A guide to large-scale solar heat collection

Industrial Engineering and Management
Bachelor Integration Project

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Abstract

Renewable energy is becoming more relevant every day. One of the renewable energy sources is solar thermal heat. The heat that is emitted by the sun is captured and distributed. Although the technique is integrated on a large scale in Denmark, the Netherlands only has one solar thermal park. This thesis develops a guide for municipalities with district heating networks that are active in the energy transition. The aim of the guide is to guide the reader through the development of a solar thermal park, show what a solar thermal park can do for them and as a result help in the decision making whether to implement a solar thermal park or not. The development is divided in 4 stages and 3 decision making moments. The pros and cons are showcased through a SWOT analysis and the guide provides a financial analysis. The guide is mainly aimed at municipalities with district heating networks, however, it can also help municipalities without a district heating network.

Contents

List of abbreviations

- DHN: District heat network
- PV: Photovoltaic
- DH: District heating
- FPC: Flat plate collector
- ETC: Evacuated tube collector
- PC: Parabolic collector
- MWh: Megawatt hour
- CO_2: Carbon dioxide

1 Introduction: Energy transition in the Netherlands

The outcome of this thesis is a guide with the development of a solar thermal park, a SWOT analysis that showcases the pros and cons and a financial analysis. The result of this will help municipalities in the decision making whether to implement a solar thermal park or not in order to reach the ecological goals of the Netherlands in 2050. The guide is presented in Appendix C, where first the development of a solar thermal park is presented. Then in Appendix D a SWOT analysis is performed and the guide ends in Appendix E where the financial analysis is performed.

In 2011 the Netherlands stated to aim for an 85-90% reduction of CO_2 emissions which should be achieved by 2050 (Rotmans, 2011). Combined with the climate agreement, in which is stated that 7 million households have to be heated independent of natural gas by 2050, a shift towards more sustainable heating has started in the Netherlands. In 2050, it is expected that 66% of the Dutch population will live in urban areas (ARUP, 2016). Especially in densely populated areas, according to (ARUP, 2016). In order to realize the reduction in CO_2 and the removal of natural gas, whilst being able to supply the heat demand, multiple renewable heat sources are required. In order to utilize the heat generated by multiple renewable heat sources, a District heat network (DHN) is required. A DHN is an underground network of insulated pipes which supply heat to houses generated by different sustainable heat sources. Solar heat is a renewable heat source that has been adopted on a large scale in Denmark.

The Danish are the leading country in solar thermal parks. In Denmark, 66% of the houses are connected to a DHN, 99% of all houses in Copenhagen are connected to a DHN (Interview with Peter Eijbergen, Appendix A.2).This also includes remote houses. In the Netherlands, it consists mostly of flats connected to a DHN. Solar thermal parks provided 63% of all Danish houses with DH generated by the $386.000m^2$ of solar collectors in 2013 (Furbo et al., 2015). The collector area increased to $1.300.00m^2$ by 2016 (Furbo et al., 2018). Currently the biggest heat networks in the Netherlands are in Amsterdam, Rotterdam, Almere and Utrecht. However, only one of them is utilizing solar heat on a big scale, which is in Almere called ''Het Zoneiland". (Bezemer & Bezemer Communicatie, 2010).

2 Context

2.1 Problem context

Of all the heat networks in the Netherlands, only Almere is utilizing a solar thermal park. This solar thermal park is 1.5 hectare big, contains $7000m^2$ of solar collectors and supplies the 10% of the heat demand of 2700 households (Bezemer & Bezemer Communicatie, 2010). In 2022, a solar thermal park will be finalized in Dorkwerd, Groningen. Other DHN's that do not have a solar thermal park implemented in their network have trouble coping with the heat demand with heat generated from renewable heat sources. For example: Utrecht has one of the biggest DHN in the Netherlands, 55000 households are connected to this network, however 20% of the heat demand still has to be supplied with heat generated by natural gas (Segers et al., 2019). The awareness on solar thermal parks among municipalities is low in the Netherlands. Combined with the relatively high investment it requires to set up such a park and the difficulty of calculating this beforehand, results in the municipalities with an existing DHN not having information on solar thermal parks and therefore not being aware of the potential benefits of the addition of a solar thermal park to their existing DHN.

