Environmental and Energy Management

Master of Science

*Master Thesis*

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# From administrative ambition to physical implementation: Thermal Energy from Surface water in the Netherlands

An analytical and exploratory research into the question of why Thermal Energy from Surface water has not yet been implemented to its maximum potential

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*“The earth, the air, the land and the water are not an inheritance from our forefathers but on loan from our children. So we have to handover to them at least as it was handed over to us”*

Mohandas Karamchand Ghandhi † - 1909

# Abstract

The Netherlands currently faces climate change adaptation and mitigation challenges. A drastic decrease in greenhouse gas emissions and sustainable alternatives for natural gas are targeted in the Dutch National Climate Agreement and the Global Paris Agreement. Thermal Energy from Surface water (TES) could be one of the sustainable alternatives in the demand of heat and cold. The potential of TES is estimated to be at least 40 percent of the cold and heat demand of the Netherlands. This thesis aims to explicate the factors that drive and hinder the implementation of TES to its maximum potential. Interviews were conducted and literature was consulted to determine driving and hindering factors. To assess those factors in terms of sustainability, a Triple Bottom Line framework was applied. A Balanced Readiness Level Assessment was executed to determine the readiness of TES implementation.

Barriers that hinder the implementation of TES concern knowledge deficiencies, the possible impact on the ecology of water bodies, getting through the bath tub phase of risk-bearing pre-investments, a lack of governance, infrastructural bottlenecks, social capacity, a short-falling subsidy system, and the current regulatory framework. Revision of the current regulatory framework, reconsideration of the existing SDE++ subsidy system, social capacity building, ecological monitoring and, agenda-setting are measures that could stimulate the implementation of TES.

This research implies important lessons. TES should be considered a very feasible alternative for heat and cold supply. The technological Readiness Level is (TRL) level 9, which means that TES is an actual system proven functional in the natural environment. One of the biggest challenges the Netherlands faces, however, is translating administrative ambition into physical implementation. Deviation from the processes that are currently being followed is necessary. And next to this, this research shows the difficulties a niche technology faces in contrast to the regime of natural gas in the Netherlands.

TES requires structural changes on a national authoritative level for the technology of Thermal Energy from Surface water to be implemented at its maximum potential. Guideline assessments, standardized permit requirements, subsidies for feasibility studies, and working out business case studies are the practical applications that can help TES in developing its potential  For this, companies should make money available for business cases, and the government should stimulate by subsidizing TES projects. Only then will TES eventually be implemented to its maximum assessed potential. If done comprehensively, TES will be a great contributor to meeting the European and nationals targets and objectives and to the whole energy transition.



***Key words:*** *Thermal Energy from Surface water, Aquifer Thermal Energy Storage, Triple Bottom Line, Technology Readiness Level, Balanced Readiness Level Assessment, Niche and regime management*

# Preface

If you are reading this, it means that I have succeeded. After nineteen years of primary school, high school, university of applied sciences, and research university I can say that I am done. For now. Life is all about learning and I am going to try to develop myself more every day.

The challenges the world is facing and will face in the (near) future motivate me to be actively contributing to the greater good of society. Obviously, the climate is at the center of everything here. Knowledge in the field of climate mitigation and adaptation is of pivotal importance. If one can learn at least one thing from this thesis, it is that we should not play around with the climate. We are in the middle of a climate crisis, and we should consider the utmost to deal with this crisis. The problem is complex, and so is the solution. However, we live in a time where every decision that is being made affects our children, grandchildren, and great-grandchildren.

Thermal Energy from Surface water is potentially one of the solutions for the energy mix of the Netherlands in our battle against climate change. The technology concerns a straightforward implementation that can have its positive impacts on the climate on multiple scales. Life is nothing like a casino, but imagine if we would sit at the roulette table, I would suggest not to go all-in on red or black. A risk-spreading tactic that yields the most, in the long run, should be chosen. To be successful, the burdens must be borne and distributed on a global scale. This implies that one player may lose, whereas other players may be profitable. All stakeholders that sit at the same roulette table have to work together to ensure that they are profitable cooperatively. This is also the main reason for a country like the Netherlands to take the lead. In the long run, it will all be worth it.

I could not have done this without some people, they deserve extra attention. First of all, I would like to thank my nearby network, Ing. B.D. Volkers MBA, CEO of WKDE (Waterkracht Duurzame Energie) in particular, for their patience in guiding and supporting me throughout the writing phase. WKDE made it possible to carry out this thesis partly during working hours. WKDE sees the importance of taking TES to the next development step and has therefore financially supported this research. It does good to know not being on your own. Besides this, I would like to thank all of the interviewees who allowed me to meet them, even though it was online. I am grateful that you sacrificed precious personal time for my research. I hope you enjoyed our conversations as much as I did. Last but not least, I would like to thank dr. E.J. Aukes. Mr. Aukes guided me through my thesis professionally. Thank you for your patience and sharing your knowledge.

Enjoy Your Reading.

Julian van Zuuk

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# List of Acronyms

| | |
|---|---|
| 3BL | Triple Bottom Line |
| ARL | Acceptance Readiness Level |
| ATES | Aquifer Thermal Energy Storage |
| CBS | Centraal Bureau voor de Statistiek (Central Bureau of Statistics) |
| Kton/year | Kiloton per year |
| kWh | Kilowatt hour |
| MJ | Megajoule |
| MRL | Market Readiness Level |
| MTA | Multi-year-agreements |
| $MWh_{th}$ | Megawatt hour (thermal energy) |
| ORL | Organizational Readiness Level |
| PJ | Petajoule |
| RRL | Regulatory Readiness Level |
| SDE++ | Subsidy Stimulation of Sustainable Energy Production |
| TED | Thermal Energy from Drinking water |
| TES | Thermal Energy from Surface water |
| TEW | Thermal Energy from Waste water |
| TRL | Technology Readiness Level |

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# 1. Introduction

## 1.1 Background

Since the industrial revolution began in the eighteenth century, capabilities that lie far beyond animal and human power were developed. Steam-powered machinery and later internal combustion engines transformed the way people produced goods and moved around the world. During the nineteenth and twentieth centuries, the industrial revolution was continued by electrification and related technologies. Today, a growing amount of people keep their homes warm during winter and cool during summer (Chu & Majumdar, 2012). The natural gas consumption of the Netherlands has been 18.000 to 27.000 million cubic meters annually since 1975, whereas the Dutch national gas extraction exceeded 70.000 million cubic meters annually since the 1970s (CBS, 2021).

One of the considered sustainable alternatives for natural gas is *Thermal Energy from Surface water* (TES) (Deltares, 2021a). TES is one of the three forms of aquathermal energy generation, with thermal energy from wastewater (TEW) and thermal energy from drinking water (TED) being the other forms. Nowadays, 25 percent of the current Dutch energy demand consists of cooling and heating of the built environment. According to Deltares (2021a), TES can provide 40 percent of the heat and cold demand in the Netherlands. It should therefore be considered as a very serious alternative in the energy transition. Although TES is not an entirely new technology (Idsø & Arethun, 2017; Mol et al., 2011; Van der Hoek, 2012; Zhou et al., 2020) the amount of scientific material concerning TES is fairly scarce.

Given that global energy consumption is expected to increase even further because of population growth and the growth of the global energy grid and despite the increase in isolation of buildings, the inevitable impact on the climate has to be taken very seriously. The amount of $CO_2$ in the atmosphere has risen from 278 ppm to over 400 ppm in the twenty-first century and is expected to increase if the present course is not changed (Chu, Cui & Liu, 2017). During the twentieth and twenty-first centuries, multiple climate agreements were developed and supported by multiple nations from all continents. One of the first ones dates from 1992, *The United Nations framework convention on climate change* (The United Nations, 1992), followed by the 1997 *Kyoto Protocol* (The United Nations, 1997) and *The Paris Agreement* of 2015 (The United Nations, 2015). The main targets of the *Paris Agreement*, the most recent global agreement, are as follows:

I. Limiting the Global temperature rise to well below 2°C, to prevent global warming
II. Strengthening the resilience and reducing vulnerability to the consequences of climate change
III. Aligning financial flows with these two goals

One of the nations that had its contribution to the aforementioned agreements, is the Netherlands. Since November 2011, climate change was added to the Dutch national political agenda to commit to national and European climate and sustainability targets (Ministry of Infrastructure and Environment, 2011). This development was followed by multiple national climate agreements, climate law, and ultimately the recently published *Climate Plan of 2021-2030* (Ministry of Economic Affairs and Climate, 2020). The national climate goals were processed in a Climate Law in which the following climate policy objectives for 2030 and 2050 were made legally binding:

I. The Netherlands must have reduced its greenhouse gas emissions by 95% by 2050 compared to 1990
II. An interim target of 49% greenhouse gas reduction has been set for 2030
III. By 2050 the electricity production has to be 100% $CO_2$ neutral

In 2019, a *Green Deal* 'Aquathermics' between the Dutch Government and several water managers, such as regional water authorities, was ratified (Government of the Netherlands, 2019). The *Green Deal 'Aquathermics'* specifically considers the following points:

- The water system as a heat source and alternative heat sources;
- Water managers can and want to contribute to the heat transition;
- It is valuable to look at the potential of aquathermal energy from different angles to use aquathermal energy in different transition models;
- Ecological, political, technical, judicial, and economic issues should be assessed now in order to determine the value of aquathermal energy and how the heat source can be utilized well;
- At the moment of publishment of *green deal* in 2019, the potential of aquathermal energy had not been mapped and brought to the attention yet. In 2020, Deltares published an online viewer of the potential of Aquathermal energy in the Netherlands for every water body;
- A lot of companies and local governments start exploring the possibilities and opportunities of aquathermal energy. Water source holders are just one link in the chain of aquathermal energy, joining forces between companies and governmental organizations is one of the goals of the green deal.

## 1.2 Problem Statement

Based on estimations as reported by Rijkswaterstaat (2021), TES technically can potentially contribute 12% in the heat demand and 54% in the cool demand in the Netherlands. The economic potential of TES, which equals the technical potential but adjusted for the financial feasibility (Scholten & Van der Meer, 2016), is estimated at 150 Petajoule (PJ) annually. This accounts for over 40% of the future cold and heat demand in the built environment (350 PJ annually) (Deltares, 2018). TES can therefore be a sustainable and substantive alternative and contribute to the efforts of municipalities to build gas-free neighborhoods (Rijkswaterstaat, 2021). Mol et al. (2011) made an inventory of the possibilities to recover sustainable energy from municipal water cycles. From this inventory, it was concluded that a substantial CO2 emission reduction in the Amsterdam water cycle potential exists up to 100 Kton/yr. Also, Van der Hoek (2012) reports the following: "First calculations reveal that energy recovery from the water cycle in and around Amsterdam can contribute to a total reduction in greenhouse gas emissions up to 74,900 ton CO2-eq/year. The potential of TES was academically assessed in 2011 and 2012 as highly potential by Mol et al. (2011) and Van der Hoek (2012). However, following the determination of the potential of TES the route from potential to practice has to be elaborated thoroughly to reach the maximum implementation potential of TES. It is particularly important to determine whether the technology behind TES is ready for implementation on a broader scale. Next to this, understanding of the factors that drive and hinder the implementation of TES from multiple perspectives have to be included in this research in order to clear the route from potential to practice for TES to be implemented.

## 1.3 Research Objective

The objective of this research is to identify factors that hinder and stimulate the implementation of TES. This research aims to contribute to national and global sustainability goals and objectives. TES could potentially contribute to greenhouse gas emission reduction as a sustainable alternative for natural gas for heating and as a sustainable alternative for cooling in the Netherlands. It is of major importance to utilize all potential sources that contribute to climate adaptation and mitigation, albeit indirectly. Therefore, the possibilities concerning TES should be researched to find out the potential contribution of TES to climate adaptation and mitigation as considered in national and global sustainability goals and objectives. The company of WKDE is interested in the question of why TES has not yet been implemented to its maximum potential. Therefore, the company made a research budget available so that the research could be executed partially during working hours.

## 1.4 Research questions

### 1.4.1 Main Research Question

The purpose of the main research question is to state the problem that will be focused on during this thesis. The research question is formulated in such a way that it will comply with the research objective and contribute to the problem statement in a resolving manner. Therefore, the main research reads as follows:

*Why has Thermal Energy from Surface water not yet been implemented to its maximum potential in the Netherlands?*

### 1.4.2 Sub-Research Questions

The sub-research questions are narrow compared to the main research question. They are meant to form a body for the information necessary to answer the main research question. The sub-research questions read:

*What is the current Technology Readiness Level of Thermal Energy from Surface water?*

*What factors drive or hinder the implementation of Thermal Energy from Surface water in terms of the triple bottom line of sustainability?*

The sub-questions were drafted in such a way that they contribute to the main research question interdisciplinary. The first sub-question was formulated to explain the technology behind TES. The second sub-question, concerning the maximum potential of TES, is meant to indicate on which quantitative scale TES can be applied. A link between the first and second sub-question exists because technology is one of the factors that partly determines the maximum potential.

The second question is also related to sub-question one. The current Technology Readiness Level, henceforth referred to as TRL, determines how far the technology has progressed on the way to implementation (Straub, 2015). This sub-question potentially covers part of the answer to why Thermal Energy from Surface water has not yet been implemented to its maximum potential in the Netherlands. The fourth and last sub-question was drafted so that the factors, next to the TRL, that drive or hinder the implementation of TES are discussed. The drivers and factors that influence the implementation have to be derived from literature research and stakeholder analysis. The triple bottom line (3BL) is a framework that consists of three sustainability pillars: people, planet, and profit. The role of the 3BL is to emphasize the performance of TES in terms of the caused impacts on the environment, economy, and society (Sajan & Gautam, 2020). All sub-questions each have their share in providing partial answers to the main question. After merging those partial answers a comprehensive and interdisciplinary answer to the main question should follow.

