimed benefits of infrared heating are that the panels only use energy when they are turned on (Electric comfort, 2019). Furthermore, the heat is noticeable as soon as it is switched on (Smart home supply, 2019). Advocates of selective infrared heating also claim this technology reduces energy cost and this type of heat is more comfortable (Herschel, 2019; ThermIQ, 2019). Lastly, the electromagnetic fields of infrared heating do not contain enough energy to harm human health (Saunders, 2003).

Even though the benefits of infrared heating seem clear, the technology has been widely neglected. The parties that can potentially benefit from this promising technology are reluctant in adopting it (Duurzaamtuus, 2018; Krishnamurthy, Khurana, Soojin, Irudayaraj & Demirci, 2008). According to the quadruple helix theory, the adoption of new technologies depends on the contribution of four different actors: civil society, policy makers, scholars and the industry (Etzkowitz & Leydesdorff, 2000). These actors represent major parties that are crucial in innovation. The actors have to actively engage in the adoption process for the adoption of new technologies to succeed (Arnkil, Järvensivu, Koski & Piirainen, 2010). In this research the quadruple helix perspective is used as it illustrates the complete picture of the adoption process. The underlying reasons of the reluctant adoption of infrared heating by these different actors are unclear. The question that comes forward is as follows: why is infrared heating not adopted yet as mainstream innovation according to the quadruple helix theory? The goal is to understand what barriers and how barriers hinder infrared heating from being adopted.

2. Theoretical framework

The aim of this section is to present key insights and concepts from the academic literature and to draft a conceptual model to understand the relationship between the concepts. In paragraph 2.1 an introduction is given about the general adoption of new technology. This is followed by an update of the current status of the adoption of infrared heating. In the next paragraph, the quadruple helix will be explained. This paragraph continues by explaining how every actor is subjected to different variables in their decision when adopting a new technology. Sub questions are made based on these variables related to the research topic. In paragraph 2.3 the conceptual model will be presented to understand the relationship between the quadruple helix theory and the adoption of infrared heating.

2.1 Adoption of infrared heating

The invention of a new technology often seems like a sudden happening. In contrast to this, the diffusion of that technology usually happens as a continuous and time-consuming process. Diffusion can be defined as the outcome of individual decisions that compare the benefits of adopting a new technology against the cost of change. These decisions are made while uncertainty is present due to limited information (Hall & Khan, 2003). In case of the adoption of the new technology infrared heating the following has been found. Companies are always looking for solutions to reduce their costs, however, they seem reluctant in adopting selective infrared heating. Consumers wish to have a comfortable house and at the same time save as much energy costs as possible. This group is, however, hesitant in introducing selective infrared heating in their houses (Duurzaamtuus, 2018). As far as the researcher has found, the government has not made any regulation around infrared heating. Next to this, scholars have done a lot of research about sustainable ways to generate energy, such as windmills, solar panels and hydrogen fuel. Additionally, much research has been done about isolating buildings, LED lightning and other energy saving methods, but selective infrared heating has been widely neglected. These paradoxes invoke questions about the adoption of infrared heating. There are no studies that go into detail or into the implementation of infrared heating. Many questions on this topic are still unanswered (Krishnamurthy et al., 2008).

2.2 Adoption of new technology from a quadruple helix perspective

Due to the increased global competition and the rapid emergence of complex problems (Hannah & Lester, 2009) the importance of organizational innovativeness and adaptability have increased to survive as an organization (Friedrich, Mumford, Vessey, Beeler & Eubanks, 2010). The triple helix model helps to explain structural developments of economic, political and managerial decision-making in knowledge-based economies (Leydesdorff, 2006; Leydesdorff, 2012). Every helix represents a major party that is crucial in innovation (Arnkil et al., 2010). The model is based on interactions with regards to innovation between the three actors research & education, government and industry. The idea of this model is that this form of cooperation positively influences innovation processes which in its turn stimulates economic and societal development. Next to this, the model provides sufficient space for actors to work on their initial objectives: governments regulating societies to improve the quality of life for citizens, universities conducting cutting-edge research to answer unresolved topics and industries producing commercial goods and services to make profit (Etzkowitz & Leydesdorff, 2000).

The advancement of several technologies, like nanotechnology and biotechnology, were threatened by the missing of a pillar in the triple helix model. The public opinion is important in the adoption of a technology and therefore civil society should be included (Yawson, 2009). More researchers pledge to include this fourth actor, as user-driven innovation is an essential factor for success of companies as well as for public organizations (Eriksson, Niitamo & Kulkki, 2005; Lundvall, Johnson, Andersen & Dalum, 2002). Organizations go through major changes in the innovation process. They use open business models, put greater focus consumer wishes, and consumers are increasingly involved in the different stages of the innovation process (Arnkil et al., 2010). The development of the quadruple helix model, with the inclusion of civil society, was thus done to include the opinion of the intended user about aspects that are important during the innovation trajectory.

Multiple stakeholders, like civil society, policy makers, industry, and research & education, influence the adoption of new technology (Gouvea, Kassicieh & Montoya, 2013). The quadruple helix model allows to discover how the four actors crucial in innovation (civil society, research & education, policy makers and the industry) relate to the adoption of a new technology. The model advocates for collaboration between the four actors to successfully adopt a new technology. Therefore, to get a complete overview of the adoption of the new technology infrared heating, the adoption will be investigated from the four different perspectives. Now every actor in relation to the adoption of new technologies will be looked at in greater detail.

2.2.1 Civil society

A new technology can sometimes be seen as a discontinuous product. Discontinuous products have features that are not present in current products and cannot be realized through developing or improving an existing technology. This changes the spectrum of (dis)advantages for customers (Calantone & Di Benedetto, 1988). Civil society takes multiple aspects into account to determine the added value of a new technology (Hasche, Höglund & Linton, 2019).

2.2.1.1 Familiarity

The first aspect that civil society takes into account to determine the added value of a new technology is familiarity. Familiarity is defined by having a good knowledge of something, or the fact that you know it so well (Cambridge Dictionary, 2019). Civil society is often resistant to adopting new technology which is unfamiliar or unproven to them (Egbue & Long, 2012). People often relate the word technology to potentially dangerous scenarios while taking the technological benefits for granted. This inequality in risk-benefit perception makes consumers worrying about hidden risks of technologies and demand strict regulation. Technological risk means the probability of physical, financial and social harm as a result of a technology during its complete lifecycle (Renn & Benighaus, 2013). Risk is perceived differently among different audiences (Bier, 2001). Perceived risk varies per person as it is heavily value laden and subjective (Árvai, 2014). People's perception of risk is mainly formed by a combination of experience, emotions, the media and other non-technical sources (Sjoberg, 1998). Perceived risk represents a twisted picture of actual risk, shaped by a lack of knowledge, prior beliefs, and subjective personal experiences (Jasanoff, 1998). Knowledge, feelings and values are of effect on the thinking and assessment of people about the seriousness and tolerability of technological risks (Slovic, 1992). Other frequent barriers that hinder the adoption of new technology is a lack of knowledge by possible adopters, a low risk tolerance and high initial costs (Diamond, 2009).

A large amount of technological uncertainty, unfamiliarity and risk comes along with the commercialization of discontinuous products. Discontinuous products are in the begin unknown for customers and this sometimes demands a change of behaviour in order to use the products. For example, new patterns and changes in customer thinking were greatly affected with the introduction of cars and telephones (Dhebar & Anirudh, 1995). To market discontinuous products extra attention and reflection is needed in comparison with products that are developed incrementally. A reason is that new products cannot directly be compared with parity products, but must be evaluated on its own (Veryzer, 1998). Unfamiliarity can to some extent be compensated by providing people superior functional knowledge about the risk and the related technology (Renn & Benighaus, 2013).

New technology is considered as attractive by some people, such as visionaries and technology enthusiasts. These people have a positive attitude towards novelty and this group is likely to adopt new technology (Heffner et al., 2007). Most of the people, however, cannot be considered early adopters, because they are uncomfortable with change and uncertainty and therefore tend to be resistant to new technology (Moore, 2002; Edison & Geissler, 2003). Based on the findings in the literature the following sub question has been constructed:

SQ1. How familiar is infrared heating at the moment and what is the influence of this familiarity on the adoption of infrared heating?