2.2 Problem statement

Therefore the problem can be stated as the following:

Municipalities with existing district heat networks are reluctant to invest in the addition of a solar thermal park to their existing district heat network due to not having information on the development process and the price as well as the pros and cons of such a park. Resulting in municipalities still generating heat with natural gas to cope with the heat demand.

2.3 Problem owner analysis

The problem owner in this project can be identified as Jelmer Pijlman, he is the director at Solarfields. Solarfields is a solar thermal park developer that is actively participating in the energy transition. The problem owner is interested in the expansion of solar thermal parks throughout the Netherlands and helping towards the 2050 goals. He has the highest stake in the system due to wanting to create more awareness amongst municipalities regarding solar thermal parks and therefore, can be seen as the key player in this project.

2.4 Stakeholder analysis

- Dick Takkebos is a stakeholder, he is the director of Warmtestad. A utility company that provides households and companies in Groningen with sustainable heat. They are currently expanding the heatnet of Paddepoel Groningen and wish to supply more than 10.000 homes in 2020 with sustainable heating (Warmtestad, 2019). The outcome of this research can accelerate the demand for solar thermal parks and Warmtestad will be able to distribute the heat.

- Wouter van der Heijde is currently the secretary of the theme-group Sustainability of the G40. The G40 is a group of 40 medium to large cities that support each other in sustainable issues of a city. The theme-group Sustainability is interested in the topic of adding solar thermal parks to existing heat networks. Wouter has a stake in the project because the theme-group is actively trying to help in the energy transition. The outcome of this research can help municipalities in the decision making whether to implement a solar thermal park or not. Wouter is considered as high interest, low power.

- RVO grants subsidies to encourage sustainable entrepreneurship, currently the SDE+ subsidy is the most relevant subsidy for solar thermal parks. Without this subsidy the park cannot be realized. Therefore, the RVO is considered as a key player, it has a high interest in energy transition and has high power due to providing the funds for the projects.

- Ronald van den Berg is Manager sustainable process energy systems for the ECN part of TNO. the ECN part of TNO aims to cooperate with knowledge institutions, companies and the government to increase the speed of the energy transition of the Netherlands. One of its expertise groups is focused on solar thermal energy. It has high knowledge of heat generation through solar collection. Due to their high interest in the energy transition, the ECN part of TNO is considered as high interest with low power.

- Local residents are other stakeholders in the current system. The solar thermal parks will always have residents surrounding the area. They should be monitored and kept informed regarding the developments of the solar thermal park that will be built. They should not be neglected, listening to their opinions and keeping them informed will result in a good cooperation.

2.5 System description

Once this all has been realized the implemented stage begins, this means that the solar thermal park is finished, connected to the heat network and that the heat generated by the park is being utilized by the residents connected to the heat network.

When solar thermal collectors are exposed to the sun, they heat up. The heat that has been collected is transferred through to a transfer fluid. Usually water, glycerol, mineral oil or air is a type of transfer fluid used (Tripanagnostopoulos et al., 2004) (Erdil et al., 2008). The heat is then transported through a heat network. After collecting the heat from the solar thermal collectors, it can be stored in two ways: Short-term heat storage and seasonal heat storage. Short-term storage is required to constantly supply heat to houses and is typically a large insulated steel tank. Seasonal storing is done if the demand is higher during the winter and is stored through ‘’Warmte- en koudeopslag”(WKO), a hot and cold storage (Baek, 2015). This is a system that uses the heat generated to heat up groundwater in a well. Once the demand rises, the heated water from the well will be further heated to the correct temperature through a heat pump and then supplied to the houses (Warmtestad, 2019).