# 2. Literature background

## 2.1 TES in practice

TES is one of the forms of Aquathermal energy generation. TES uses differences in the temperature of surface waters during the changing seasons. Existing technologies are applied interconnectedly to utilize energy from surface water. During warm seasons, a heat exchanger is applied to subtract energy from the surface waters. The heat is transported through a network and can then either be taken off directly or stored in an Aquifer Thermal Energy Storage (henceforth referred to as ATES) installation (heat and cold installation) underground. This stored energy can later be used during cold seasons to warm buildings supported by a heat pump. In such situations, the heat pump runs considerably more efficiently because the temperature of a TES source is approximately 18°C which is significantly higher than the temperature of the surface water and outside air during the winter (Deltares, 2021a). A schematic overview of this technique is shown in figure 1.

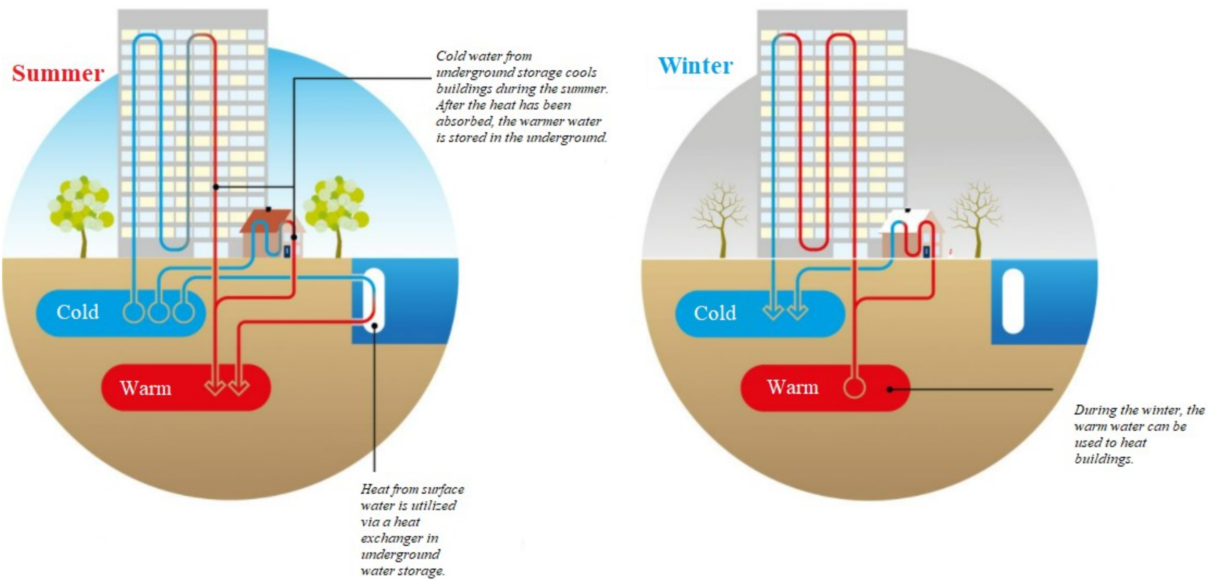


*Figure 1: Schematic Overview of TES technique. Left: situation during summers. Right: situation during winters. Retrieved and translated from Deltares (2021a)*

The thermal energy from a surface water system is extracted by passing the water through or beside a heat exchanger. A heat pump system's medium is heated, which passes through via a separate circuit of the heat exchanger. Thermal energy can be exchanged through the heat exchanger because of a temperature differential between the systems. The cooled surface water remains in the surface water environment or is injected back into it. Even if the temperature is below ten degrees Celcius, heat can theoretically be extracted from the surface water. A higher temperature of the surface water is better from the standpoint of energy generation efficiency. The demand for thermal energy in the built environment is highest in the winter. This contrast is called seasonal counter-cyclical, and an ATES is the most utilized storage technology to solve this (Stowa, 2020a). An ATES can store energy from surface water in the soil for the next season, a heat or cold deficit can be recovered in such a way. Next to heat supply by surface water, a cold supply can also be realised. However, the potential of cold supply from TES is considerably lower than the heat supply as discussed before. The temperature of surface water bodies is one of the important parameters for the opportunities for TES implementation. The impact of heat and cold supply by TES on the temperature of the surface water is up for discussion later in the literature review.

The technique explained in figure 1 is a TES installation in combination with an installation. Another type of TES without the application of an ATES installation can also be realised. The figure below gives a schematic overview of the different TES techniques.

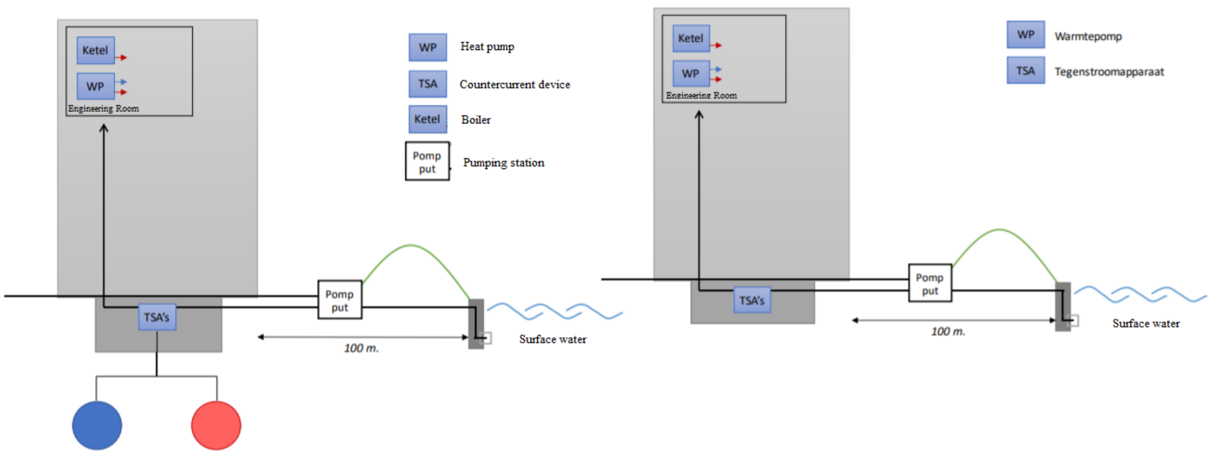


*Figure 2: Schematic overview of TES type 1 (left) and type 2 (right). Retrieved and translated from Techniplan Adviseurs bv (2018)*

A system exists that functions somehow similar to TES, this system is called *Ocean Thermal Energy Conversion* (OTEC). Another system is *Aquifer Thermal Energy Storage* (ATES). As discussed before, ATES is a big component in the development of TES systems.

## 2.2 Aquifer Thermal Energy Storage

ATES can be applied for large-scale projects to provide heating and cooling such as buildings, district heating, or industries. This system is also very sustainable and environmentally friendly. It saves up to 0,46 kg CO2 and 6,7 MJ in energy savings per pumped $m^3$ water (IFTechnology, 2020). ATES systems are bidirectional which means that they allow efficient seasonal storage of warm and cold energy in the form of groundwater in an aquifer (Dickinson et al., 2009). According to Fleuchaus et al. (2018), there currently are more than 2800 ATES systems in operation worldwide. As discussed before, one of the two types of TES installations functions in conjunction with the ATES systems, and therefore the functioning of ATES should also be included here.

## 2.3 Practical experiences from TES case studies

Practical outcomes from a couple of realized TES projects, based on a report from Stowa (2020a), are discussed below. The practical outcomes are divided into four categories: legal, environmental, economic, and technical.

### 2.3.1 Legal

The legal practical experiences concern the permit procedures, the role of municipal government and water managers, and cold extraction. The permit procedures are considered to be long and complicated and it is not clear who is responsible for what. The role of municipal governments and water managers is very big, and regulations are getting stricter. TES and local area developments should be coordinated and harmonized in concurrence. Sustainable energy policy makers are willing to develop, permit granters are lagging due to a shortage of knowledge.

### 2.3.2 Environmental

The positive practical experiences in the environmental category are that the ecology is being influenced positively due to cold discharges from a TES installation. Next to this, TES systems are considered to be potentially affordable, reliable, and sustainable. The negative practical experiences concern drought, being one of the determining factors of success, surface water temperatures, freezing could occur, and varying water levels. The most important focus point for TES should be the water quality according to one of the project’s interviews.

### 2.3.3 Economic

The projects that Stowa (2020a) discusses, come with quite positive economic practical experiences. First of all, full depreciation of investments could be possible after 15 years, TES can be seen as an economic way of heat generation that is easily applicable, and the TES system can be affordable, reliable and, sustainable. Another practical experience is that potential heat and cold surpluses exist in projects. Those could be economically interesting for exploitation.

### 2.3.4 Technical

Positive technical practical experiences concern the affordability, reliability, and sustainability of TES systems. Also, a maximum of 5 °C temperature difference is enough for heat generation, and a TES system in combination with an ATES system is a trustworthy heat source that is applicable in many locations. However, the downsides of TES concern pollution due to thickening of existing contaminants in the surface water that causes clogging in the filters, expensive pipework (titanium instead of stainless steel pipework), and TES systems do in some projects not provide cooling because the selected heat pumps do not generate cold. Next to this, a suggestion was done: try to build as close to the source as possible because of the transport of heat. A shorter distance could also prevent or minimize infrastructural problems. A heat pump also generates high temperatures, the heat pump should therefore be positioned close to the location where the heat will be released. Usage of a low-temperature net, which is normal in ATES systems, helps to minimize heat losses.

### 2.3.5 Case Study Hoogdalem

Since 2012, more than 230 houses in the project of *Hoog Dalem*, Gorinchem, have been provided with energy based on the TES method without connection to the national Dutch gas network. At the time of the realisation of the project, *Hoog Dalem* was the first all-electric (100% $CO_2$ emission decrease) neighbourhood of the Netherlands in which buildings were heated in cold seasons with heat that is extracted from nearby ditches. A way had to be found to cope with the higher demand for warm water during the year to counteract the imbalance in the soil. Part of the required heat for this comes from the discharging warm water from houses, the rest of the heat is extracted from the nearby ditches. Afterward, the cooled water is discharged on the ditches around the buildings. Side effects of this project were proven to be either neutral or positive in terms of impact on the nearby environment (Deltares, 2021b).

# 3. Conceptual Framework

## 3.1 Readiness Levels

### 3.1.1 Technology Readiness Level

One of the sub-questions of this thesis concerns the Technology Readiness Level (TRL) of TES. The Technology Readiness Level is a system of 9 levels and was developed by NASA in the twentieth century, hence the description 'flight proven' for level 9 of the system indicating the link to space travel (Straub, 2015). In the 2000s, Brown and McCleskey proposed a level 10 for the TRL system indicating 'flight-certified maturity', also called proven operations. Figure 3 shows a diagram of TRLs including this tenth level.

The technology readiness level of TES is of major importance because it is one of the decisive factors in answering the main research question of why TES has not been implemented to its maximum potential yet. The conclusion that should follow from investigating the TRL of TES is how far the technology has matured and what needs to be done to reach level 9 and 10, *system operational* and *proven operations* respectively, if not already achieved.

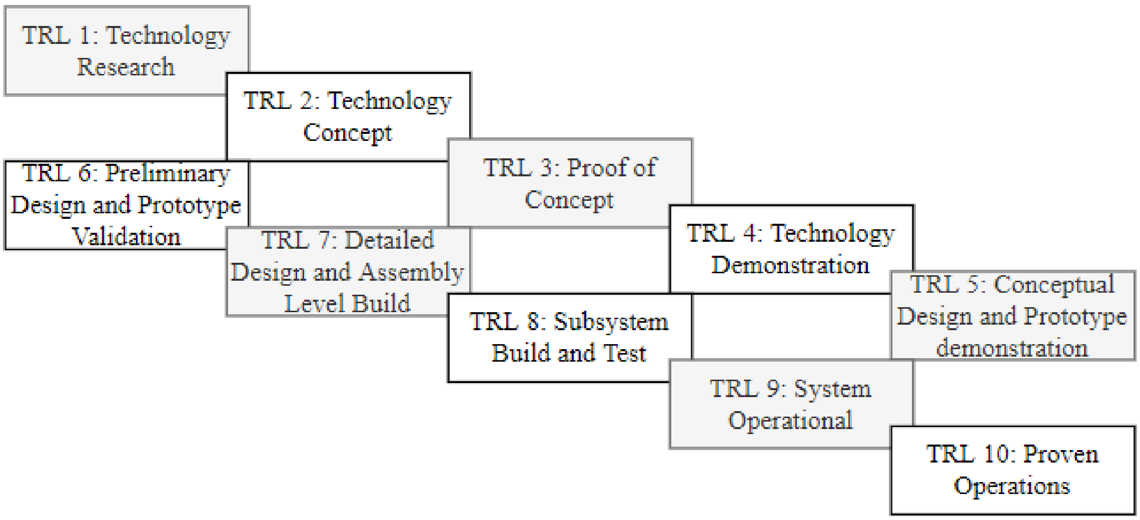


*Figure 3: Technology Readiness Levels as described by Straub (2015)*

In earlier research, the TRL was assessed successfully. Dovichi Filho et al. (2021) applied the TRL criteria to evaluate the maturity level of biomass electricity generation technologies, and Essien et al. (2021) assessed the recovery of bioactives from kanuka leaves using subcritical water extraction. But, The TRL also has its downsides. Essien et al. (2021) consider that description of the TRL based on the descriptors of figure 3 can be arbitrary, particularly when multiple processing technologies must be evaluated in an early stage design setting and detailed analysis is not feasible.

Further, Vik et al. (2021) wrote the following about the TRL: "… as has been noted by many, the development of new technologies is not linear and cannot be grasped by the readiness of the material technology alone … Furthermore, new technologies may conflict with organizational, societal and/or political regulations and understandings… So even if technologies have a high TRL …, this does not tell us if and how new technology is being *domesticated* by its users…". This insight indicates that other readiness levels should be considered: *the market readiness level (MRL), the regulatory readiness level (RRL), the organizational readiness (ORL), and the acceptancy readiness level (ARL)* (Vik et al., 2021). The readiness levels are summarized in a balanced readiness approach.