2.2.1.2 Ethical matters

The second aspect that civil society takes into account to determine the added value of a new technology are the ethical matters. Ethical relates to beliefs what is morally right and wrong (Cambridge Dictionary, 2019). Values are viewed as a point of reference by individuals to determine if their actions are justified and also to grade other people's behavior. Ethical matters in this research are considered as the environmental and social values consumers take into account with the adoption of a new technology.

Firstly, people who most value environmental values behave more in an environmental responsive way (Alonso, 1999). The moral consciousness of people towards the environment is a strong predictor of consumer actions that protect the environment, such as the adoption of new technology (Oliver & Rosen, 2010). The amount of environment-conscious consumers is growing. People become more aware of environmental problems and are increasingly willing to engage in action. This type of consumers is known for its self-fulfilment feeling as they want to improve themselves as person and take actions that are intended as a new challenge (Fraj & Martinez, 2006).

Secondly, social values also influence the development of new technology (Smith, 2005). It can incite to a technology resistance, such as with the anti-nuclear movement or with agricultural biotechnology (Rüdig, 1990). It can also form a pro-active movement on technology. Alternative technology activists promote disruptive technologies that can help in realizing social and environmental goals (Smith, 2005). As a counteract against capitalism, there is increasing resistance to corporate brands and globalization. Social movements by consumers pursuing their values is sometimes labeled as consumerism (Hollenbeck & Zinkhan, 2006). Consumerism seeks to increase the rights and powers of buyers in relation to sellers (Kotler, 1986). By this, consumers aim to decrease their moral risk which they are subjected to, such as a limited freedom of choice or long subscription obligations. The expression of displeasure by consumers can harm brands, but it could also be seen as a way of feedback towards companies. Next to this, disruptive power or new business

models may emerge in response to the desired values of consumers (Hollenbeck & Zinkhan, 2006). The presented literature invoked the following sub question:

SQ2. How do environmental and social values influence the adoption of infrared heating?

2.2.1.3 Financial and practical matters

The third aspect that civil society takes into account to determine the added value of a new technology are the financial and practical matters. For consumers the advantage is the increased utility from the new technology (Hall & Khan, 2003). Utility is the usefulness of something, especially in a practical way (Cambridge Dictionary, 2019). Consumers maximize utility by choosing options based on preferences, budget and knowledge of alternatives (Roche, Mourato, Fischedick, Pietzner & Viebahn, 2010). Financial matters relate to money or how money is managed (Cambridge Dictionary, 2019). Practical matters compromise non-economic aspects, such as the pleasure of being the first person in their social circle with the new technology. Other less obvious aspects that play an important role in the demand for new technologies is the strength of the companies' relation with its customers and the network effects that come along (Hall & Khan, 2003). Civil society prefers to choose options that benefit them financially. Apart from a group of technology enthusiasts and environmentally conscious consumers, the adoption of new technology by civil society is greatly increased if it has financial benefits (Heffner, Kurani & Turrentine, 2007). Based on the findings in the literature the following sub question has been constructed:

SQ3. What is the influence of financial and practical matters on the adoption of infrared heating?

2.2.2 Policy making

Policy making plays a pivotal role in the adoption of new technology. The car industry is a sector in which a lot of policy is made. A stakeholder analysis has shown that members of the car industry, end users and policy makers acknowledge that taxation in the form of environmental performance is the most effective approach to stimulate purchases of environmentally friendly vehicles (Mairesse, 2009). Decreasing the purchase costs and at the same time stimulating advantageous financial effects of environmentally friendly vehicles by implementing a combination of policies, such as lowering excises on clean fuels, introducing taxation based on environmental performance and excluding owners of green cars to pay road taxes increases green car sales. At the same time policies are made to discourage the purchase of conventionally fuelled vehicles (Mairesse, Macharis, Lebeau & Turcksin, 2012). The interference by policy making in the car industry by writing policies, acknowledging subsidies and implementing taxation regulation made a clear landscape for car producers, new entrants and civil society. The government was at the same time able to work on its goals, such as emission reduction and safety (Mairesse et al., 2012). It makes things unclear for multiple stakeholders when policy is lacking with regards to a new technology. Simultaneously, policy makers miss out on the chance to steer the adoption of the new technology into their preferred direction.

The way how topics emerge onto the technology policy agenda is a complex process. Many societal or technological problems may occur at the same time. Some of these matters can exist for years or decades without receiving any policy attention, while other matters are apparently important enough to be put on the policy agenda and receive the required resources. The procedure of agenda setting has a couple of characteristics. Opportunities for agenda setting arise when the following

three factors are present at the same time: a dominant problem definition appears, a solution that is regarded as suitable is formulated, and the political climate is favourable (Edler & James, 2015).

Ambiguity is also a key aspect. Some concepts have an ambiguous nature and these concepts can be interpreted in multiple ways by actors depending on their interests and positions. This gives possibilities for agenda setting. When successfully put on the agenda, the broad concept can slowly be steered to the underlying cause (Edler & James, 2015). The literature invoked the following sub question:

SQ4. How can infrared heating be put on the policy agenda and how does this influence the adoption of infrared heating?

2.2.3 Industry

Companies are increasingly competing on environmental topics. The reason why organizations are increasingly acting in ecologically responsive ways has different underlying motivations and contexts (Bansal & Roth, 2000). First of all, stakeholders, such as customers, local communities and environmentalists incite organizations to take conscious decisions with regards to the environment (Berry & Rondinelli, 1998). Further, by taking the stakeholder groups serious and acting on their ideas, managers can prevent negative public attention and create support of stakeholders (Dillon & Fischer, 1992). Next to this, economic possibilities also stimulate ecological responsiveness. Revenues can be made by the sales of products or services contributing to environmental protection (Cordano, 1993). Moreover, organizations that are ethically motivated act because they see measures as “the right thing to do” (Wood, 1991). Company values and members of the board are crucial in leading companies to fulfil its role in the society (Buchholz, 1998). Lastly, (upcoming) regulation imposed by policy makers can also be a factor to pursue environmental responsiveness. According to paper of Bansal and Roth (2000), the above-mentioned motivations for ecological responsiveness can be divided in three groups that all have benefits that correspond to it. Firstly, competitiveness as in higher profits, bigger market share and a higher share price. Secondly, legislation as in survival of the organization, license to operate and avoiding fines. Thirdly, social responsibility as in individual satisfaction and employee morale. Policy makers and civil society must however acknowledge the deeds of organizations pursuing ecological responsiveness. They seek proof of the value of products or services of organizations and the contribution to environmental goals before purchasing decisions or the formulation of policy are made. In the case of solar panels there are differences in quality and lifetime (Aleo, 2019). For consumers it can be hard to determine which solar panels to buy. A certification has been developed that verifies if the minimum requirements of quality and lifespan of solar panels are met. This helps consumers in making conscious purchasing decisions (Arndt & Puto, 2010). The following sub question has been constructed based on the findings in the literature:

SQ5. What barriers do infrared heating manufacturers encounter in spreading the ecological responsiveness of their product?

2.2.4 Research & education

The work of scholars plays a pivotal role in the development of the knowledge-based economy (Etzkowitz, 2002). It is remarkable that a lot of research has been conducted about isolating buildings and LED lightning, while the topic infrared heating has been widely neglected by scholars. Research & education cope with the pressure from the industry and policy makers to determine their research

direction. Political and industrial interests are embedded into evaluation and performance measurements of academic research to insure the direction and quality (Benner & Sandström, 2000). A hot topic can thus emerge if there is interest towards a topic by society and policy makers with the industry responding to it by putting it as priority on the research agenda.

Another factor that influences research directions is the allocation of resources. Funding enables the continuity of research. It is a form of recognition for work that is achieved. Well-performing organizations active in the academic field are better in attracting funding, recognition and prestige (Benner & Sandström, 2000). The criteria made by funding agencies to allocate funding and how the quality of research is monitored, influences how the academic system evolves. Agencies handing out funding determine the research performance of the universities and research groups. These agencies, but also private research sponsors, can therefore steer the direction of research topics (Elzinga, 1985). The literature invoked the following sub question:

SQ6. How do the allocation of funding and the demonstration of interest in infrared heating by actors such as civil society, the industry and policy makers influence the adoption of infrared heating as research direction by scholars?