Groningen is currently in the process of building the 2nd solar thermal Park in the Netherlands. This park is managed and developed by Solarfields. They have joined with the municipality of Groningen, the province of Groningen, K3Delta and the RVO to build a solar thermal park to generate heat (Mortelmans, 2019), which will be transported by Warmtestad, who owns and manages the heat network of Groningen, to provide 10.000 households with heat in 2020 (Warmtestad, 2019).

3 Scope: Focus on decision making of existing DHN

The biggest bottleneck is the decision making whether a municipality wishes to implement a solar thermal park or not. This is based on the fact that there currently is only one solar thermal park in the Netherlands. Therefore, the scope of this project shall be on the decision making of municipalities with an existing DHN. Municipalities can take different roles when deciding on the implementation of a DHN (Spaans & Resink, 2019), the deliverable of this report will, however, also affect the municipalities without a DHN. The guide may influence the decision making for the implementation of a DHN and consequently whether to implement a solar thermal park or not. However, they do not possess current data on solar thermal parks or DHN and therefore they are not added in the scope.

4 Goal statement: What will be performed

Having identified the stakeholders, described the system and having defined the problems, a goal can be formulated according to the S.M.A.R.T criteria (Doran, 1981):

4.1 Goal

To develop a guide that provides the reader with the entire process of the development of a solar thermal park. The guide will also provide the pros and cons of a solar thermal park through a SWOT analysis. The result of this will help municipalities with the decision making of implementing a solar thermal park such that the quota of 2050 can be reached. This should be developed within 3 months.

5 Research questions

The following set of (sub)questions will provide the knowledge required to realize the goal. The main questions can be stated as the following:

1. *What does the development process of a solar thermal park look like in terms of parameters and timeline?*

2. *What are the pros and cons of a solar thermal park?*

In order to answer the main questions, several sub questions will be assessed that will provide the answer to the main questions:

1. What are the financial benefits and the costs of implementing a solar thermal park?

2. What are the ecological benefits of implementing a solar thermal park?

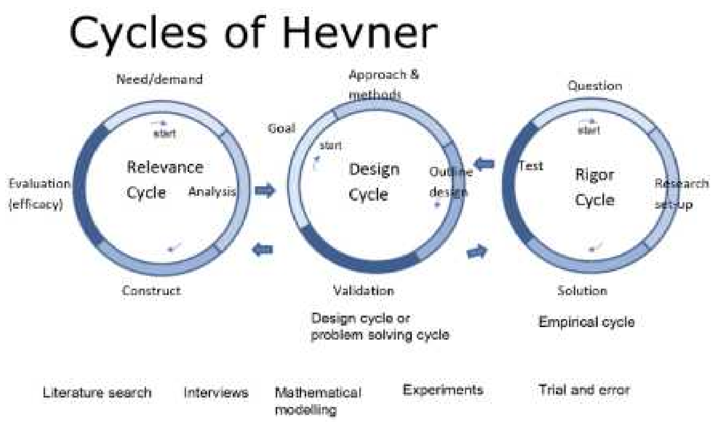
3. What are the prospects of solar thermal heat in terms of output and demand?

4. What parameters have to be taken into account during the development of a solar thermal park?

5. What parties are involved during the development of a solar thermal park

6 Methods and tools

6.1 Cycles of Hevner



The main focus of this thesis is on practice oriented research. Some parts however, are knowledge oriented. Therefore, a cycle needs to be chosen that is both design oriented and knowledge oriented. The rigor- and the design cycle of (Gregor & Hevner, 2013) will be used to better understand the problem.

6.1.1 The relevance cycle

Firstly, the relevance cycle is entered to investigate what stakeholders have interest and influence within the system and who the key players are. Furthermore, to deliver this research to the outcome of the world, this cycle is used.

6.1.2 The rigor cycle

New information is added from the rigor cycle to the current knowledge base. In this cycle, the first step is to formulate main questions. Thereafter, research startup will take place. The data acquisition, which is discussed in section 7.2, is part of this research start up. The solution to the questions will give the required information to be used in the design cycle. The knowledge that has been found can be added to the knowledge base after the research.