### 3.1.2 A balanced readiness approach

Vik et al. (2021) developed and presented a methodology for a balanced readiness assessment of novel agricultural technologies. It is stated that to grasp technology development and deployment, a multi-dimensional assessment of technology readiness is required. Questions concerning market readiness, legal considerations, and societal acceptance are questions that the balanced readiness approach should address. The results of the research executed by Vik et al. (2021), the balanced readiness approach, is summarized in figure 4. The balanced readiness approach as elaborated by Vik et al. (2021) will be used to assess the implementation of TES.

| Level | TRL «Development» | MRL «Commodification» | RRL «Legalization» | ARL «legitimization» | ORL «domestication» |
|---|---|---|---|---|---|
| 1 | Specific technological idea is formulated | Hunch of a market need | The legal and/or regulatory aspects of the technology is unpredictable or unknown or unpredictable | The technology is or will be seen as illegitimate or unacceptable | The technology represents a fundamental break with existing work processes or organizing |
| 2 | The technology idea is explicitly described | Market and product are described | Use or production will require changes of laws. | The technology will be seen as controversial in large parts of the population | Unclear how the technology might be adapted to existing work processes/organization |
| 3 | Experimental proof of concept | Market need and market supply are explicated. | Use and/or production will require change or reinterpretations of regulatory framework | The technology is seen as unwanted or inappropriate among groups of the population | An idea about integration domestication exist |
| 4 | Technological elements are tested and validated in lab or simulated environment | Validation of market/small pilot campaign | Use and/or production will require demanding permissions or approvals | The technology is seen as controversial among groups of the population | Integration with work processes/organization is formulated |
| 5 | Integrated technology tested and validated in lab or simulated environment | Business model described | Use and/or production will presuppose accessible permissions or approvals | Use of the technology is seen as unwanted or inappropriate among key actors in the sector | A concrete plan for integration with existing work processes is formulated |
| 6 | Technology demonstrated in relevant environment | Products are being launched in limited scope | Necessary approvals are likely | Use of the technology is seen as unwanted or inappropriate among a few actors in the sector | Large/fundamental organizational changes are needed in order to use the technology |
| 7 | System prototype demonstrated in natural environment | Customers confirm progress/improvement | Necessary approvals for use or production are "just around the corner" | The technology is seen as controversial in parts of the sector | Small organizational changes are needed in order to use the technology |
| 8 | Product tested and validated, and the functionality is being optimized | Stable sale makes income predictions possible | Use or production fulfill general conditions | The technology is seen as controversial among marginal interest groups | Technology is adapted to work processes and/or existing technology |
| 9 | Actual system proven functional in natural environment | Market confirms stability/growth | Use and production are regulatory unproblematic | The technology is generally accepted/applauded | The technology works seamlessly with existing technology |

*Figure 4: Balanced Readiness Level Assessment as elaborated by Vik et al. (2021)*

One difference between the TRL as discussed before and the approach in figure 4 has to be highlighted: the amount of TRL levels do not match. Figure 3 discusses ten TRL levels, whereas Vik et al. (2021) discuss 9 TRL levels.

However, the balanced readiness approach of Vik et al. (2021) covers the ecological dimension of a technology insufficiently. Therefore, a new dimension, the 'Ecological Readiness Level (ERL)' should be considered. The ecological readiness level depends on the impact of technology on the ecological values of an environment on the one hand, and on regulations that protect ecological values on the other hand. In the case of TES, the effect on the ecology by influencing water temperatures and the regulatory framework of TES are indicators for the ERL. To provide an integrated approach, a proposal for nine levels of the ERL similar to those of Vik et al. (2021) is shown in table 1.

*Table 1: proposed levels of Ecological Readiness*

| | | | |
|---|---|---|---|
| Level 1 | Environmental impacts are unknown and regulatory framework has not yet been drafted | Level 6 | Ecological monitoring and a draft version of a regulatory framework |
| Level 2 | The technology is seen as controversial in terms of ecological impact | Level 7 | Review phase of the ecological monitoring and the draft version of the regulatory framework |
| Level 3 | Vulnerability of environmental body is assessed, ecological impacts yet to be researched | Level 8 | The ecological impact is researched thoroughly and the regulatory framework is near-to-ready |
| Level 4 | An idea about environmental impacts exist | Level 9 | The ecological impacts of the technology are negligible or positive, supported by a regulatory framework |
| Level 5 | The initial stage of a regulatory framework | | |

## 3.2 Sustainability policy

### 3.2.1 Niche and Regime management

According to Sengers, Wieczorek & Raven (2019), Niches are places where the co-evolution of technology, user behavior, and regulatory institutions can be nurtured and experimented with. Niches are the areas where radical, opposed to gradual, innovations can emerge without being stifled by the current regime's strong selection constraints (Senger, Wieczorek & Raven, 2019). TES should therefore be considered a niche for now.

Socio-technical regimes are complex arrangements of three interconnected dimensions: a network of actors and social groupings, formal, normative, and cognitive rules that guide actors' actions, and material and technical factors (Sengers, Wieczorek & Raven, 2019). Regimes are the heart of the socio-economic system, which creates stability and continuity while also posing obstacles to structural changes that lead to sustainability. The process by which niche experiments can alter regimes is called 'upscaling' (Jolly, Raven & Romijn, 2012). Jolly, Raven & Romijn (2012) add to this that "The normative orientation of niche experiments is thus the creation of market niches as part of processes towards broader regime shifts. Actors who are outsiders to the incumbent regime are considered critically important. Great emphasis in Strategic Niche Management is put on the role of users in niche experiments".

Path-breaking in such situations, sustainable innovations face a structural disadvantage since they are too demanding in terms of their socio-technical implications for the regime. Early regime concepts were primarily concerned with socio-cognitive and market dynamics that determine which technical innovations engineers and investors consider feasible and worth developing. Later, conceptualizations expanded the concept of regimes to include a broader set of sociological selection processes that operate outside of enterprises and research institutes, in an attempt to understand their emergence and decline (Smith & Raven, 2012):

- Established industry structures, such as established network relations, industry platforms, strong user-producer interactions, shared routines and heuristics, existing capabilities, and resource allocation methods, create a selection environment. Because they do not fit with existing industry frameworks, ground-breaking inventions entering the market may be rejected. Path-breaking innovations may be rejected because they do not fit with current industry structures and decision-making procedures that have evolved in tandem with the dominant design.

- Dominant technologies and infrastructures, for example, enforce specified technical norms and infrastructural arrangements on emerging inventions to create a (material) selection environment. Because ground-breaking innovations necessitate distinct standards and infrastructures to work optimally (technically and commercially), they are viewed as troublesome.

- The established knowledge base's guiding principles and socio-cognitive processes are tailored toward incremental knowledge development rather than paradigmatic shifts. Academic and private research institutes feel disincentives due to a lack of dedicated journals, conferences, and research groups, and path-breaking discoveries are rejected because insufficient resources are given to new knowledge development, Research, Design, and Development (RD&D), and so on.

- Through stabilized market institutions, supply and demand, price mechanisms, user preferences, and routines, markets and dominant user habits create a selection environment. Path-breaking innovations have a difficult time entering the market, for example, because external environmental costs are not reflected in end-user prices, or because they necessitate unpleasant user behavior when contrasted to standard practices.

- Through existing regulations, policy networks, and relationships with established industries, public policies and political power create a selection environment. In terms of jobs, tax base, and votes, political power is used to sustain the status quo. This is a disadvantage for path-breaking inventions, as they necessitate new policies and laws, as well as new political economies.

> -Through, for example, extensive symbolic representation and appreciation, the cultural meaning associated with a given regime creates a selection environment. Because they represent divergent cultural values and lack extensive established representations, -breaking inventions are at a disadvantage.

Hess (2016) reports: “In the U.S. utilities have attempted to slow the growth of distributed generation (DG) solar by reversing policy support, and they have greater financial and political resources than the solar industry”. Niche organizations can overcome such political power via three mechanisms: build coalitions with political parties that support niche technologies, gain support from competing industrial organizations and build coalitions with social movements. The niche-regime pattern is affected by the political opportunity structure (Hess 2016), in this case, the House of Representatives. According to Ratinen & Lund (2016), for evaluating socio-technical changes, two dimensions are considered. A combination of technical advances, such as the deployment of renewable energy technologies, and legislative changes that will improve democracy and citizen participation. To bring about these kinds of changes, new forms of policies are required. Regardless of their goals, most policies have only yielded little results.

### 3.2.2 Agenda-Setting

During the early stages of the emergence of new technologies such as TES, the situation is complex and appears chaotic, making it nearly impossible to guide and manage. A deeper understanding of the factors that contribute to the emergence is required to allow for the potential of controlling such complicated situations. The dynamics of expectations are strongly linked to the agenda-setting process when shared priorities for work are expressed to meet expectations. Actors connect in various sorts of networks as these agendas become operationalized in the field’s ongoing actions (Van Merkerk & Robinson, 2006). These networks are composed of mutual dependencies that can be based on shared rules and routines, on the exchange of intermediaries and their translation, or on the exchange of resources, etc.” (Van Merkerk & Robinson, 2006).

Van Merkerk & Robinson (2006) add to this that: “Expectations guide the activities of the actors within a technological field, while, in turn, expectations will be shaped and reshaped by research results, findings in other technical fields, successful commercialization, and external trends and forces. Over time, choices are made and priorities are set, which results in shared agendas. For new and emerging science and technology, these processes result in an enlargement of the attention in related journals, conferences on the subject are organized, start-ups are founded and companies start collaborations”.

### 3.2.3 Social Capacity Building

Social capacity building refers to the development of ‘capabilities’ that enable citizens to cope with socio-ecological stresses and pressures (De Voogt, Bisschops & Munaretto, 2019). De Voogt, Bisschops & Munaretto (2019) say: “Capacity building is increasingly mentioned as a viable strategy towards an envisioned future of less vulnerable societies". They also articulate five key dimensions of social capacity: knowledge, motivation, networks, finance, and participation". These dimensions function as a framework for demonstrating what capacity-building efforts can contribute to policy making for a technology such as TES. Matsuoka et al. (2004) add to this that the development of social capacity is the most significant task in implementing environmental policy and environmental cooperation effectively and efficiently. Social capacity building could thus be of major importance for a technology like TES.

## 3.3 Environmental Impact

### 3.3.1 Ecology

Ecology is one of the factors that should be taken into consideration in research TES. According to Primack et al. (2009), warmer temperatures are expected to exacerbate disparities in phenology across species. However, it is questioned whether extrapolation of trends can be extrapolated from regions among themselves. Primack et al. (2009) consider field studies to be necessary to determine to see how patterns of variance in species responses to climate change affect species interactions and their adaptation abilities to changing conditions. Ibáñez et al. (2010) add to this that spring and autumn phenologies have been shifting due to warming temperatures.

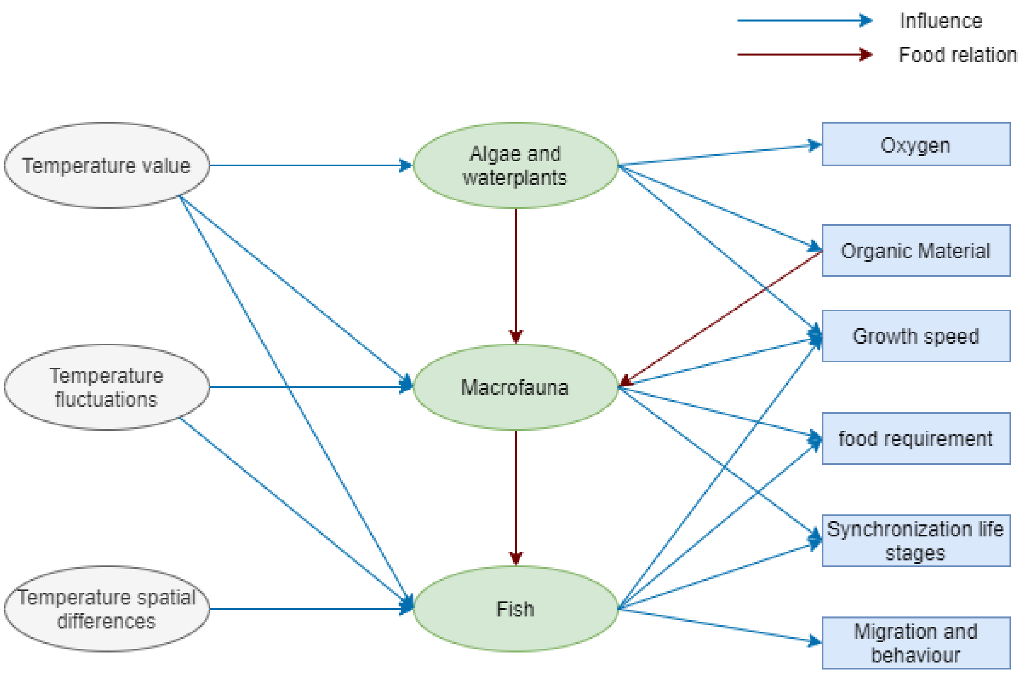


*Figure 5: potential impacts on ecological functioning and food web of surface waters by applying TES (Author's own illustration, cf. deltares, 2020)*

On a local scale, warm water discharges could impact the ecology of water bodies. However, in the Netherlands TES will most likely be used more for heating than cooling. This means that cold water discharges come into play. Ellwood et al. (2012) state that insect reactions were weaker than those identified for plants in prior studies, indicating the possibility of ecological mismatches with negative consequences for both sets of species. Thackeray et al. (2013) indicate that phytoplankton and zooplankton undergo phenological shifts in response to temperature changes and progress as nutrient availability changes. As a result, there was a mismatch in the availability of zooplankton for fish.

## 3.4 Triple Bottom Line

The Triple Bottom line (3BL) consists of three dimensions, the environmental, the social, and the economic dimension for sustainable development (Gimenez, Sierra & Rodon, 2012), also called *People, Planet and Profit*. During this thesis, the impact of TES on the three components of the 3BL will be investigated. The impacts of TES on the three dimensions are especially interesting, since from those impacts the factors that driver and hinder the implementation of TES can be derived. From here, solutions and recommendations can be thought of on how to overcome the factors that hinder, and how to profit from the factors that drive the implementation of TES.