2.3 Conceptual model

Six sub questions have been constructed about the quadruple helix actors in relation to the adoption of infrared heating. The conceptual model depicts the relationship between the quadruple helix and the adoption of infrared heating (see figure 1). In between those two concepts the variables that are of influence on the adoption of infrared heating are displayed. These variables are according to the literature of influence on the adoption of new technology and therefore help to explain the relationship between the quadruple helix actors and the adoption of infrared heating.

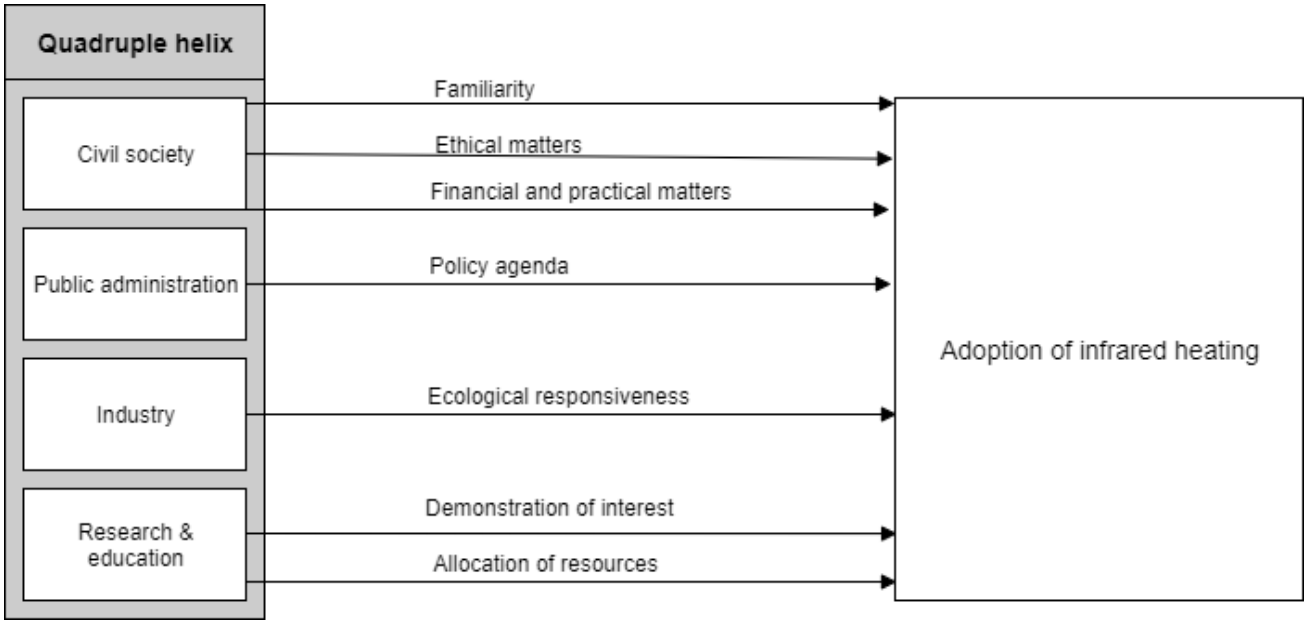

Figure 1: Conceptual model

3. Methodology

In this section the methods are explained with regards to how information is collected and analysed.

3.1. Methodological approach

The adoption of infrared heating involves many parties, so the researcher zooms out by using a systematic approach with the quadruple helix model. The quadruple helix model is a tool that helps to understand the underlying reasons of different actors why infrared heating is not widely adopted yet. The actors that are included are civil society, policy makers, the industry and researchers. As infrared heating is relatively unknown and not much data is present about the technology, the research uses a qualitative approach to answer "how" and "why" questions and is done by conducting interviews. This descriptive study aims to answer the research question: *why is infrared heating not adopted yet as mainstream innovation according to the quadruple helix theory?*

3.2. Data collection

Semi-structured interviews are conducted to understand what and how barriers hinder infrared heating from being adopted. As a result of this qualitative approach, respondents can give explanations when answering a question, what will improve the quality of data. Furthermore, respondents can directly ask for clarification if something is unclear, which reduces the impact of interpretation differences. To obtain information about infrared heating, the theory of the previous section provided input to constructs a list of questions per actor (see appendix 1). For the actor civil society, a standard explanation about infrared heating will be provided to inform the consumers about the technology. The explanation is short and objective (see appendix 3). Any questions that are evoked and asked by the interviewees to the interviewer will be ignored, because the purpose is to discover their opinion and not start a dialogue. Next to this, some pictures will be shown to visualize what infrared heating looks like (see appendix 4). Based on the provided information the interview can be held.

The interviews will be face-to-face, via Skype or by telephone and after permission is given, the conversation will be recorded. These recordings make it possible for the researcher to transcribe the interviews, after which it can be coded and analyzed. The face-to-face conversations will be held at either at the Wageningen university or at their desired location. The respondents will also sign an informed consent form that describes how the data is managed, that participation is voluntary, the data is anonymized, recording will be deleted after the research, and some more formal matters. The respondents for civil society are chosen from the researchers' social circle. Requirements to be approached are that they own a house, so they make their own decisions with regards to heating. Furthermore, a diversity of gender and age will be aimed for. The respondents that explain the perspectives of the industry, policy makers and researchers are found via the internet and via the social networks of the researchers' contacts. The criteria for people active in the industry are that they are directly involved with the technology infrared heating. At least one producer of infrared heating is desired. The criteria for policy makers are that they work at policy level and thus are involved in decisions regarding policies and subsidies with regards to sustainable building and heating. The criterion for researchers active in the academic world is that they are active in the fields of heating, smart energy and sustainable building. Furthermore, it is desired that the researchers work at different universities.

As stated above, all four different actors will be subjected to questions to map the underlying reasons how each helix is prevented or encouraged to adopt infrared heating. Meanwhile, the content gathering process has also another goal. Notes will be taken during interviews which questions work well and which questions do not. In this way, the interview sessions contribute to building a theory that can help further research towards quadruple helix related innovations.

3.3. Data analysis

The obtained data from the interviews is transcribed and coded with the help of ATLAS.ti. The coding will be done with the top-down approach, because the coding scheme is based on the concepts of the literature. These variables also come back in the sub questions. In addition to this, the bottom-up approach will be used as it is a qualitative research with semi-structured interviews and inductive reasoning. After the interviews, the researcher has to determine if remarkable answers fall within the predetermined concepts or if new concepts are mentioned. If that is the case, additional codes will be made to put the answers in a certain category. Coding allows the researcher to compare data within the same helix. The coding schema can be found table 1. Next to this, it also helps to draw conclusions about transcending topics between different helixes. The results are to be found in the next section.

Table 1: Codes used in ATLAS.ti

Helix	**Codes**
Civil society	Familiarity Ethical matters Financial and practical matters
Policy makers	Barriers for policy makers
Industry	Ecological responsiveness Other barriers from the industry perspective
Research & education	Allocation of funding Demonstration of interest by civil society, industry and policy makers Demonstration of interest by researchers

4. Results

In this section the results obtained from the interviews will be discussed. Interviews were conducted with six people of the civil society, two people active in the industry, two persons active in the academic world, and with a person representing a triple helix actor (closely involved with practices of the industry, researchers and policy makers). It was not possible to speak to policy makers, therefore the person representing the triple helix actor was subjected to questions with regards to the industry adoption as well as to questions that were constructed for policy makers. This input has been used to write about the policy adoption.

The results will be presented based on the perspectives of each of the four helixes. First, the user adoption will be discussed, including the three subjects familiarity, ethical matters, and financial and practical matters. Second, the adoption of policy makers will be discussed. Third, the market adoption will be discussed. Finally, the results of research adoption are presented. Further, the results will be clarified by using quotes from the interviews.

4.1 User adoption

In this section the barriers will be described from a user perspective. The barriers will be described based on three subjects: familiarity, ethical matters, and financial and practical matters.

4.1.1. Lack of adoption due to unfamiliarity

Respondents were not familiar with infrared heating technology. Their knowledge is limited and multiple respondents actually never heard of this type of heating method before. Respondents did not have knowledge of anyone using this heating method. Various associations are evoked when consumers think about infrared heating, such as saunas, a tanning bed or infrared thermology (to search for heat in the dark). These associations are a barrier in the adoption of infrared heating as associations result in prejudices about safety with regards to radiation, magnetic fields and fire hazards.

"If I hear infrared, I think about the army. Soldiers can see with actions during the night by using infrared. I think that is the biggest application" - Consumer 3

"I would at least want to know more about safety, fire hazards and those things" - Consumer 2

Consumers wonder if infrared radiation is sufficiently researched. As a result of this ignorance, consumers perceive this technology as being harmful.

"The question is: is it sufficiently researched? If it has harmful effects for the future if you are exposed to it for a prolonged time" - Consumer 4

Two consumers replied infrared heating is not something to be afraid of. One interviewee trusts all electricity wires will be well fused which excludes the danger of fire. This person also mentions that infrared radiation is something natural and is therefore not something to be afraid of.

"It is an electrical device. Of course, short-circuiting can always happen, but I honestly think it will all be well fused and short-circuiting or fire cannot happen. Look, infrared heating is of course not something new. Infrared is something natural and that is why I am actually not scared for health issues. People quickly think about radiation and that kind of stuff, but that is actually not something where I am afraid for as it is a physical phenomenon" - Consumer 5

Consumers reply their knowledge is too limited to answer the question if they are open to adopt infrared heating it in the future. Remarks are made respondents rather wait for the teething troubles to be resolved where first users have to deal with.

To summarize, the researcher observed a difference in levels of familiarity as well as a difference in risk perception due to their lack of solid information regarding this technology. The barriers to adopt are as follows: respondents have not heard of infrared heating before, respondents have prejudices about safety with regards to radiation, magnetic fields and fire hazards, and consumers rather wait for the teething troubles to be resolved.

4.1.2. Lack of adoption due to ethical matters

To the question what type of heating consumers see as environmentally friendly, two consumers mentioned a central heating system shared with the neighborhood. District heating works with residual heat from greenhouses and electricity factories or is generated heat by bio mass plants. Warm water is transported by big pipelines to households to provide heat and when the water cools down it is transported back to the heating sources (Eneco, 2019). Next to this, consumers cannot agree if gas is good or bad. It is remarkable that consumers who claim gas is relatively good in comparison to other energy sources provided an argumentation. The other consumers seemed to talk mostly out of intuition with regards to this subject.

"It is all made possible by Eneco, which sends, well, they have one heat supply in the district. My daughters do not have gas in house, so then I think, that is kind of good. If it is achievable to do it for everybody, I doubt it" - Consumer 1

"In my opinion gas is environmentally friendly. I think it is the cleanest way of fossil fuel in comparison to stone coal, brown coal and biomass. I do not believe in biomass at all. I think they look at it completely incorrect" – Consumer 3

"Many countries are now switching to gas. And what I hear from the media is that gas is still one of the most environmentally friendly ways to heat your house. Mainly because electricity is produced in coal factories and not in a sustainable way" - Consumer 5

Respondents see the feature environmentally friendly with regards to heating as important for the future of the planet. Environmentally friendly heating is associated with taking responsibility for younger generations.

"Well, we cannot really ignore that we have to look for other ways for the future than we use now. For the future of the youth and name it, I think it is really important. Not only for the youth, but also for the planet. Something must happen" - Consumer 1

"We all want to keep walking around on the planet for a long time, so I think if we are environmentally active it is good for everyone" - Consumer 6

Most consumers have no idea how unfriendly their current heating needs to be in order to switch. Two consumers responded that they would switch to another heating method if they had a wood-burning stove. Not a single respondent feels pressure from other people to adopt a sustainable heating method, however, they do all feel everyone should share the responsibility. They also say it will be hard to get everyone the same page.

"It would be nice, but it remains everyone's own responsibility. You cannot force people. I do not believe in that. You have to convince people based on arguments" - Consumer 3

Consumers do not know the CO2 footprint of their house. If the assumption is made that their footprint is higher than average, consumers react in different ways. It is remarkable that consumers add financial aspects, such as the price tag of taking measures to reduce their CO2 footprint, while questions about ethical matters were asked. It shows respondents consider financial aspects at least as important as reducing their CO2 footprint, if not more.

"If it [reduce my CO2 footprint] would somehow be possible, I would take measures for it. But of course, there is also a price tag involved, so you would have to carefully consider it against each other" - Consumer 1

Four consumers admit their opinion with regards to a heating method is influenced by the media. The media sources that were mentioned are news on the television, NOS-app, nu.nl, Facebook and de Volkskrant. Two consumers stated the media does not affect it. Either because they isolate themselves from it or because the only influence on their choice with regards to a heating method is the government. Next to this, consumers react differently to the question if their decision to adopt infrared heating would be influenced if it brings new players on the market that disrupt the energy oligopoly in the Netherlands. Some respondents do want do increase their rights and powers in relation to the energy producers, which is called consumerism. Other respondents attach less importance to this social value, because they argue the focus lies on their own household. Arguments are illustrated in the quotes below:

"No, I do not think so. I honestly do not see the consequence of that. I am busy with my own place with respect to that matter" - Consumer 2

"The big boys you just mentioned, do a lot with imagination, but not content wise: experiencing more with the outside than with the inside. For me it would definitely have influence" - Consumer 3

To summarize, as for environmental values, the feature environmentally friendly with regards to heating is seen as important for the future of the planet. Environmentally friendly heating is associated with taking responsibility for younger generations. Respondents would switch to another heating method if they had a wood-burning stove. Respondents consider financial aspects at least as important as reducing their CO2 footprint, if not more. As for social values, not a single respondent feels pressure from other people to adopt a sustainable heating method, however, they do all feel everyone should share the responsibility. The media influences the opinion of consumers with regards to a heating method. Not all respondents care about their power in relation to energy providers. These consumers do not mind about the existent energy oligopoly in the Netherlands and potential disruptive power of new heating methods.

4.1.3. Lack of adoption due to financials and practicalities

In the adoption process consumers also take financials and practicalities into account. People go through a variety of thoughts when it comes to decision-making. Respondents questioned out loud if it would be possible to heat the whole house with it, if it would become cheaper if more people purchase it, how infrared heating would be maneuvered away so it is aesthetically responsible, and if it is worth the investment.

"My first thoughts are if it would be something for me. I would look at two things: is it profitable, is it worth the investment? Secondly, if it is also applicable within my house and if it does also fit optically? The panels are quite big, so the question rises how pretty that Is within your home" – Consumer 5

One consumer wondered out loud if the heat of infrared heating would not rise to the top of the room. Another respondent wondered how comfortable it is in a house. People are curious how it works, what the requirements are of their house, the advantages, the disadvantages, the costs in comparison to other forms of heating and how much electricity it uses.

Most of the respondents do not consider themselves as early adopters (only one), but rather find themselves part of the group in the middle (four) within their social circle to acquire new technology. One person considered itself a late adopter. Consumers have plenty of thoughts about the advantages of infrared heating: local, direct and quick heat, based on electricity, lower energy costs and the placement of panels on walls.

"It is obviously better for the environment. That is for me a big advantage. It consumes less space than the radiators on the wall. You can hang them at the ceiling. At this picture you have a towel hanging on it, so it is at the same time an article of use" - Consumer 1

"An important advantage for me is that your body absorbs it immediately, so you do not have to heat for a long time and your energy costs therefore will be lower. And that for example you can place it on the wall, because the radiators we have now are in fact unwatchable" – Consumer 6

Every consumer would change or consider to change to infrared heating if it benefits them financially, however, some consumers have extra conditions that have to be met. Examples of these conditions are that it is only considered as a new heating method when moving houses, a recurring condition is comfort and next to that it must be aesthetically responsible.

A variety of answers were given when consumers were subjected to the question if the government should provide incentives to stimulate the adoption of infrared heating. Five respondents think the government has to provide financial incentives to stimulate adoption of infrared heating. Next to this, providing more information about this technology and put more attention on it is seen as an important task of the government. Only one respondent is against the idea of the government giving incentives to stimulate the adoption of infrared heating.