According to Arslan & Kisacik (2017), the 3BL emphasizes the idea that operating just for profit purposes will not be successful if the social and environmental dimensions are ignored. It is emphasized that sustainability is described as an a number of economic activities in proportion to the ecological life support system, as well as a fair distribution of resources among current and future generations. If a system or technology operates in such a way that it gratifies the social and environmental dimensions, it can be considered bearable. If the system or technology gratifies the social and economic dimension, it is equitable. If the system or technology gratifies the environmental and economic dimension it is considered to be viable. If it gratifies all dimensions, the system or technology will be sustainable. In figure 6 the 3BL framework is illustrated. The 3BL framework functions as a framework in which the factors that drive and hinder the implementation of TES can be placed and from there put into perspective in the discussion and conclusion section.

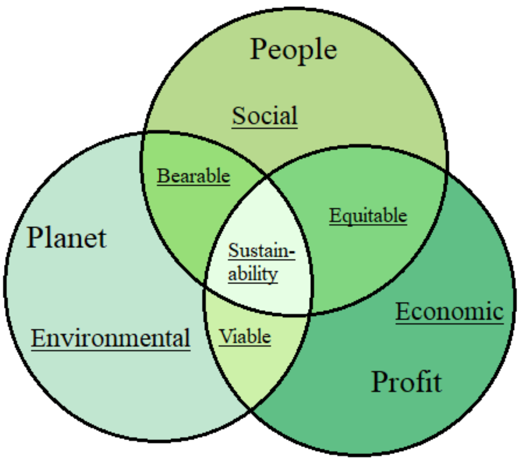


*Figure 6: Three dimensions of the Triple Bottom Line and their interconnectedness with sustainability (Author's own illustration, cf. Arslan & Kisacik, 2017; Coenen, 2020)*

# 4. Methodology

## 4.1 Data Collection

### 4.1.1 Interviewing

One of the means of data collection is interviewing. Interviews were conducted to answer the research questions comprehensively. Interviews are commonly used in qualitative research when the researcher wants to gather facts, gain insight into or understanding of people's thoughts, perceptions, and perspectives (Rowley, 2012). Deciding whether to use interviews or questionnaires is a common concern, Rowley (2012) states: "The big advantage of questionnaires is that it is easier to get responses from a large number of people, and the data gathered may therefore be seen to generate findings that are more generalizable". For this thesis, the intention was to obtain specific information from the interviewees rather than generalizable results for extrapolating causes.

#### *4.1.1.1 Interview Structure*

The interviews were appropriately designed and the interviewees were carefully selected so that useful insights and understandings were gathered. Rowley (2012) defines three types of interviews, structured semi-structured, and unstructured interviews. Structured interviews can be quite similar to questionnaires, where the same order of questions is repeated for every interviewee, and the answers are expected to be short. Structured interviews often produce quantitative data (DiCicco-Bloom & Crabtree, 2006). Unstructured interviews on the other hand are interviews that are based on a limited amount of topics or questions on which interviewees can shine their light during the interview. During unstructured interviews, the questions may then be adapted to the answer of the interviewees. The third type of interviewing, semi-structured interviewing, is the one that was applied during this thesis. According to Rowley (2012), semi-structured interviews are the most common type of interview. In semi-structured interviews, the type of questions is adapted to suit the interviewee's experience and knowledge of a topic, such as TES. How the interview was conducted in its entirety is outlined in Appendix I.

#### *4.1.1.2 Interview Questions*

During the interviews conducted in the thesis research phase, a semi-structured interview consisting of well-chosen and well-phrased questions was applied. The questions were flexible to suit the interviewee in their role or function and the knowledge and experience they have with TES. During the interviews, where possible, additional questions were posed to obtain more information on a certain topic of interest. The big advantage of this type of interviewing is obtaining additional or different information than intended beforehand. DiCicco-Bloom & Crabtree (2006) support this by saying that semi-structured interviews are usually structured around a collection of predetermined open-ended questions, with additional questions arising from the conversation between the interviewer and the interviewee.

The interviews that were conducted were of an individual / small group in-depth origin. This type of interviewing enables the interview to dig deeper into the experience and knowledge of the interviewee. DiCicco-Bloom & Crabtree (2006) state that “The iterative nature of the qualitative research process in which preliminary data analysis coincides with data collection often results in altering questions as the investigators learn more about the subject”. Every interview yielded new data and results, which resulted in slight adjustments for the subsequent interview.

*4.1.1.3 Interviewee Selection*

The interviewees should be reasonably homogeneous and share key similarities with the research query so that answers of all interviews can be compared. Interviewee selection aimed to maximize the depth and richness of data to answer the research questions (DiCicco-Bloom & Crabtree, 2016). Interviewees from multiple different stakeholders were selected to gain a broad overview of the available knowledge in the field of TES, in addition to the information found online. Taking into account the privacy agreements as summarized in Appendix II, the interviewees and the interviewees’ activities related to TES are listed below, in random order:

1. An operator of sustainable, collective, and decentralized installation. A heat, and cold supplier. From development to completion, contracting and exploitation are all part of the process. This operator is technique-independent, which means that the aim is to match the demand with the possibilities for a certain project.
2. Cooperation of companies specialized in energy saving, sustainability, and transition management. Works on projects for governments, businesses, and Small and Medium Enterprises (SMEs). This organization calculates TES potentials, develops business cases, develops system designs, applies for subsidies, and develops initial concepts into feasible business cases.
3. One of the waterboards of the Netherlands. Waterboards regulate water levels, purify waste water, manage dikes, manage nature in and on the water, and control (swimming) water quality. Waterboards make water and the heat stored therein available for initiators in situations where this is plausible.
4. One of the independent institutes for applied research in the fields of water and subsurface. This institute considers TES as one of the sustainable alternatives to natural gas and develops knowledge, techniques, and management measures to make good use of this energy source.
5. One of the water companies of the Netherlands that takes care of the entire water cycle. This water company executes feasibility studies, business case calculations, quick scans and contributes ideas concerning the application of TES.
6. One of the organizations that cooperate closely with the waterboards of the Netherlands. This organization takes care of public affairs, media policy, education, digital media, and visioning

and strategy development. This organization defines TES as a sustainable alternative for natural gas and as a suitable technique to heat and cool the built environment.

### 4.1.2 Literature Study

Interviews were conducted to give a comprehensive answer to the research questions. Interviews are a common qualitative research method. However, a literature study was also applied during this thesis. A literature study is often considered to be ad hoc and to lack thoroughness and rigor (Snyder, 2019). A combination of interviewing and a literature study should take care of this. Furthermore, Snyder (2019) states that “building your research on and relating it to existing knowledge is the building block of all academic research activities, regardless of discipline.” Interviews could lack scientific content, this scientific content is provided by a literature study. During the literature study, reading reports and policy documents were consulted.

## 4.2 Data Analysis

### 4.2.1 Analysis Method

According to Leech & Onwuegbuzie (2007), analysis of data is one of the major steps in the qualitative research process. Verschuren & Doorewaard (2010) add to this that data analysis concerns what should be done next with the material collected as discussed in paragraph 3.3.

More than twenty qualitative data analysis tools exist. One of these tools concerns a constant comparison analysis, which will be applied during this research. In a constant comparison analysis, all data will first be gathered. After doing so, the data will be separated and divided into smaller parts (Leech & Onwuegbuzie, 2007). In the table below a summary of the data and information required to answer the sub-research questions and the method of analysis, either qualitative or quantitative is displayed.

*Table 2: Required Data Information and the analysis method for answering the research questions*

| **Data/information per sub-research question** | **Analysis Method** |
|---|---|
| SRQ1: Thermal Energy from Surface Water | Analyze how thermal energy from surface water works – *a qualitative approach* |
| SRQ2: Maximum potential of TES | Analyze the maximum potential of TES – *a quantitative approach* |
| SRQ3: Technology Readiness Level of TES | Analyze the current technology readiness level of TES – *a qualitative approach* |
| SRQ4: Driving factors of TES implementation | Analyze the factors that drive the implementation of TES – *a qualitative approach* |
| SRQ4: Hindering factors of TES implementation | Analyze the factors that hinder the implementation of TES – *a qualitative approach* |
| SRQ4: Triple bottom Line | Analyze the driving and hindering factors in terms of the triple bottom line – *a qualitative approach* |

As can be concluded from the table displayed above, this research mainly consists of a qualitative approach, except for sub-research question 2 which consists of a quantitative approach. According to Haverland & Yanow (2012) "drawing on a deductive logic of inquiry, theoretical formulations are worked out before the empirical research acts of data collection and analysis". However, during this thesis the opposite – inductive - research path will be taken. The empirical research acts of data collection and analysis will be worked out before the deduction of patterns as theoretical formulations.

## 4.3 Data Validation

The basis for this research was a literature study and interviews. To ensure validation, triangulation is used. Carter et al. (2014) state that triangulation has been viewed as a strategy in qualitative research to test validity. Triangulation concerns the use of different methods or data sources in qualitative research setting to develop an in-depth understanding of techniques such as TES. Four types of triangulation were identified by Denzin (2017) and Patton (1999). Data source triangulation, which involves data collection from multiple individuals and groups (Carter et al., 2014), is applied in this thesis. This will be done to obtain views from multiple perspectives and validation of data.

The validation of the quantitative approach concerning the maximum potential of TES is obtained by collecting quantitative data by a '*within method'* type of methodological triangulation. This type of methodological triangulation uses more than one procedure of data collection (Bekhet & Zausniewski, 2012). In this research, interviews and a literature study are the two procedures that will be followed to obtain validation of quantitative data.

## 4.4 Triple Bottom Line

The Triple Bottom Line (3BL), as introduced in Chapter 2, consists of three dimensions: the environmental, the social, and the economic dimension for sustainable development (Gimenez, Sierra & Rodon, 2012). The dimensions are also called *People, Planet and Profit*. During this thesis, the 3BL framework functioned as a framework within which the sustainability of TES, per dimension, was explained. It is emphasized that sustainability is described as a number of economic activities in proportion to the ecological life support system, as well as a fair distribution of resources among current and future generations (Arslan & Kisacik (2017).

The sustainability per dimension concerning TES was assessed through interviews combined with existing literature. Each of the dimensions was researched separately as well as interconnectedly. After the results, a conclusion follows in which TES is concluded to be either bearable, equitable, viable, or if all three dimensions are gratified: sustainable.

## 4.5 Balanced readiness level approach

It was stated that to grasp technology development and deployment, a multi-dimensional assessment of technology readiness is required (Vik et al., 2021). Questions concerning market readiness, legal considerations, and societal acceptance are questions that were addressed in the balanced readiness approach. The readiness levels were assessed through interviews in combination with existing literature. In figure 7 a pentagon is displayed. This pentagon represents the Balanced Readiness Level Assessment.

From the interviews, policy documents, and reading reports, the readiness levels can be derived. The readiness levels that resulted from data gathering were presented in such a pentagon in the results section. The pentagon provides a clear overview of the scores per readiness level.

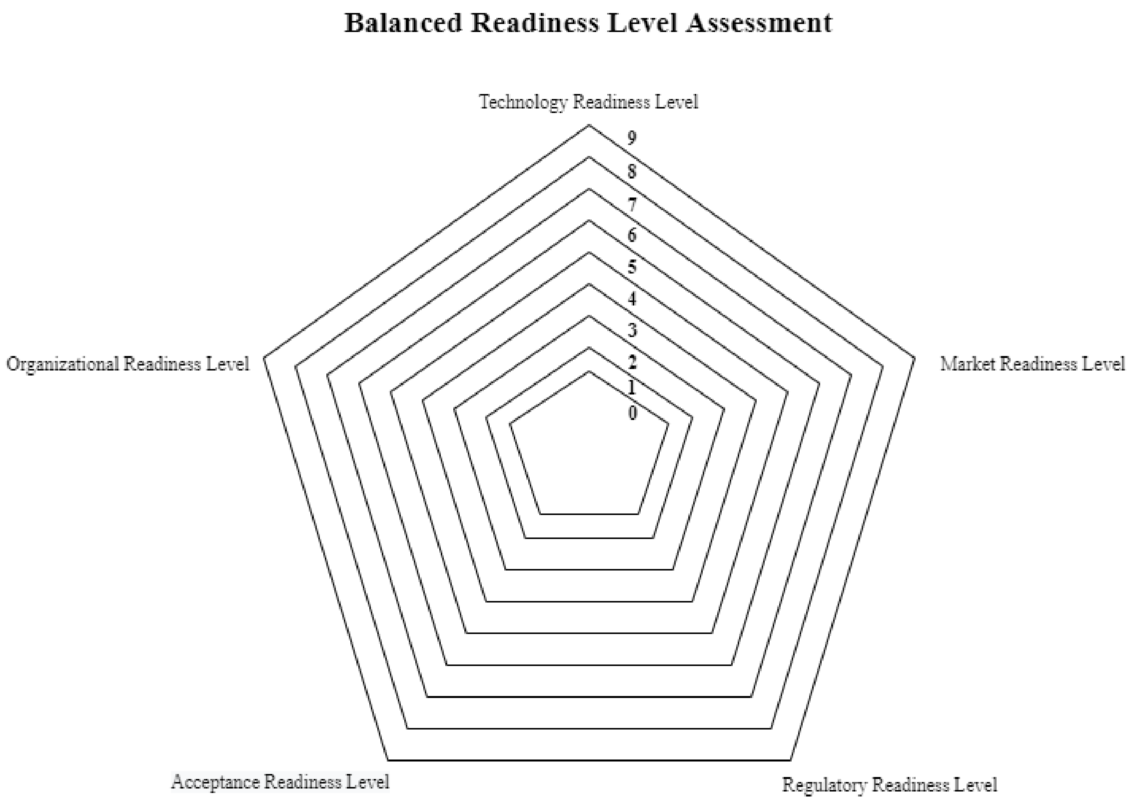


*Figure 7: Balanced readiness level assessment framework illustration cf. Vik et al. (2021)*

However, as discussed before in paragraph 3.1.2, the balanced readiness level assessment of Vik et al. (2021) lacks consideration of ecological readiness. Therefore, a revised framework including the ERL is presented in figure 8.