"Stimulate it, give it more attention. Do you hear anything about it?" - Consumer 1

"If it is more sustainable, because of a lower electricity usage, yes. I think economic incentives, but mainly information. It is super unknown. I think few consumers in the Netherlands know it" – Consumer 3

"No, currently not. I also do not see how the government has interest in that, in which way. Look if the use of an infrared panel would really be sustainable and would contribute to the climate, I would say yes. But at this moment that is not the case in my opinion" – Consumer 5

Consumers also sum up a list of disadvantages when they think about infrared heating. One consumer mentioned the high price, although the researcher did not mention anything about how much the panels would cost, so it seems like a preconception. Five out of the six consumers talk about design. The panels placed on the ceiling and on the walls are experienced as ugly. They say valuable space is taken by infrared panels in comparison to floor heating as that is completely maneuvered away. Consumers see decreased utility of infrared heating, because they find the installation of a new heating system a hassle. One consumer makes the remark that it is of course temporarily. One consumer highly doubts if infrared heating is able to provide enough heat if the floor consists of piles.

"In our apartment it is fine the way it is. I would not want to revamp it anymore. No, I do not want to revamp it here" – Consumer 2

"It is actually a pity if you already have a heating system. You are then using your current infrastructure, especially with floor heating" – Consumer 4

"With a tiled floor the floor remains cold, so you need another method to heat your house, because otherwise it is not comfortable enough. I think with for example a carpet it would be possible, but in

the living room with a tiled floor I think it is still not warm enough, so then you still have to heat in another way. And if you want to do that electrical then it will have to be electrical floor heating, because otherwise I do not think there is a possibility to get the floor warm" – Consumer 5

The costs are very decisive for consumers. They wonder if infrared heating is a saving and if it gives economization benefits. Every consumer mentioned it during the interview, and most of them even multiple times. To the question if consumers would change to infrared heating if it would not benefit them financially, the male respondents directly said no. The female respondents were more open to it, but some had extra conditions that should be met, such as safety assurances:

"Yes, if it would be entirely safe and if it would be comparable, then it would be easier to change" – Consumer 1

"If it does not give big disadvantages, and if it is equal to another heating or kind of equal. I do not mind to pay some extra, but not 200 euro's each month so to speak. A heat pump is also expensive to purchase. You have to choose for something, so then I would rather look what I find comfortable in my house and sustainable" – Consumer 2

To summarize, respondents wonder about several practical and financial issues with regards to infrared heating. Consumers have questions about the technology, such as if it would become cheaper if more people purchase it, if the heat would not rise to the top of the room, how it works, what the requirements are of their house, the costs in comparison to other forms of heating, and how much electricity it uses. Respondents find the installation of a new heating system a hassle. Some consumers would only switch to infrared heating when moving houses. Furthermore, different thoughts were expressed about the aesthetics of infrared heating. Some respondents experience the panels placed on the ceiling and on the walls as ugly. According to them, valuable space is taken. Others argue the placement of panels on walls is something nice as you can also use it to hang things on it. Next to this, infrared heating must be comfortable. There are doubts if infrared heating is able to provide enough heat if the floor consists of piles. Additionally, costs are decisive factor. Interviewees wonder if infrared heating is a saving and if it gives economization benefits. Every respondent would change or consider to change to infrared heating if it benefits them financially. Furthermore, respondents do not consider themselves as early adopters and apparently do not see benefits of being the first person to adopt. Next to this, respondents argue that the government has to provide financial incentives, more information, and put more attention to stimulate the adoption of infrared heating. Furthermore, consumers have plenty of thoughts about the advantages of infrared heating: local, direct and quick heat, based on electricity, and lower energy costs.

4.2 Policy adoption

According to the respondent, infrared heating is not really included in innovation programmes. It is a fully developed technique, so it does not really need policy attention. The government decides where it wants to go and determines which techniques fit within the objectives. At the moment the two most important topics are to reduce CO2 emissions and to get rid of natural gas. A lot of attention is given to heat networks, hydrogen energy and other forms of renewable energy ideas. According to the interviewee, heat pumps are energetically a better alternative than infrared heating panels as a replacement for natural gas. Heat pumps with a source can also produce cold during hot summers, while infrared heating can only produce heat. A barrier that applies for heat pumps as well as for infrared heating is that the electricity network does not have enough capacity.

There must be a necessity to put something on the policy agenda. Nothing is excluded and the energy transition can go to different directions. If parties show with prove, numbers and calculations

that infrared heating has a fantastic solution, it will surely be taken into consideration. The respondent emphasizes that at the moment it is however not the case.

To summarize, infrared heating is a fully developed technique and therefore does not need policy attention, according to the respondent. In addition to this, the interviewee argues that heat pumps are energetically a better alternative than infrared heating panels as a replacement for natural gas. Furthermore, heat pumps with a source can also produce cold during hot summers, while infrared heating can only produce heat. Lastly, the electricity network does not have enough capacity.

4.3 Market adoption

This section describes the barriers for the market adoption of infrared heating. The first subject is about the much-debated ecological responsiveness of infrared heating and the second part describes other found barriers.

4.3.1. Ecological responsiveness

According to a respondent, one-on-one heating, electricity for heat, may only happen when we have a 100% sustainable electricity supply. The Netherlands is far away from that goal and it is therefore 20 years too early to think about making the switch now. According to this person who is active in the industry, it is currently an unsustainable thought to switch to electrical heating. The interviewee argued that it would be better to heat with a gas boiler than using infrared heating, as the yield of electricity production is only 40%. A heat pump is a good heating method, because it counters those production losses with its efficiency it is again on 100% [the respondent assumes a COP of 2.5].

The fallacy of energy neutrality is a problem. Even if solar panels are used in combination with infrared heating panels it is still not a sustainable heating technique, according to the interviewee. The amount of sustainable energy during winter is significantly lower than in summer. During summer energy is produced by solar panels and the abundant energy is send to the power grid. If energy is bought from the power grid in winter, it is not the same energy. Infrared heating panels then use the quality of electricity that is supplied by the power grid.

"In politics we have created the pitfall of energy neutrality which is that you can deduct the yields of solar panels in summer from what you need in winter, while that is physically nonsense" - Person active in the industry 1

In all energy models that are used, like the energy regulation, it does not lead to the desired energy performance to reach the construction norms. Electrical heating is as sustainable as the quality of the Dutch electricity grid, which is far from sustainable in the Netherlands. This person active in the industry uses infrared heating in his own projects as a technique supplementary to heat pumps. This is done because heat pumps work to a certain level and an infrared heating panel can help out. In the eyes of the respondent, the infrared heating sector should wait a while until the Netherlands has a sustainable energy supply. At the moment it breaches the sustainability story of the Netherlands if electrical heating would currently be used instead of heating with gas boilers. The CO2 emission of the Netherlands will be 2.5 times worse off if the heat pump is forgot as the yield of electricity production with natural gas is only 40% due to production losses.

When the question was asked to a producer if infrared heating is sustainable, the counter question was asked: is an electrical car sustainable? The respondent argued that if a car drives on electricity that is produced by natural gas or coals it is actually not sustainable as fossil fuels are still used. That

is the same for infrared heating panels. The producer admitted that when electricity is obtained from an electricity plant the device is less sustainable. Infrared heating panels do, however, have life spans of 25 years and contain possibilities for reuse and circularity, for example the glass and the aluminium. When infrared heating panels use green energy, it becomes a sustainable device.

Another respondent argued that two different topics emerge when talking about infrared heating: what type of energy is needed and what is the energetic efficiency? Infrared heating is sustainable if green energy is used for infrared heating. The interviewee also mentions that the COP of infrared heating panels is worse than the COP of alternative heating methods, such as heat pumps. If one unit of energy is put into a heat pump, 3 to 5 times the amount of heat is produced, which is very efficient. In contrast to this, for infrared heating 1 kWh energy results in 1 kWh heat.

"It is a sustainable way of heating if you produce green electricity, but energetically it is not better than the alternatives" - Person active in the industry 3

To summarize, the COP of infrared heating panels is worse than the COP of alternative heating methods. In all energy models that are used, like the energy regulation, it does not lead to the desired energy performance to reach the construction norms. Infrared heating panels do have life spans of 25 years and contain possibilities for reuse and circularity. Furthermore, infrared heating is sustainable if green energy is used for infrared heating. When infrared heating panels use the quality of electricity that is supplied by the Dutch power grid, with few sustainable energy, it is far from sustainable.

4.3.2. Other barriers

According to a producer, the Dutch society is not ready yet for advanced electrical applications replacing traditional techniques, which is also the case with electric cars. Another person active in the industry adds that consumers want comfortable houses and are now used to heating with natural gas. Infrared heating is something new. The first step is to show that it works, it has the same or better comfort, and also that the energy consumption is not more than the current option. The current gas boilers are very cheap, so to compete with the gas boilers infrared heating panels have to become cheaper. Economies of scale and technology development are very important in reducing the costs, so people start purchasing.

"If you look at the current gas boilers, then you see they are dirt cheap. We have to go to those levels" – Person active in the industry 3

The producer said that without subsidies nothing would happen in the electrical car market. This is another barrier for infrared heating as no subsidies are given. Furthermore, the word radiation sometimes results in negative associations. The interviewee also mentioned that the gas boiler production industry and the maintenance and service industry of gas boilers have a big interest in keeping their business model going. On a yearly basis there is a routine maintenance and every 10-15 years a new purchase is done. An infrared heating panel does not need maintenance and has a lifespan of 25 years. It is therefore hard to find partners to hang up and install the infrared heating panels. The infrared heating sector does not have the lobby power like the heat pump industry that has UNETO-VNI, the business organization of the installation industry and technical retail, supporting them.

"As small organization, and with us some more organizations, with a relatively small and innovative up-and-coming technique. It is hard to form a fist" - Person active in the industry 2

The producer also mentions that the COP is a very quantitative way of measuring and the respondent rather sees qualitative aspects also involved, such as comfort.

"The COP of other systems may have a higher COP, but these infrared panels with a theoretical COP of 1 perhaps have a comfort score of 10" - Person active in the industry 2

A respondent argues that it would require enormous amounts of energy to heat non-insulated buildings. The electricity connection would be an obstruction, because the power grid would not pull it. Buildings need to be isolated better and the Dutch electricity infrastructure needs to be improved if everyone switches to infrared heating. Another respondent adds to this heat cannot be buffered inside an infrared heating panel, like with a heat pump. The infrared heating panel makes use of the power grid as soon as it is turned on. Therefore, users of infrared heating are very dependent on energy producers and energy network operators.

The producer mentioned people often quickly come to the conclusion infrared heating does not work, because they have seen an infrared panel that was based on metal or on ceramic, with few capacity and power. The construction market sells for example small infrared heating panels, but these panels are totally different and cause misconceptions. Additionally, the respondent mentioned that the difference in quality of infrared panels cannot be seen by the appearance. The interviewee pledges for a quality mark that is based on the degree of emission of radiation.

To summarize, the Dutch society is not ready yet for advanced electrical applications replacing traditional techniques as people are used to heating with natural gas and infrared heating is something new. In addition to this, the current gas boilers are very cheap, so to compete infrared heating panels have to become cheaper. Furthermore, no subsidies are given to infrared heating. Next to this, the word radiation sometimes invokes negative associations. Additionally, the gas boiler production industry and the maintenance and service industry of gas boilers have an interest in keeping their business model going. Furthermore, the infrared heating sector does not have enough lobby power. Next to this, the COP measures performance in a quantitative way and does not take the qualitative aspect comfort into account. Additionally, the power grid would not pull it if everyone switches to infrared heating. Furthermore, many buildings in the Netherlands are not well isolated. Lastly, due to quality differences in infrared heating panels there are misconceptions about infrared heating panels.

4.4 Research Adoption

In this section the barriers to adoption will be described from a research perspective. The following topics will be discussed: allocation of funding, the demonstration of interest in infrared heating by actors, such as civil society, industry and policy makers, and the demonstration of interest in infrared heating by scholars.

4.4.1. Funding

The allocation of funding is confirmed by the respondents to be important for something to become a research topic. The government is currently mainly focused on the challenge how to get rid of natural gas, which is why energy saving methods are sometimes forgot.

"All the focus is put on that. That is why there is so much attention for PV and hydrogen" – Scholar 1

With PV (photovoltaics) the scholar means solar panels. In addition, the scholar mentioned that if infrared heating turns out to be a great heating source, a subsidy arrangement will be created. As a result, requests with good, solid research proposals can be submitted. The money will then probably become available. In the Netherlands the NWO (Nederlandse organisatie voor wetenschappelijk onderzoek) is the national research funder. Scholars submit proposals to this organization to request funding. Requests also happen together with the industry, because results of researches may sometimes be applicable in the industry, for example hydrogen energy. Next to this, TKI Urban Energy is another organization that funds research projects about sustainability and built environment. According to the scholar, TKI has a list of technologies which are ranked by most promising technologies for a cheap transition.

To summarize, funding is important for something to become a research topic. The government is currently mainly focused on the challenge how to get rid of natural gas, which is why energy saving methods are sometimes forgot. If infrared heating turns out to be a great heating method, a subsidy arrangement will eventually be created. Afterwards, requests for subsidies with good, solid research proposals can then be submitted.

4.4.2. Demonstration of interest in infrared heating by other actors

The researcher wondered why scholars are relatively less interested in infrared heating in comparison to other energy subjects, such as solar energy and hydrogen energy. A scholar responded that infrared heating is on another level. Solar energy and hydrogen energy are about generating energy. That is a discussion about alternative sources of energy. Infrared heating is a technology linked to electricity and falls in the research category about energy saving measures.

"That is one of the reasons it is not part of the most actual problems: how do we stop using natural gas and make sure to not use finite sources anymore" – Scholar 1

In a later stadium infrared heating might get attention of scholars, but for now in the race of looking for alternative forms of energy, it is not the first point of attention. Scholars have academic freedom, which makes them free to decide where they do research about. Most patents are written in the area of solar-energy. There is a lot of space for further research in that direction. Infrared heating might be seen as too simple where too few breakthroughs are possible.

"I have also noticed it. I can only guess. I have the idea that it is too simple, in a certain sense. There are no components, except that you can apply the coatings in different ways to generate infrared heating. After that it has more practical applications: the heat that I generate travels somewhere, but where exactly? I think scholars do not see it as a technology to research in depth" - Scholar 2

"The fundamental insights of infrared heating are there, but the practical applications of fundamental research are not. What can we do with it in practice with living and working? I think that remained out of sight. It is a deadly sin, especially because the practical consequences have so many consequences" – Scholar 2

According to both interviewed scholars, the higher purpose and the common interest needs to be seen before something becomes a hot topic within research. If there is a need for certain knowledge, scholars will dive into it. Furthermore, a scholar mentioned that people are used to traditional types of heating and should first see radiant heating as a serious alternative. Afterwards the topics to research about infrared heating are already closer to matching the needs of people and the questions that arise can be picked up by researchers and the industry.

"It is not a goal by itself to do research about it" – Scholar 1

Most people only know infrared heating from patio heaters. That is approximately the most energy energy-consuming heating method that exists. It is therefore not at all associated with energy saving. It literally heats the open air. In the past, infrared heating was known from bathrooms that did not have heating and there would hang infrared heating. It is therefore seen as something old-fashioned. To overcome this lack of knowledge, proof must be provided that infrared heating is something that people appreciate. Only then it can be put on the research agenda.

"There is a big lack of knowledge. It would be good to draw attention to the successes of infrared heating, so the evaluation of houses of Marx P., showing that people really appreciate it. These are mechanisms that precede before it is put on the research agenda and follow-up research is done" - Scholar 1

To summarize, scholars are relatively less interested in infrared heating in comparison to other energy subjects. It does not fall in the category of generating energy, but in the research category of energy saving measures. In addition to this, infrared heating might be seen as too simple where too few breakthroughs are possible. Next to this, the higher purpose and common interest need to be

seen before something becomes a hot topic within research. If there is a need for certain knowledge, scholars will dive into it. Furthermore, people are used to traditional types of heating and should first see radiant heating as a serious alternative. Also, infrared heating may be seen as something old-fashioned.

4.4.3. Demonstration of interest in infrared heating by scholars

Both interviewed scholars find infrared heating interesting, however, they think differently about the way how to use it. One scholar sees infrared heating as basis heating, while another scholar sees it as an additional heating method. Additional heating can be seen as heating a certain place that is often used to get it more comfortable, next to the basis heating by for example a heat pump. According to the scholar infrared heating is direct, fast radiant heating which is very much appreciated.