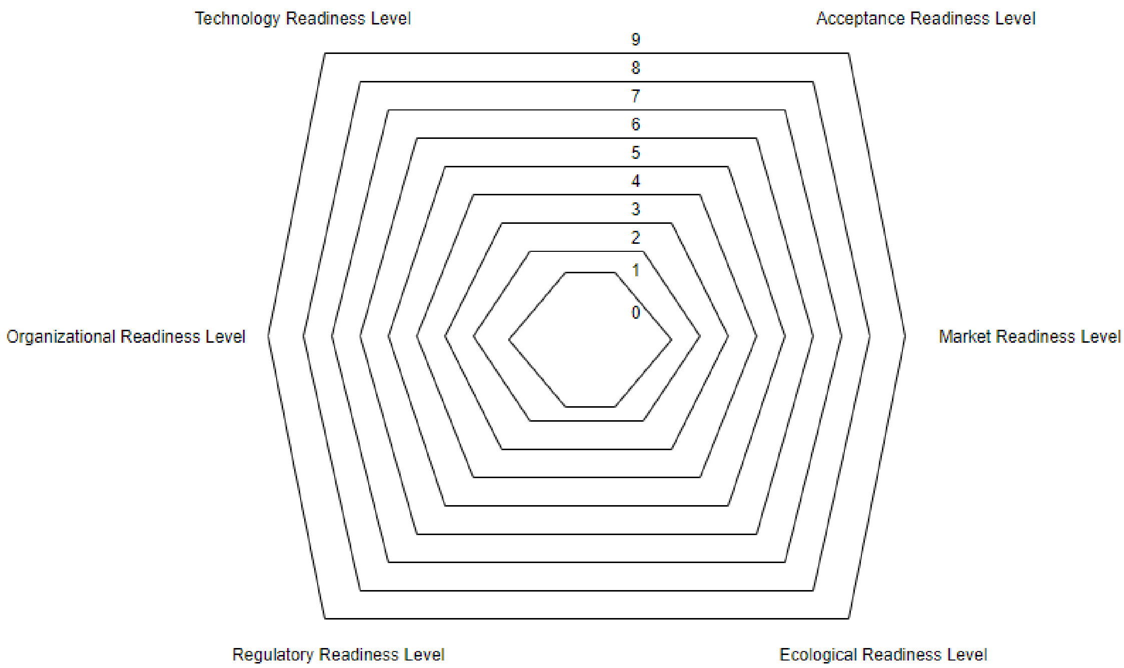


*Figure 8: Revised Balanced Readiness Level Assessment*

As a result, it can be concluded in an instant in what readiness levels the opportunities for further development lie. Per readiness level, questions concerning legal considerations, societal acceptance, technological development, market readiness, ecological readiness, and organizational factors were considered. In such a way, each of the readiness levels was assigned a score.

If, for example, the TRL reaches level 9, this means that the technology is an actual system proven functional in a natural environment. If the product has been tested and validated, and the functionality is being optimized, but it is not actual system proven, then it means that the technology readiness is level 8. But only if the technology has passed level 7. As explained before, the readiness levels are derived from information and data gathered during the interviews and literature study.

# 5. Results

## 5.1 Acceptance Readiness

### 5.1.1 Acceptance Readiness

As stated in chapter 2 ‘literature review’, the amount of scientific material concerning TES is low. Some of the interviewees said that TES is quite unknown in the Netherlands. One of the interviewees brought up the saying *“What we do not know, we fear.”* The transition from gas to electricity is one of the steps that have to be taken in the challenge against the altering climate. The focus in the Netherlands was on wind and solar energy, and district heating was also considered to be fine, there was just little focus on heat. These two transitions, from gas to electricity and from wind, solar, and district heating to heat, are challenges of recent years. People have to get used to new things, also if it is socially difficult.

### 5.1.2 Economic impact

TES is more expensive than natural gas. It is highly likely that if this would have been the other way around, TES would have been implemented earlier, or even in advance of natural gas. The acceptance readiness should be considered from the relation between the valuation of climate adaptation and mitigation, and the willingness to pay. Johnson & Nemet (2010) wrote a review of estimates on the willingness to pay for climate policy, in this review they say: “Among the many difficulties inherent in designing policy to address climate change, the combination of near-term and local costs with longer-term and globally dispersed benefits must rank among the most severe. Unsurprisingly policy discussions have focused on the former. Debates about how, and how much, to address climate change, have almost exclusively focused on minimizing the costs of achieving prescribed emission reduction targets. But the motivation for adopting reductions and bearing some costs must ultimately originate from some conception that there are societal benefits to reducing emissions.”

Hulme (2009) adds to this that climate change has its impacts on sources of human welfare for which there are no markets. Secondly, the slow and long-term character of climate change effects needs appropriate valuation procedures that take into account future beliefs and attitudes (Nemet & Johnson, 2010). Research executed by Graham et al. (2019) shows that, in Great Britain, more than 60 percent of the survey population were willing to pay to prevent future rises in climate-related mortality. The willingness to pay depends on income as well as the perception of potential impacts of climate change (Graham et al., 2019).

### 5.1.3 Social and administrative capacity

According to the interviewed water board, social capacity has to be built for the implementation of TES. The water board added to this that people have to be educated. Over 70 percent of the investment of TES systems concerns the infrastructure. The major investments and infrastructural change have to be brought to light. One example in Amsterdam was cited: “When a low-temperature network has to be constructed in Amsterdam, it would take 20 years if 100 kilometers of a network was to be constructed.” The challenge the Netherlands faces should be clear. If done correctly, social capacity can be built.

TES is a local solution, the generated heat cannot be transported over long distances. This makes local initiatives for sustainability interesting for the implementation of TES. However, as will be explained later, the role of the policy makers and (local) politicians is very big. Administrative capacity is therefore of major importance.

### 5.1.4 TES and ATES

The importance of ATES in the implementation of TES was denoted in paragraph 4.5.4. The potential heat and cold supply from TES is 12% and 50% respectively, in the Netherlands. According to all interviewees, ATES installations are very important. The acceptance Readiness of ATES systems is something that should be taken into account as well. According to the Dutch ECW (ECW, 2020), over 2000 ATES installations have been constructed, whereas the worldwide total of ATES installations is around 2700 (Fleuchaus et al. 2018). It is some kind of an understatement to say that ATES installations are accepted on a broad scale in the Netherlands. TES and ATES installations should be considered on a local scale, because some areas, such as dry parts of the Veluwe, are less suitable for TES and ATES than for example wet parts in the western part of the Netherlands.

### 5.1.5 Acceptance Readiness Level

As far as the interviews and literature have shown, the acceptance readiness level (ARL) is high. Level 8 on the scale of ARL is ‘The technology is seen as controversial among marginal interest groups’. In principle, the technique is not considered controversial. Although the ecological effects still need to be and are being monitored, serious controversy amongst interest groups could not be detected. Therefore, the acceptance readiness level can be classified as 9: ‘The technology is generally accepted/applauded’.

## 5.2 Market Readiness

### 5.2.1 The Market

Three years ago, the potential of TES was assessed by Deltares. Since then, the interest in TES accelerated massively. TES is one of the local sources that could potentially be applied. Next to this, other sources of energy or heat such as solar power, wind power, geothermal energy, ATES, thermal energy from waste water (TEW), and thermal energy from drinking water (TED) could be applied. The climate adaptation and mitigation challenge is clear, and the market needs are explicated.

### 5.2.2 Business Case

As stated before, TES is, like other new technologies, currently more expensive than natural gas. It is highly likely that if this would have been the other way around, TES would have been implemented earlier, or even in advance of natural gas. A couple of TES projects have been finalized and show to be successful. Small projects seem to be mature with a successful business case. However, in contrast to small TES projects, big well-developed projects in the Netherlands are rare. The market readiness also depends on subsidies. According to the conducted interviews, the available subsidies fall short. Some issues that need to be overcome to have a successful business case are the subsidies, infrastructural changes, and scale size. The business case should be made conclusive, and for this to happen, customers need to be acquired.

### 5.2.3 Market Readiness Level

The Market Readiness Level (MRL) concerns commodification. The interviews and literature review have shown that small pilots and a few projects have been realized, as described in MRL 6. MRL 5 reads 'Business model described'. A business model for TES has not yet been described in its entirety, this is necessary because a project needs to be profitable for a successful implementation. However, the technology is being launched in limited scope. The technique is straightforward and it was just mentioned that some projects have already been realized successfully.

Market validation, as described in MRL 4, concerns a method for ensuring that a product or technique complies with its standards and fulfils its intended function. It can be based on the outcome of the interviews that the market of TES was validated. Therefore, the MRL can be classified as level 6: 'Products are being launched in limited scope'. Customers indeed confirm progress/improvement as described in MRL 7, but there are currently too many complications when implementing TES on a large scale. Those complications concern ecological monitoring, regulatory readiness, and organizational readiness.

## 5.3 Technology Readiness

### 5.3.1 TES

TES is a technique that is very situation-dependent. The surface of water bodies, the water temperature, policy, ecology, type of built environment, whether or not to install an ATES, a source net, and many more factors determine the implementation of TES. The TRL of TES can be derived from the practical experiences and information gathered from interviews.

### 5.3.2 Maximum Potential

Three years ago the 40% potential of cooling and heating by TES was assessed by Deltares. Since then, the attention for TES accelerated. According to the interviews the potential of TES is estimated correctly. As explained before, it was said that the maximum potential could even be enlarged by creating new water sources. In principle, no resource should be lost, especially if the potential is so great.

### 5.3.3 System Design

One of the important steps that have to be walked through is the system design of TES. In the system design, certain factors have to be taken into account. First of all, the local factors have to be considered. Local factors concern the built environment and isolation, demand and supply, policies and ecology, and the availability of water surface. The water surface is the decisive factor in the potential heat supply, rather than the water depth.

Next, the question is whether the design should be based on peak load or base load. The peak load is the heat demand on the coldest winter days of the year. Both were suggested during interviews. Design on peak load would mean that no backup is needed. However, for a long time during the year, little is done with the peak power. A design on base load would mean that in most cases the design matches the base load. However, in such a case a backup installation is needed. In some current cases, these backup installations are not sustainable. The design on either peak or base load depends on the maximum costs for a project, whether it has to be 100 percent sustainable or whether the 100 percent sustainability can be achieved in the long run. A solution for the peak and base load problem can be found in ATES systems as a backup installation.

The next question is how much water a net can transport, and whether or not the network can handle the peak. Subsequently, a choice between two networks has to be made: 50 degrees Celsius HT-nets (with a collective heat pump) or 15 degrees Celsius LT-nets (with individual heat pumps). As stated before, cooperating with drinking water companies could facilitate the construction of these so-called nets. Drinkwater nets have the same specifications as heat nets, the only difference is that heat nets are a double version: in and out.  Next to this, it should also be noted that one of the interviewees proposed a prohibition on HT-nets in newly built neighbourhoods.

### 5.3.4 Built environment

There also is a difference in terms of design between existing neighbourhoods and newly built neighbourhoods. Newly built neighbourhoods are well isolated and built for sustainable alternatives next to gas. It costs more to make old neighbourhoods more sustainable, but it is not inconceivable. These neighbourhoods need good isolation and a new source net. One of the sustainable alternatives for TES as proposed during the interviews concerns bio gas. The opportunities here lie in urban design. When designing new districts, a heat network, as well as the construction of new water sources, should be taken into account. This allows thinking about a sustainable neighbourhood in the initial phase of the building process. What should not be forgotten, according to one of the interviewees, is that the power grid is saturated. The grid cannot handle the current and growing electricity load. Energy hubs, local storage of energy, are proposed solutions for this problem. However, the energy demand for heat is 70% of the total demand. The application of ATES and TES could cause a decrease in electrical infrastructure load while the heat demand remains the same.

### 5.3.5 Collective systems

It has become evident from the interviews that collective systems are the key to success for TES. Concerning the business case, collective systems will most likely be cheaper than multiple individual systems. It has been explained before that individual systems seem to be well developed, but in terms of costs, collective systems should be preferred, Also, the challenge of upscaling can be facilitated by large collective systems. According to one of the interviewees, TES is used as an adjustment of the imbalance of ATES systems.

### 5.3.6 The role of ATES systems

ATES systems are a major factor in the success of TES. TES is a regeneration measure and is being used to imbalance ATES systems. Cold demand from TES in the Netherlands is seen as a 'utility' according to one of the interviewees, but this can be solved with ATES systems. The benefit of a combination of TES and ATES systems is that they are easily connected to cold and heat demand. This is very interesting for the Netherlands since summers can be very warm and winters can be very cold too.

Also, ATES installations prevent freezing problems. If TES is being applied during winter to supply heat, the water temperature decreases. This could lead to freezing of the pipework and installation. Storage of heat generated by a TES installation during warmer months can be stored in the ATES, and the cold demand can be met by cold generation from deep groundwater layers.

TES could also do without an ATES installation on some occasions. Big rivers can be used to generate heat without freezing. Working without an ATES could in such situations cause problems for the cold demand during summer. However, heat generation from rivers is only a local solution since, as stated before, the infrastructure is the largest cost of the system. Small projects could also do without an ATES installation, but this also depends on the local features and the water source.

### 5.3.7 Case studies

The project Huis aan de Tsjonger (House by the Tsjonger river), has been operative since 2018, and at least until 2020, no problems have occurred (Stowa, 2020a). This would place the TES technology readiness level at 9 since the operations are proven and the system functions even without an ATES installation. However, the report shows that the Tsjonger only provides the house of heat, because a cold extraction prohibition in the Tsjonger river is in effect. Next to this, freezing of water could lead to technical issues. In these situations, the system is proven operation. However, not every single building is located next to a river or canal such as the Tsjonger, and not all conditions can be identical to this example.