"The combination with infrared heating can be very interesting for specific places if you do not really use the house. You can leave everything on a low temperature and at the places where you sit, you can make it comfortably warm" – Scholar 1

"I have put my whole house full with infrared" – Scholar 2

According to a scholar, the build of materials of an infrared heating panel is around 50 Euros. The scholar expects that economies of scale could reduce the price massively as the panels currently cost around 400/500 Euros. The reduction in price could remove the financial barrier. Another barrier for infrared heating is that electricity contains much more energy taxes than natural gas. In the Netherlands, much of the electricity is made in gas and coal plants which have returns of 40-50%.

"Electricity is made in gas plants and also in some coal plants in the Netherlands, but mainly gas plants. There you have returns of 40/50%. For the creation of electricity, you need 2 times as much energy in a plant than you would need in your own gas boiler" – Scholar 2

A scholar mentioned that the Dutch energy mix is not sustainable. Therefore, the tax on electricity is higher than on gas. Another barrier for infrared heating are the performance norms used in the construction industry. According to a scholar, these are 'high school' formulas which are too simple and it is a shame these are used. The coefficient of performance (COP) is the provided heat expressed in watt divided by the electricity usage expressed in watt, so how efficient energy is used in a heating method. Infrared heating, which is based on radiant heating, goes directly to the surface of objects and people. You need less heat, because you do not have circulating air flowing around. You have a certain feeling of comfort, because the bodies around you are not so cold. Convection heating creates currents, whereby air circulates from warm to cold. It came forward that some things cannot purely be described in quantitative ways and the qualitative aspects, such as feeling of comfort, are not taken into account.

"Because there is less draught, you need a lot less heat. It is like a cup of thee that is hot, if you stir it cools down quicker and if you do not stir it remains warm. That is what draught does. And that advantage is not included in the calculation" – Scholar 2

To summarize, both scholars agree infrared heating is fast radiant heating which is very much appreciated. There are different opinions if infrared heating should be used as basis heating or as additional heating method. Economies of scale could reduce the price of infrared heat panels and remove the financial barrier. Another barrier for infrared heating is that the Dutch energy mix is not sustainable. As a result, electricity contains much more energy taxes than natural gas. Furthermore, the COP does not take qualitative aspects, such as comfort, into account.

5. Conclusion

In this section an answer will be given on the main question: *why is infrared heating not adopted yet as mainstream innovation according to the quadruple helix theory?* The purpose of this research was to get insights on the barriers that hinder infrared heating from being adopted. Therefore, the goal is not to make a judgment about infrared heating or alternative heating methods.

At the moment there is limited knowledge by consumers about infrared heating. This limited knowledge causes many speculations about all kinds of dangers. Some respondents have actually not heard about infrared heating before. Unfamiliarity with infrared heating limits the adoption of infrared heating. Furthermore, environmental friendly is seen as important with regards to a heating method. Financial attractiveness is considered at least as important as reducing the CO2 footprint, if not more. As for social values, sharing the responsibility of adopting a sustainable heating method is seen as important. In addition to this, the opinion of consumer about heating methods is influenced by the media. When these mentioned ethical factors are present, it has a positive influence on the adoption of infrared heating and vice versa. Consumers take many financial and practical matters into account. The most important topics are financial and aesthetical aspects which are recurring criteria that have to be met. Next to this, the instalment has to be easy for consumer to adopt infrared heating.

It is not a goal in itself to put infrared heating on the policy agenda, but there must be a recognized necessity. It has to be a feasible heating method with respect for the climate. The energy transition can go to different directions. If parties show with prove, numbers and calculations that infrared heating is the best solution, it will surely be taken into consideration.

The COP of infrared heating panels is worse than the COP of alternative heating methods. Infrared heating is sustainable if green energy is used for infrared heating. When infrared heating panels use the quality of electricity that is supplied by the Dutch power grid, with few sustainable energy, it is not.

Funding is crucial for something to become a research topic. If infrared heating is acknowledged as the right heating method, allocation of funding is likely to occur to stimulate the adoption of infrared heating as research direction. Academic freedom of researchers is still the most important determinant that steers research directions. Infrared heating might be seen as too simple where too few breakthroughs are possible. The higher purpose, common interest and need for certain knowledge need to be seen before something becomes a hot research topic.

To conclude, multiple barriers hinder infrared heating from becoming a mainstream innovation. Different thoughts play roles in the perception of sustainability and the choices about heating methods. It makes the landscape of heating unclear. More information should become available to tackle prejudices about safety and to make people aware about (hybrid) applications of infrared heating. The most important barrier that came forward during the research is the quality of the Dutch electricity grid with its unsustainable electricity. With the availability of green electricity, the technology infrared heating can be seen as a fully sustainable heating method. This would greatly decrease the degree of difficulty to overcome other barriers and adopt infrared heating as mainstream innovation.

6. Discussion

In this section the theoretical contributions will be discussed, furthermore the limitations of the research and suggestions for future research are described.

The theoretical contribution of this research is the overview of barriers that hinder the adoption of infrared heating and contributes to the limited available literature about this technology. The quadruple helix theory provided insights about the adoption of infrared heating from all four perspectives. The conclusion shows the quadruple helix actors are interdependent. Different sequences of actors adopting new technology are possible. An interesting way of approaching the adoption of infrared heating is to think if the adoption would be possible without per se all four helixes involved. The triple helix actor mentioned that a fully developed technique actually does not need further policy attention. This means that the adoption of infrared heating can also happen without policy makers interfering in this process. Further, researchers can contribute to the adoption of infrared heating by conducting research to the practical applications of infrared heating. This actor can help to justify the valuable contributions of the technique, however, as the fundamental technique is existent, the presence of the helix in the adoption process is not a prerequisite. Finally, the helixes civil society and industry are indissolubly linked to the adoption and cannot be excluded.

The quadruple helix theory puts people and organizations in boxes. It assumes that they belong to one helix and the border limits them to exceed their domain. During the research it has come forward that people and organizations can in fact be ‘multi-actors’. A scholar which was interviewed during the research, has a background in the industry and is meanwhile also a consumer, because this person has infrared heating installed in one’s own house. Next to this, a person of an organization was interviewed that closely collaborates with research institutes, policy makers and the industry. These type of people and organizations provide broader insights than from just one quadruple helix perspective. The quadruple helix theory makes it hard to categorize the obtained data when this phenomenon occurs. After all, the quadruple helix theory is a tool to understand different perspectives about a subject and should not necessarily be used as a strict way of conducting research.

Four interviews with consumers were done via telephone or Skype, and two interviews were conducted face-to-face. The interviewer observed that in the face-to-face conversations' interviewees were constantly looking to start a dialogue. When questions were asked by the interviewer, especially in the beginning, interviewees responded by asking a new question to the researcher. In the future it is therefore recommended to use every time the same method of interviewing, preferably by telephone or Skype, to prevent the initiation of dialogues. All consumers, except one, argued that the government should provide incentives to stimulate the adoption of infrared heating. The remark must be made that it seemed like most consumers simply assumed it is a sustainable technique and are not critical if the technology is worth stimulating by the government.

A limitation of this research is the absence of policy makers as respondents. Despite putting a lot of effort into it, the researcher was not able to interview someone from public administration. This could mean people representing public administration simply did not have time for it, but it could also mean no-one from public administration is actually a specialist in this field. As the triple helix actor mentioned public administration must see the necessity to put something on the policy

agenda. If the necessity to put infrared heating on the policy agenda is indeed not seen, it is explicable why no-one within public administration is appointed to take the lead with regards to infrared heating and no-one feels like talking about infrared heating. Another limitation of the research is the small group of respondents interviewed from each helix. The research resulted in an elaborate list of barriers, but the list is not exhaustive as more barriers to adopt may exist.

The research has provided answers to what and how barriers hinder infrared heating from being adopted. The research and the input of respondents also invoked new questions for future research: How does infrared heating fits in a hybrid heating method? Here, it would be interesting to discover what basis temperature of for example a heat pump or gas boiler is needed and from which level infrared heating can supplement it, as economically and ecologically as possible, to a comfortable level. Furthermore, a second question that was invoked: how can a COP be constructed that includes qualitative aspects? This could be done by for example having two different climate chambers, one with infrared heating based on radiation and one with a heat pump based on convection heating with all other variables held equal, to measure the qualitative aspect feeling of comfort.