Another example is the horticulture company Knoppert, located in Naaldwijk, 's-Gravenzande and Monster. Knoppert installed an ATES installation in 2012, and they also added a TES installation to balance the ATES installation. Since 2016, the ATES installation has not been used anymore, due to changed regulations. Since then, TES is being used for heating with co-firing(gas) during winters. Although Knopperts system is operational, it cannot be stated that the TRL level in this situation is level 9: proven operations. The TES system in this case study falls short in heat supply, and next to this other technical issues also occurred.

A third and last example, that of a collective TES installation, was found in the TES project Blaricummermeent, located in Blaricum. 830 houses were meant to be provided with a sustainable energy system. The TES system is being used as a regeneration measure for an ATES system. Because of upscaling, the maximum regeneration has been reached. In this situation, the TES system is considered to be reliable and works somewhat similar to a gas network. Limitations are found in communication with residents, intensive maintenance, leakages, and during winters the water temperature is often too low to extract heat. Although similar to the previously discussed system, this system is operational, it cannot be stated that the TRL level in this situation is level 9: proven operations. The TES system in this case study falls short in heat supply, and next to this other technical issues also occurred.

### 5.3.8 Technology Readiness Level

All interviewees consider the technique as functional, and this is confirmed by the case studies discussed during this thesis. The technology can operate successfully if the situation allows it. The TRL is level 9: 'Actual system proven functional in a natural environment'. However, a side note has to be made. The functionality of TES has to be optimized over and over again because the technology keeps developing. It was suggested in one of the interviews to keep inventing and implementing new prototypes.

## 5.4 Organizational Readiness

### 5.4.1 Organizational Readiness

According to Vik et al. (2021), the organizational readiness level (ORL) "is mainly about the *domestication* of technology, and the degree of how compatible the new technology is to existing technologies". For the ORL to be at its highest, the technology needs to work seamlessly with existing technologies.

### 5.4.2 Organizational change

To implement TES, organizational change is needed. The transition from gas to electric and the reduction of greenhouse gas emissions is described as one big puzzle by one of the interviewees. TES is one of the puzzle pieces, accordingly a big one. It has to be made clear how the technology could be adapted to the current organization and it needs a concrete plan for integration to be formulated. The Regional Energy Strategy (RES) is one of the first steps that was taken to initiate this organizational change. However, it was discussed many times during the interviews that TES is just a local solution. On a national scale, it has great potential, but the possibilities for implementation depend on a lot of local factors. Therefore, an energy approach per neighbourhood has been suggested by one of the interviewees.

### 5.4.3 Water management

The role of regional water authorities is considerable. Regional water authorities have a stimulating role and a permit granting role. This role is equivalent to the beginning phase, the stimulator, and part of the end phase, the permit granter. According to the interview with one of the Dutch regional water authorities, water authorities provide information on, for example, water flow, water quality, and water temperature, facilitate and stimulate by providing a potential map and as mentioned before, grant permits. The main attribute of the regional water authorities is that they are of public interest as a governmental organization.

However, the water authorities are not the initiator of TES projects. They are part of the chain of TES development and implementation, but the responsibility of initiating a project lies outside the scope of the water authorities. During one of the interviews, it was stated that water managers hold back due to a lack of knowledge. However, the potential benefits for water managers should be seriously considered. Potential benefits are a reduction in $CO_2$ emission, a reduction of heat stress, and improved water quality. The role of Regional water authorities is very important, and those institutions need to participate in the process of knowledge sharing and acquisition to fulfill this role.

### 5.4.4 Governance

The government has multiple roles in the implementation and development of TES. TES depends on a variety of stakeholders and factors. An integral, holistic approach is thus needed for governance to be successful. According to most of the interviewees, fragmentation among companies is one of the problems concerning the implementation of TES. From here on, the government comes into play. The government should step up to bring knowledge together and organize to cooperate, invest, learn, and trust with companies of interest. However, during the interviews, it became clear that nobody wants to 'pick up the gauntlet'. A lack of governance due to a shortage of knowledge on the subject of TES was identified by a large share of the interviewees.

Extra governance is needed for TES to be implemented and developed successfully. Knowledge should be enhanced and gathered. One of the interviewees used drinking water companies as an example. During that interview, the potential role of drinking water companies in the rolling out of a low temperature(LT) water net should not be underestimated. These kinds of companies have a broad knowledge of water nets, and the infrastructure of an LT network is very similar to a drinking water network. Other interviewees identified energy companies and heat companies as potential load-bearing forces for TES projects.

One of the pillars of administrative success is social capacity and building this is vital. However, before starting the build of social capacity, administrative capacity must be built first. During the interviews, it was stated that nor social capacity nor administrative capacity are considered to be accomplished. If there is no support for the implementation and development of TES at the administrative level, support at the societal level is unlikely, to say the least.

However, according to the interviews, the Dutch government is risk-averse. The biggest challenge in governance is to translate administrative ambition into the physical implementation of this ambition. To do so, according to some of the interviewees, the current system's thinking has to be released. As described before, a holistic view is necessary to overcome being slowed down by the current system's thinking. It is suggested that normal processes, the processes that 'we' are used to, need to be thrown overboard. Even the covid crisis of 2020 and 2021 passed by in a couple of interviews for a couple of reasons. The covid crisis showed that the Dutch government understands what it takes to battle a crisis, and it also turned out that, if there is urgency involved, there is a lot of room in financial terms. Necessity and feasibility are the most important factors that should be addressed in the challenge of adaptation and mitigation to climate change.

One of the interviewees also considers the importance of re-election for politicians to hinder the release of normal processes. Another adds to this that the plan for TES implementation as part of climate adaptation and mitigation measures should be spread out over several parliamentary four-year terms, just like the Delta Program. The Delta Program is a course for the future and it concerns annual proposals in the field of flood risk management, extreme weather events, and freshwater supply (Dutch National Government, 2021).

### 5.4.5 Energy inequality

The focus on water as a potential energy/heat source is a conscious choice. The choice of energy depends, among other things, on scarcity and abundance. At least eleven percent of the Dutch surface consists of water. There is a lot of water and the additional advantage is a large energy potential. The energy challenge of the 21st century was defined by one of the interviewees as a big puzzle of which TES is a major puzzle piece. Opting for sustainability has been a luxury up to now, but it should become a necessity. An energy approach per neighbourhood on top of the Regional Energy Strategies (RES) should contribute to an acceleration of change. Thereby, pilots in existing (old) built environments have to be embraced.

The Dutch population can be divided into three groups based on housing: owner-occupied properties, social rental housing, and private rental housing. According to the interviewees, owner-occupied property holders are considered to be the richest group, followed by private rental housing and social rental housing respectively. Implementation of sustainable measures, such as TES, comes with different incentives for each of the groups. The social rental housing group depends solely on the housing association for incorporating sustainable alternatives, whereas the two other groups can decide for themselves whether or not to incorporate sustainable alternatives.

In mixed neighbourhoods, with at least two of the three groups represented, energy inequality could occur. During the interviews, it is generally assumed that collective systems are financially more attractive than individual systems. There is a probable situation where one of the wealthier groups is more advanced in the field of sustainability, giving them a head start in development. As a result, the implementation of later projects for the other groups could be costlier, leading to energy inequality.

### 5.4.6 Public company on municipal level

During one of the interviews, a solution for energy inequality was suggested. To do so, heat should be considered a utility, being owned by the Dutch government. Until 1995, housing corporations were often municipal housing companies. Starting from 1992, the housing sector became privatized. Since the privatization, hardly any money goes the way of corporations from the government (De Corporatie Strateeg, 2018). Next to this, in 2001 a start was made on liberalizing the energy market (deenergiegids.nl, 2021).

One of the interviewees stated that returning to a system with public housing and energy corporations could be very effective in making the Netherlands more sustainable. It is believed that the focus of housing and energy corporations is on making money and other less prominent matters rather than sustainability. The nationalization of housing and energy corporations could be one of the solutions for the implementation of TES. The nationalization could lead to a controlled and equal energy supply in social neighbourhoods where current housing and energy corporations fail to do so. So, there are opportunities here that can bring about change on a large scale because housing corporations owned at least 29 percent of all houses in the Netherlands in 2020 (CBS, 2020).

### 5.4.7 Educate and inform

People have a great understanding of drastic change when it comes to finances. However, organizational change cannot be initiated if people do not understand the concept of change. One must have some idea of what is needed to participate in the process of change. Information on what has to be done is important, but it is also good to inform people about the possibilities. Opting for sustainability has yet been a luxury, but it should be a necessity from now on.

### 5.4.8 Fragmentation

One of the problems that occur in the field of TES is *fragmentation* into a collection of companies or interest groups. The implementation of TES depends on many stakeholders each with their vision and methods. The upscaling of TES concerns a lot of people, but one logical group of companies or organizations to cooperate cannot be defined. Cooperating, investing, learning, trusting, and organizing are steps that have to be taken for TES to be implemented successfully. The NetwerkAquathermie (NAT) contributes to this but needs to be further developed. As discussed before, it was stated during one of the interviews that there is not one organization that wants 'to pick up the gauntlet' and be responsible for the development of TES.

### 5.4.9 Organizational Readiness Level

The organizational Readiness Level (ORL) concerns the domestication of a technique such as TES. The highest level of ORL reads 'the technology works seamlessly with existing technology'. Based on the gathered data, this cannot be concluded. What can be concluded is that the current state of organizational readiness is represented in level 6 of the ORL ladder. 'Large/fundamental organizational changes are needed to use the technology'. Fundamental organizational changes on a national scale are needed to develop TES successfully.

## 5.5 Regulatory Readiness

### 5.5.1 Regulatory Readiness

The regulatory readiness is described by Vik et al. (2021) as the "legalization of a product". For the regulatory readiness to reach the highest level, use and production are regulatory unproblematic. The lowest level of regulatory readiness is "the legal and/or regulatory aspects of the technology is unpredictable or unknown" (Vik et al., 2021).

### 5.5.2 Existing policies

Aquathermal energy generation, including TES, is not a direct part of existing policies. The sustainability policies do focus on natural gas-free facilities, but aquathermal energy is not prescribed as a recognized technique within natural-gas free facilities. This is partly due to the relatively long payback period of approximately 15 years for this type of project, as a result of which, for example, the Multi-Year-Agreements (MTA) do not contain any obligations to apply aquathermal energy (Noij & Bos, 2020).

As explained in the introduction, a 'Green Deal Aquathermal Energy' – Green Deal C-229, was ratified in 2019. In the Green Deal, participating parties join forces and are linked in a chain of the utilization of aquathermal energy. The intended result is that aquathermal energy is being usefully applied as an alternative heating system for the built environment. The parties collaborate to accelerate the heat transition. The focus is on six components:

1. Forming a network with all stakeholders to join forces.
2. Joint fact-finding with all stakeholders.
3. Sharing lessons learned from practical projects to enable upscaling.
4. Remove barriers and increase opportunities for the application of aquathermal energy through knowledge and to put innovation questions on the agenda and strive to answer them.
5. Identify and further develop best practices for governance, organization, and financing of aquathermal energy projects.
6. Actively link to the bodies where knowledge and information are needed concerning aquathermal energy and where knowledge and information are collected, such as the Regional Energy Strategy (RES), the regional heat structure, the Heat Expertise Centre, and the Natural Gas-Free Knowledge and Learning Program Neighbourhoods (KLP) (Government of the Netherlands, 2019). In 2020, 20 of the 30 Energy Regions had published their Regional Energy Strategy. In all of them Aquathermal energy, TES in particular, was considered to be a potential heat source (Netwerk Aquathermie, 2020).

### 5.5.3 Government

During the interviews, it became very clear that the regulatory readiness is considered to be 'close to zero'. It was said that the government needs to set boundaries and frameworks that indicate the possibilities but most importantly the impossibilities. It was also said during one of the interviews that governance is lacking due to the idea that governments are considered risk-averse.

### 5.5.4 Financial

#### 5.5.4.1 Subsidies

New techniques, such as TES, qualify for the SDE++ subsidy (*Subsidy Stimulation of Sustainable Energy Production*) since 2020. In a letter written by the minister of Economic Affairs and Climate, Van 't Wout (2021), it is announced that the SDE++ opens up for categories such as TES in 2021. In 't Groen et al. (2020) advise the Ministry of Economic Affairs and Climate on the extent of the subsidies for TES. In table 2, the amount of potential subsidy for TES in SDE++ 2021 compared to 2020, is displayed.

*Table 3: potential SDE++ subsidy for TES projects, 2020 and 2021 ( In 't Groen et al., 2020)*

| Parameter | Unit | Final Advice SDE++ 2020 | Final Advice SDE++ 2021 |
|---|---|---|---|
| Basic amount | [€/kWh] | 0,115 | 0,117 |
| Duration of subsidy | [year] | 15 | 15 |

The financial aspect is one of the biggest challenges in the transition from natural gas to sustainable energy that The Netherlands is facing. For TES to be successful, subsidies will be needed. The costs cannot be borne by society alone. However, as stated by many interviewees, the subsidy SDE++ is not properly set up. The subsidy is aimed at preventing overstimulation, and the focus in the Netherlands was mainly on wind and solar energy, and little focus was on heat. The subsidy gives priority to the cheapest $CO_2$ reduction measures. TES is more expensive than wind and solar energy on most occasions. However, TES produces energy when there is no wind or sun, like in winter. Therefore, subsidies should vary over time instead of amounts on an annual basis.

It was also stated that heat pumps need to be stimulated more. According to one of the interviewees, the subsidy assumes that "cooling is only applied if the system is profitable" and "cold supply concludes the business case". From the interviews, it became very clear that the SDE++ subsidy needs to be reconsidered significantly, to support the development of TES. Society must be financially relieved, and the role of the government in this is undeniable.

#### 5.5.4.2 Financial challenges

The financial challenges are making the business case conclusive and upscaling, according to the interviews. TES is all about scale size: enough volume of heat is needed, and one is dependent on the consumers. It was said during one of the interviews that small projects seem to be relatively well developed. One of the interviewees indicated that the assumption 'cold supply completes the business case' is incorrect. Even if a TES system supplies cold energy, it could still be loss-making. It was also stated that the possibility that TES is not a stand-alone business case must be taken into account, and it should be kept in mind that more than 70 percent of the investment consists of the infrastructure. However, the positive sides of TES should also be highlighted. According to one of the interviewees, the low fixed costs in the long term and the comfort of TES are positive sides. Subsequently, another big challenge is to get through the 'bath tub' phase, as explained in the next paragraph. Lastly, one of the interviewees stated that all potential sources should be considered seriously, even though the business case could be a stumbling block.