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Appendix 1: Interview questions

1.1 User adoption (civil society)

Familiarity:

1.1 What type of heating do you currently use? What are the alternatives?
1.2 Do you know what infrared heating is?
<now give a short presentation about infrared heating with the help of a plasticized a4 sheet of paper that shows a picture, quotes, some text and numbers>
1.3 Imagine you see a commercial about infrared heating. What are your first thoughts? Would you think of risks?
1.4 How important is it that you know a lot about a product like infrared heating before you switch to it?
1.5 Are you usually one of the first, in between or one of the last persons to acquire new technology in your social circle?
1.6 Are you open to adopt infrared heating now or in the future?
1.6.1 If yes, why? What is decisive?
1.6.2 If no, why not? What is decisive? What more would you like to know about how it works or about the features?
1.6.3 Why is that important to you?

Ethical matters (environmental and social values):

1.7 Do you know the carbon footprint of your house? If it is assumed that it is above average, what do you think?
1.8 What is environmentally friendly heating according to you?
1.9 Let's assume your provider sends you a letter and says: 'listen, this is a new environmentally friendly heating method'. What would your first thought be? How important is this feature for you?
1.10 How environmental unfriendly does your current heating method need to be in order for you to switch?
1.11 Should everyone share the responsibility to adopt a sustainable heating method? Do you experience approval of others to comply with this?
1.12 Does the media influence your opinion with regards to choosing a heating method?
1.13 Nuon, Essent and Eneco are the main established energy providers. These brands have a big market share in their sector. If infrared heating would bring new players on the market and disrupt this oligopoly, would that matter for your decision to adopt?
1.14 We talked about sustainability and social justice, what other things come into your mind when you think about ethical values in relation to heating?

Financial and practical matters:

1.15 What are for you the most important advantages of infrared heating?
1.16 Would you change to infrared heating if it benefits you financially?
1.17 Do you see increased utility by using infrared heating?
1.18 Do you think the government should provide incentives to stimulate the adoption of infrared heating? What kind of incentives?

Financial and practical risks:

1.19 What are for you the most important disadvantages of infrared heating?
1.20 Would you change to infrared heating if it does not benefit you financially?
1.21 Do you see decreased utility by using infrared heating?

1.2 Policy adoption (policy makers)

2.1 What are the current dominant issues that need attention, policy wise, with regards to heating (discuss in max 5 minutes)?
<now give a short presentation about infrared heating with the help of a plasticized a4 sheet of paper that shows a picture, quotes, some text and quotes>
2.2 What is the current status of infrared heating with regards to policy?
2.3 I understand that a topic usually emerges in society before policy is created around that topic. How do policy makers determine the current interest for infrared heating in the society?
2.4 When is a topic important enough to put it on the policy agenda?
2.5 What is the attitude of the government towards infrared heating?
2.6 Is the current political climate positive for infrared heating? Why?
2.7 Why do you think there is no specific policy about infrared heating yet?
2.8 What would it take to make encouraging policy for infrared heating?
2.9 Is infrared heating with its usage of electricity considered to be a suitable replacement for gas as this is prescribed in the Climate Agreement?
2.9.1 If yes: how do you think the government should stimulate the use of infrared heating?

1.3 Market adoption (industry)

3.1 What is the current market situation of infrared heating?
3.2 What are the barriers?
3.3 Who are your competitors on the infrared heating producers' market?
3.4 With solar panels the yields vary enormously. I can imagine infrared heating panels also differ in terms of quality. How can you measure the quality of infrared panels?
3.5 Can it be shown to civil society and policy makers infrared heating contributes to environmental goals?
3.6 Which steps can the industry take to stimulate the adoption of infrared heating?
3.7 What help does the industry need from other sectors to stimulate the adoption of infrared heating?

1.4 Research adoption (research & education)

4.1 A lot of research is done about solar energy and hydrogen energy. Why are academics relatively less interested in infrared heating?
4.2 Do you have experience with a similar situation (technology where at first hardly any research was conducted about, but later on a lot of research was done about?)
4.3 What can we learn from that?
4.4 What does it take for something to become a hot topic for research?
4.5 How can infrared heating become a hot topic? What needs to happen?
4.6 How can funding be acquired to do research about infrared heating?
4.7 Do you find infrared heating interesting?
4.7.1 If yes: What do you find interesting? What are the questions others find interesting?
4.7.2 If no: Why not? Why not dedicate time to this technology? If it is relatively unvisited, wouldn't you benefit from being a discoverer'?

Appendix 2: Interview guide

2.1 User adoption (civil society)

Questions Civil Society (read how it is written)	Points of attention
1. Ok, let's talk about heating	What are the barriers? Why?
1.1.	
1.2.	
1.3.	Focus on familiarity. Not on ethical and financial issues.
1.4.	
1.5.	
1.5.1.	
1.5.2.	
1.5.3.	
1.6.	
1.7.	Skip this introductory question when lack of time.
1.8.	Skip this introductory question when lack of time.
1.9.	
1.10.	
1.11.	
1.12.	
1.13.	
1.14.	
1.15.	Examples: easy to understand and install, pretty attachment to ceilings, saves energy, financial benefits e.g. save money.
1.16.	
1.17.	
1.18.	
1.19.	Examples: difficult to understand and install, waste of money, ugly attachment to ceilings.
1.20.	
1.21.	

2.2 Policy adoption (policy makers)

Questions Policy makers (read how it is written)	Points of attention
2.	How high/low is infrared heating put on the political agenda? Why?
2.1.	
2.2.	
2.3.	
2.4.	
2.5.	With attitude I mean openness (or lack of it), support (or lack of it), etc.
2.6.	
2.7.	Story about energy labels.
2.8.	Examples: assigning of subsidies, creating favourable tax measures, make recognized government labels and certifications, etc.
2.9.	

2.3 Market adoption (industry)

Questions Industry (read how it is written)	Points of attention
3.	Why is infrared heating (not) a good investment?
3.1.	
3.2.	Ask how every barrier works and why it is a barrier.
3.3.	
3.4.	
3.5.	
3.6.	
3.7.	

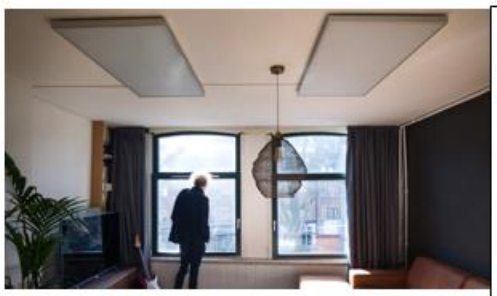
2.4 Research adoption (research & education)

Questions Research & Education (read how it is written)	Points of attention
4.	How (un)sexy is the topic infrared heating? Why?
4.1.	
4.2.	
4.3.	
4.4.	
4.5.	
4.6.	
4.7.	
4.7.1.	
4.7.2.	

Appendix 3: Standardized explanation about infrared heating

Op het plaatje linksboven zie je twee infraroodpanelen aan het plafond hangen. Op het plaatje linksonder zie je een infraroodpaneel aan de muur hangen. Infraroodverwarming is op basis van elektriciteit. Het geeft hele plaatselijke warmte. Het straalt namelijk naar je toe. In deze ruimte waar we nu zitten, worden we opgewarmd door de lucht. Omdat de lucht een bepaalde temperatuur heeft, voelen wij ons nu aangenaam. Bij infraroodverwarming is het zo dat als je je dichtbij een infraroodpaneel bevindt hij jou eerst opwarmt. Het warmt eerst personen en objecten op. Het is vergelijkbaar dat als je in de winter op skivakantie bent, en het is nul graden, en je zit op een terrasje dan voelt het toch aangenaam in de zon. Het is snelle warmte. Als je de infraroodverwarming aanzet, voel je binnen enkele minuten de warmte ervan afkomen.

Appendix 4: Visualization of infrared heating



Op basis van elektriciteit

Plaatselijke warmte

Snel verwarmd