#### 5.5.4.3 'Bathtub phase'

One of the interviewees described the finances of TES projects as being a bathtub. The project needs big investments in advance to get off the ground. In the figure below a bathtub model, as described during an interview, is displayed. Before a project becomes profitable, a 'debt phase' has to be worked through. For this, risk-bearing pre-investments have to be made. As stated during some of the interviews, these investments cannot be borne by society, so governments, municipalities, for example, should bridge this period. Firstly, the bathtub fills up with investment money. From a certain tipping point, the bathtub drains slowly, which means that the invested money is earned back. The deeper the bathtub, which represents bigger pre-investments, the longer the payback period is, in principle.

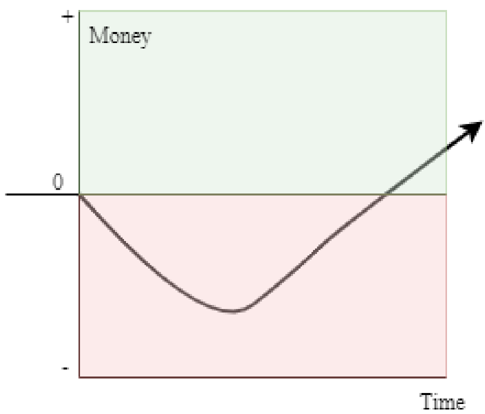


*Figure 9: Visualization of the bath tub phase as discussed in the interviews (Author's own illustration, cf. interviews)*

However, the covid crisis showed that the Dutch government understands what it takes to battle a crisis. It also turned out that, if there is urgency involved, there is a lot of room in financial terms. To get through the bathtub phase, it may be possible to apply these financial resources that seem to be destined for times of crisis.

### 5.5.5 Regulatory Readiness Level

The Regulatory Readiness Level (RRL) concerns the legalization of a technique such as TES. As explained before, for the regulatory readiness to reach the highest level, use and production are regulatory unproblematic. The lowest level of regulatory readiness is "the legal and/or regulatory aspects of the technology is unpredictable or unknown". As was indicated by all interviewees, the regulatory framework has to change. Based on the interviews it can be concluded that the RRL of TES is 3: 'Use and/or production will require change or reinterpretations of regulatory framework'.

## 5.6 Ecological Readiness

### 5.6.1 Ecological Impacts

As explained in paragraph 4.1.1, the ecological impact of TES is being monitored. The ecological impact of TES was repeatedly discussed during all of the interviews, but an estimation of the impact could not yet be made. The ecological factor is considered a barrier, since upscaling of TES is unlikely without knowing its impact. The ecological impacts of TES concern potentially positive and negative impacts. TES could cause the water temperature to decrease, during heat extraction, or increase, during cold extraction. Cooling and heating should be carefully considered on a seasonal basis according to the interviews, and continuous research has to be executed.

During Ramaker's (2020) master thesis research, it was concluded that TES can potentially affect the ecology of a water system positively and negatively. To prevent negative effects of TES on the ecology due to cold discharges, TES should not be applied in (late) winter and (early) spring. However, further research can be done. This is also supported by Primack et al. (2009) who say that long-term and spatially broad studies will be required to gain a thorough understanding of species responses to warming of the water. A new monitoring plan was set up by Deltares in 2020 to monitor the effects of cold water discharges properly and keep track of the ecological functioning of a water system. Previous measurements of the effects of TES are only designed and implemented for a limited number of projects. Monitoring increases insight into the effects of TES on water systems. This insight is required to avoid uncertainties regarding TES impacts becoming a 'showstopper' for TES application in making the energy supply more sustainable. The monitoring plan of Deltares exists of 3 types of monitoring, summarized in the figure below (Deltares, 2020).

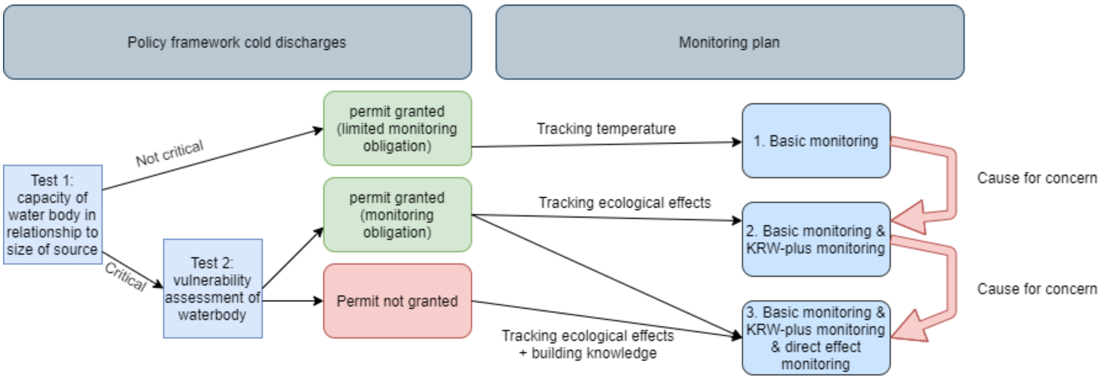


*Figure 10: Schematic overview of the three types of monitoring in relation to the policy framework of TES (translated from Deltares, 2020)*

The left half of the figure shows the policy framework of cold water discharges, connected to the right half of the figure, the monitoring plan. The policy framework show 2 ‘tests’. From this, a permit may be granted with (limited) monitoring obligation, or it may not be granted. This depends on the vulnerability of a waterbody. From this point, the type of monitoring comes into play. For a permit with limited monitoring obligation, only basic monitoring is obliged and the temperature should be watched. If total monitoring is obliged, effects on the ecology should be watched and knowledge has to be built and gathered. The monitoring plan was designed to detect a negative impact. However, during some of the interviews, it became clear that interviewees believe and expect that the implementation of a TES system could have a positive impact on the water environment. In such a case, it would be even more valuable to investigate the potential benefits of a TES system on a broader scale.

### 5.6.2 Opportunities in water management

During the interviews, opportunities in water management were suggested. A large part, if not all, of the Dutch waters are managed. This means that the amount of water that is let in can be adjusted. Other drainage patterns can help prevent drought, but next to this these changing patterns could potentially provide more energy for TES systems. So there is an opportunity to relieve the climate on several fronts.

Another suggestion, that insisted on ‘creating’ TES sources, could potentially contribute to the climate adaptation and mitigation challenges as well. The flooding of polders is one of the options for creating sources. The flooding of polders is not a new idea, this has been done for different reasons such as tactical flooding in the second World War (De Kraker, 2015). However, the more surface of water there is, the more potential energy could be extracted with TES. Also here, an opportunity to relieve the climate on several fronts occurs.

### 5.6.3 Ecological Readiness Level

The ERL of TES can be determined based on the results as discussed in chapter 5. The monitoring of ecology has started and draft versions of (parts of) a regulatory framework exist. The ERL does not reach level 7 because the ecological monitoring and regulatory framework have not yet reached the reviewing phase. From this, a revised version of the balanced readiness approach of Vik et al. (2021) can be made, displayed in the figure below.

## 5.7 Balanced Readiness Level Assessment

All the results from the readiness level approach have been summarized in the figure below. This figure, the balanced readiness level assessment, gives a clear overview of the readiness levels in contrast to the other levels. The TRL and ARL are defined as level 9. The MRL and ORL are level 6, and the RRL is level 3. Last but not least, the ERL is level 6. This indicates that in Regulatory Readiness, the most can be achieved. On top of this, the MRL, ERL, and ORL can also be developed further for the Balanced Readiness Level Assessment to reach the highest level of readiness.

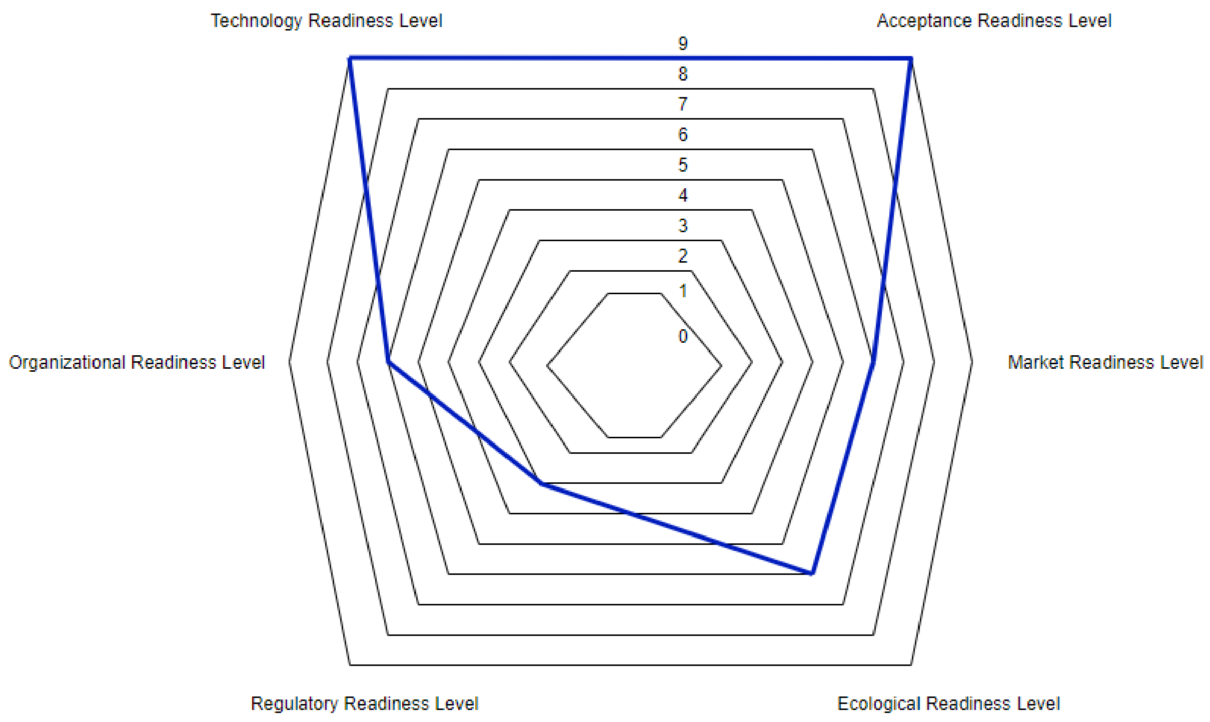


*Figure 11: Revised Balanced Readiness Approach, based on Vik et al. (2021)*

# 6. Discussion

Some things can be stated and discussed based on the most important findings of this study. As was previously expected, the technology of TES does not pose a barrier to the implementation. On top of this, it was substantiated that the estimations of the maximum potential are accurate. The maximum potential can function as a basis for policymakers. However, other important findings imply that there is still work to be done in developing and implementing. ATES and TES systems should for example be taken into consideration in the revised regional energy strategies. So, the next step in the implementation phase of TES has not yet been taken.

Some barriers were identified that pose problems for the implementation in light of the three dimensions, people, planet, and profit, of the triple bottom line (3BL) of sustainability. Initially, a lack of governance due to a shortage of knowledge on the subject of TES was identified by a large share of the interviewees. It also became clear that nobody wants to 'pick up the gauntlet'. This responsibility-taking problem also stems from a shortage of knowledge. This problem can be solved if TES will be considered a feasible alternative in the new regional energy strategies. Following this, consultants can execute feasibility studies that should be subsidized by the government. Then governments and market parties can determine whether a business case and financing will be set up or not. Another major barrier is thus the financial aspect. The existing subsidy, the SDE++, focuses on preventing overstimulation rather than stimulating development.

The major investments that have to be done in advance, defined as 'the bathtub phase', to get TES off the ground, are complicated partially due to the shortcomings of the Dutch subsidy system. As has been experienced during the covid crisis, discussed by some of the interviewees, there is a lot of room in financial terms. These financial resources can potentially be applied to get through the bathtub phase. The 'caused impacts' of TES as discussed by Sajan & Gautam (2020) in terms of the triple bottom line, thus concern environmental, economic, and social impacts.

It also became clear that TES projects need to be approached collectively, and the major importance of ATES systems should also not be underestimated. Individual TES systems do not require an ATES system, but ATES systems are necessary for big projects. The importance of social capacity should also be considered. People need to get some kind of experience with TES systems. TES is not just negative and costly, it provides comfort and low fixed costs in the long run. The implementation of TES is considered quite radical but necessary. However, it was stated during the interviews that people also have to get used to new things too.

The balanced readiness level assessment, depicted in figure 10, shows opportunities for the development of TES. Social acceptance and technology are considered to be 'ready'. However, changes in regulations, the market, and organizations will be needed to get the balanced readiness level assessment at the highest readiness level, level 9. In summary of the interviews and literature, the balanced readiness level assessment taught us a few things. First of all, the use and/or production of TES will require change or reinterpretations of the regulatory framework. Next to this, fundamental organizational changes on a national scale are required to further develop TES. It can be recommended that standard realization and design conditions could be drawn up at a national level that can be applied by municipalities. Guidelines such as BRL that are already being used in other sectors, such as the ATES sector, could be useful for designing parties, consultancies, and contractors.

As was already explained in paragraph 5.7, the Balanced Readiness Approach of Vik et al. (2021) comes short when considering the ecological readiness of technology such as TES. In figure 11, the ecological readiness level is included. This hexagon-shaped figure gives a clear overview of the levels of readiness of all of the dimensions of TES, and it shows the opportunities in the development of TES. As explained in the previous paragraph, changes in regulations, the market, and organizations will be needed to get the balanced readiness level assessment at the highest readiness level, level 9. However, the ecological readiness level is currently level 6, because of ecological monitoring and uncertainty of the ecological impact of TES. After monitoring the ecological impacts, these impacts should be translated

The comparison between natural gas and TES has been made several times during the interviews. The costs are compared most of the time, but the $CO_2$ savings should be used as a benchmark instead. Here, niche and regime management come about. Sengers, Wieczorek & Raven (2019) define regimes as the heart of the socio-economic system, which creates stability and continuity while also posing obstacles to structural changes that lead to sustainability. On the other hand, niches are defined places where the co-evolution of technology, user behavior, and regulatory institutions can be nurtured and experimented with. Market niches can emerge from technological niches. In the Netherlands, the natural gas energy supply is the regime, whereas TES is a niche.

The process by which niche experiments can alter regimes is called 'upscaling' (Jolly, Raven & Romijn, 2012). This is in line with what has been stated in the interviews: upscaling is one of the challenges of TES implementation. Sustainable innovations face a structural disadvantage since they are too demanding in terms of their socio-technical implications for the regime (Smith & Raven, 2012). Some of the socio-technical implications of TES concern an infrastructural problem, adaptations in the built environment, and social capacity.

One of the major barriers that have to be encountered in the Netherlands is bringing about changes in the niche-regime pattern. Ratinen & Lund (2016) consider two dimensions for evaluating socio-technical changes: a combination of technical advances, such as the deployment of renewable energy technologies, and legislative changes that will improve democracy and citizen participation. To bring about these kinds of changes, new forms of policies such as assessment guidelines are required.

Agenda-setting and social capacity building are steps to be taken to bring about these kinds of changes. Van Merkerk & Robinson (2006) stated that as agendas become operationalized in the field's ongoing actions, actors connect in various sorts of networks. “These networks are composed of mutual dependencies that can be based on shared rules and routines, on the exchange of intermediaries and their translation, or on the exchange of resources, etc.” (Van Merkerk & Robinson, 2006). Practice shows that in the field of TES, actors do connect in various sorts of networks such as the ‘NetwerkAquathermie’. Van Merkerk & Robinson (2006) added to this that “Expectations guide the activities of the actors within a technological field, while, in turn, expectations will be shaped and reshaped by research results, findings in other technical fields, successful commercialization, and external trends and forces. Over time, choices are made and priorities are set, which results in shared agendas. For new and emerging science and technology, these processes result in an enlargement of the attention in related journals, conferences on the subject are organized, start-ups are founded and companies start collaborations”. The interviews reveal many similarities between the current ongoing processes in the practice of TES, and the literature written by Merkerk & Robinson (2006).

“Capacity building is increasingly mentioned as a viable strategy towards an envisioned future of less vulnerable societies” (Bisschops & Munaretto, 2019). Capacity building can contribute to policymaking. Matsuoka et al. (2004) add to this that the development of social capacity is the most significant task in implementing environmental policy and environmental cooperation efficiently and effectively. However, the gap between agenda-setting and social capacity building has to be bridged by politicians. From the process of agenda-setting, coalitions with political parties that support niche technologies have to be built. If done successfully, these political parties can bridge the gap between agenda-setting to social capacity building in collaboration with interest groups.

In this research, the three dimensions of the 3BL were useful in terms of dividing the results. However, sometimes a result could not be placed between one of the borders of the three dimensions. For interdisciplinary results, the 3BL is a little too abstract. For this, a framework consisting of multiple pillars would work. A framework consisting of dimensions such as ‘socio-economic’ and ‘ecological economics’ would be very accommodating in this case.

Further research should focus on the breakdown of multi-level governance, including national, provincial, municipal levels. Due to time constraints, this could not be accomplished. This has no negative consequences for the outcome of this study since the results do show actual barriers and drivers. This forms a basis for further research. On top of this, there has to be talked with the government concerning the outcome of this dissertation. How will the results of this research be handled and what does it imply for future governance and the regulatory framework?

Other follow-up research, concerning the monitoring of impacts of TES on the ecology of water bodies, is currently underway. This monitoring study will have to be completed as soon as possible so that the ecological barrier may be overcome if the results are promising. Other very interesting outcomes that are well worth investigating further are creating additional potential and possibilities in water management. A large part, if not all, of the Dutch waters are managed. This means that changes in water management could contribute to the optimization of TES development. The other suggestion, creating additional potential by developing new surface water bodies, could also contribute to the climate adaptation and mitigation challenges as well as creating the additional potential for TES development.

This research shows how big of a challenge it is for a niche to compete with existing regimes. It shows that structural, fundamental socio-technical changes are required for a technology such as TES to be implemented successfully. A good technology on its own is not sufficient for its implementation to be successful. On the occasion of TES, more complications pose barriers to the implementation. The results of this dissertation also contribute to opportunities that can be applied for climate mitigation and adaptation measures.

The biggest challenge here is translating administrative ambition into physical implementation, taken into account the barriers and drivers that are presented in this research. In light of what was already known and has been published about TES, these findings imply a new dimension of the complications that currently hinder the development of TES and contribute to explicating the opportunities of TES.

# 7. Conclusion

Climate adaptation and mitigation measures are well needed to constrain the impacts of climate change. This thesis aims to examine the factors that drive and hinder the implementation of Thermal Energy From Surface Water (TES) to its maximum potential. To assess these factors in terms of sustainability, a Triple Bottom Line framework was applied. Next to this, a Balanced Readiness Assessment was executed to determine the market, organizational, technological, regulatory, ecological, and acceptance readiness levels. The potential of TES is estimated to be at least 40 percent of the heat demand of the Netherlands. During this research, it is concluded that TES will require a structural change on a national authoritative level for the technology to be implemented at its maximum potential.

Barriers that hinder the implementation of TES concern knowledge deficiencies, the possible impact on the ecology of water bodies, getting through the bathtub phase of risk-bearing pre-investments, a lack of governance, infrastructural bottlenecks, social capacity, a short-falling subsidy system, and the current regulatory framework. Revision of the current regulatory framework, reconsideration of the existing SDE++ subsidy system, social capacity building, ecological monitoring, and agenda-setting are measures that could stimulate the implementation of TES.

The balanced readiness assessment shows opportunities for development in different dimensions. For the MRL to reach a higher level, customers need to confirm progress/improvement. This will require products to be launched in a limited scope and subsequent empirical market research to inquire about progress/improvement. The ORL could reach the highest level if TES would work seamlessly with existing technologies. For now, this is not the case. However, work is being done on an integrated approach that includes many existing and new sustainable technologies. Of all levels, the RRL is the lowest. Due to a shortage of knowledge, the use and production of TES are regulatory problematic. Gathering and sharing knowledge will support the regulatory bodies in their development so that approvals for a TES installation could be realized fairly smoothly. The last analyzed dimension of the balanced readiness assessment that implies opportunities, is the ERL. For the ERL to be developed to the highest level, a regulatory framework has to be set up that supports the technology. Next to this, the ecological impacts of the technology should be researched thoroughly and in situations where the ecological impact is positive or negligible, the technology can be implemented.

From this research, important lessons can be learned. TES should be considered a very serious, feasible alternative for gas as a supplier of heat in the built environment. On top of this, TES could potentially meet a part of the cold demand of the built environment. To meet the main targets of the Paris Agreement of 2015 and the objectives from the Dutch national Climate Plan of 2021-2030, TES is a feasible and comfortable solution in terms of sustainability. One of the biggest challenges that the Netherlands faces is translating administrative ambition into physical implementation. To overcome this challenge, deviation from the processes that are currently being followed is necessary. Lastly, this research shows the difficulties a niche technology faces in contrast to the regime in the Netherlands. On this occasion, TES concerns the niche, whereas natural gas represents the regime. Upscaling of a niche such as TES can alter regimes, however, upscaling is one of the challenges that is being faced.

TES has incredible potential as a sustainable alternative to natural gas. Guideline assessments, standardized permit requirements, subsidies for feasibility studies, and working out business case studies are the practical applications that can help TES in developing its potential. For this, companies should make money available for business cases, and the government should stimulate by subsidizing TES projects. Only then will TES eventually be implemented to its maximum assessed potential. If done comprehensively, TES will be a great contributor to meeting the European and nationals targets and objectives and to the whole energy transition. The coming years are of major importance for society in terms of mitigation and adaptation to climate change. It is therefore vital that the right choices are made for which this research provides guidance.

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# Appendices

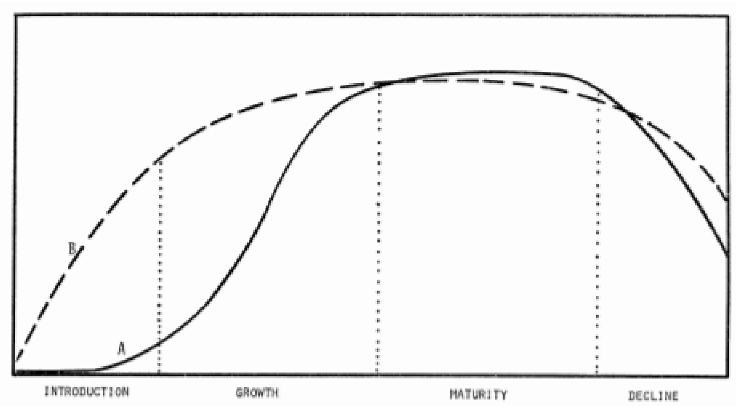
## Appendix I: outline of the interview

First, in short, the objective of the study was stated:

"As an Energy Management student, I look at TES as a sustainable option to apply during the energy transition to meet the heat (and cold) demand. In this thesis I research TES and specifically how the next step can be taken in the process of TES implementation. For this I turn to … in view of your knowledge of and experience with TES."

The next step was to pose the main questions:

The phase in which TES is in can be traced back from the following graph:




Poli & Cook (1969)

- At what stage would you place TES (fill in the dots….)?

For you as a company: …………………………………………….

For the licensing authorities: ………………………………………

For the potential customers: ……………………………………….

- How do you assess differences in this? Is it the weakest link that determines the implementation or is it different here?
- What are the barriers to the development of TES for you?
- Where do you think there are opportunities in the development of TES?

Issues I read during the literature review:

Scale size (suppose one household wants TES installation) and application without ATES

- Does … see a lot of potential in TEO systems without ATES connection? Do you use these often?
- TEO is mainly applied to larger projects. If individual households with small water bodies in the vicinity are also interested in such a situation, what is possible?

Pollution

- Pollution in the filters and corrosion in the pipework are problems based on experience from existing TEO installations. What is (interviewee) experience? Do you also (possibly not always) use self-cleaning filters?

Dryness, freezing and varying water levels

- How do you deal with the expected drought in the future?
- How do you deal with varying water levels?
- In winter conditions there is a risk of freezing of the pipework. One measure that can be taken is a deeper inlet point where possible. But in severe winter conditions, frostbite can still occur, how does (interviewee) prepare for this?

Long permit processes

- Practice shows that permit procedures are long. What is (interviewees) vision with regard to this procedure, and how do you deal with this?

## Appendix II: information sheet for interviewees “Thermal Energy from Surface Water”

Informatieblad voor onderzoek ‘Thermal Energy from Surface Water’ UNIVERSITY OF TWENTE.

Doel van het onderzoek
Dit onderzoek wordt geleid door: Julian van Zuuk.

Als student Energy Management kijk ik naar TEO als een duurzame mogelijkheid om in te zetten tijdens de energietransitie om te voorzien in de warmte (en koude) vraag. In deze thesis doe ik onderzoek naar TEO en specifiek naar hoe de volgende stap gezet kan worden in het proces van TEO implementatie.

Hoe gaan we te werk?
U neemt deel aan een onderzoek waarbij we informatie vergaren door:

- U te interviewen en uw antwoorden te noteren en/of in overleg op te nemen via een audio-/video-opname. Er zal tevens een transcript worden uitgewerkt van het interview

De resultaten zullen niet gedeeld worden en zullen uitsluitend gebruikt worden voor het onderzoek. De eventuele opnamen zullen verwijderd worden aan het einde van de scriptieperiode.

Potentiële risico’s en ongemakken

- Er zijn geen fysieke, juridische of economische risico’s verbonden aan uw deelname aan deze studie. Uw deelname is vrijwillig en u kunt uw deelname op elk gewenst moment stoppen. Daarnaast hoeft u geen vragen te beïnvloeden die u niet wilt beantwoorden.

**Vertrouwelijkheid van gegevens**

Wij doen er alles aan uw privacy zo goed mogelijk te beschermen. Er wordt op geen enkele wijze vertrouwelijke informatie of persoonsgegevens van of over u naar buiten gebracht, waardoor iemand u zal kunnen herkennen.

Voordat onze onderzoeksgegevens naar buiten gebracht worden, worden uw gegevens zoveel mogelijk geanonimiseerd, tenzij u in ons toestemmingsformulier expliciet toestemming heeft gegeven voor het vermelden van uw naam, bijvoorbeeld bij een quote.

De onderzoeksgegevens worden indien nodig (bijvoorbeeld voor een controle op wetenschappelijke integriteit) en alleen in anonieme vorm ter beschikking gesteld aan personen buiten de onderzoeksgroep.

**Vrijwilligheid**

Deelname aan dit onderzoek is geheel vrijwillig. U kunt als deelnemer uw medewerking aan het onderzoek te allen tijde stoppen, of weigeren dat uw gegevens voor het onderzoek mogen worden gebruikt, zonder opgaaf van redenen. Het stopzetten van deelname heeft geen nadelige gevolgen voor u.

Voor bezwaren met betrekking tot de opzet en of uitvoering van het onderzoek kunt u zich ook wenden tot de Secretaris van de Ethische Commissie van de faculteit Behavioural, Management and Social Sciences op de Universiteit Twente via ethicscommittee-bms@utwente.nl. Dit onderzoek wordt uitgevoerd vanuit de Universiteit Twente, faculteit Behavioural, Management and Social Sciences. Indien u specifieke vragen hebt over de omgang met persoonsgegevens kun u deze ook richten aan de Functionaris Gegevensbescherming van de UT door een mail te sturen naar dpo@utwente.nl.

Tot slot heeft u het recht een verzoek tot inzage, wijziging, verwijdering of aanpassing van uw gegevens te doen bij de Onderzoeksleider. Dit onderzoek is beoordeeld en goedgekeurd door de ethische commissie van de faculteit **BMS**.