6.1.3 The design cycle

Once the needs of the key player are clear, the design cycle is entered and an approach is formulated to satisfy them. Hereafter an outline of the design is made, which will be a guide on the development of a solar thermal park. The rigor cycle is entered and literature research is committed to come up with a solution to the design questions.

6.2 Data acquisition

Data acquisition for this thesis is required through literature research, desk research and interviews. The literature research will provide information about what solar thermal heat is, the different types of collectors and what is required in order to utilize solar thermal heat. The desk research will be used to estimate prices and output. Interviews are conducted with a solar thermal park developing party, a district heat network managing party and a solar thermal collector developing party. They will provide the required information to map the development of a solar thermal park. Hereafter, a SWOT analysis is composed to further analyse the aspects of a solar thermal park and a financial analysis to give an indication on the price.

6.3 SWOT analysis

Furthermore, a Strength Weakness Opportunities and Threats (SWOT) analysis will be performed on solar thermal heat. The collected data through the literature research and interviews will provide enough information to develop a SWOT analysis. The SWOT analysis is constructed according to (Chermack & Kasshanna, 2007) in which they add an extra row and an extra column to the SWOT such that combinations can be made. These combinations will showcase the interactions of the different aspects of the SWOT and assumptions can be made on how they will do in the future. It is important to conduct the SWOT in an unbiased manner.

7 Deliverable and validation

The deliverable that is presented is a guide that guides the reader with the development of a solar thermal park, showing the pros and cons of such a park through a SWOT analysis and a financial analysis for a price indication. The deliverable is mostly intended for municipalities with a DHN that are active in the energy transition. For municipalities without a DHN the deliverable can be a persuasion in the decision making of the development of a DHN and the implementation of a solar thermal park. It is important that the outcome that will be provided is complete and correct. Although solar thermal heat is a relevant subject in Europe, it is not very relevant in the Netherlands. The best way to validate the deliverable is to compare the guide with the process of an already existing solar thermal parks in Europe or compare the guide with the development process of ''het Zoneiland" in Almere, the Netherlands.

8 Quick risk analysis and feasibility

The risk of this thesis is in the possibility that information regarding the decision making on this subject in the Netherlands is difficult to find, therefore, assumptions have to be made. This is because not every municipality in the Netherlands makes decisions in the same way with the same designated people. Furthermore, the growth of solar thermal park can be obstructed by municipalities not wanting to implement a DHN due to the majority of the municipalities in the Netherlands not having a DHN. However if all DHN's in the Netherlands will implement a solar thermal park, it will be a substantial step towards a natural gas free Netherlands, therefore the deliverable will still be feasible.

9 Theoretical framework

The following section will focus on the existing literature on solar thermal collectors and solar thermal parks. In order to support the research questions, the following questions have been formulated. These will be answered in section 10

9.1 Literature research

This thesis is focused on solar thermal parks, in order to better understand the subject, the following questions have been formulated:

1. What is solar thermal heat?
2. What are solar thermal collectors?
3. What are the different type of collectors?
4. What is required to use solar thermal heat?
5. What is a solar thermal park?
6. What are the different type of parks?
7. What is heat storage?
8. What is the current position of the Netherlands in the energy transition?
9. How many solar thermal parks does the Netherlands have?

9.1.1 What is solar thermal heat?

The sun emits enormous amounts of heat everyday. The capturing of this radiation can be done by letting the heat of the sun warm up a panel, which in its turn heats a fluid and then utilize the heat. Solar thermal heat can be defined as the following: *Solar thermal heat is the collecting of the sun's emitted heat and using it to heat up households.* Solar thermal heat capturing can be performed in two ways, small scale and large scale. Large scale capturing is the capturing of the heat through a solar thermal park, elaborated on in 9.1.4, small scale capturing is the placement of solar thermal collectors on a house and using the heat to heat up that particular house.

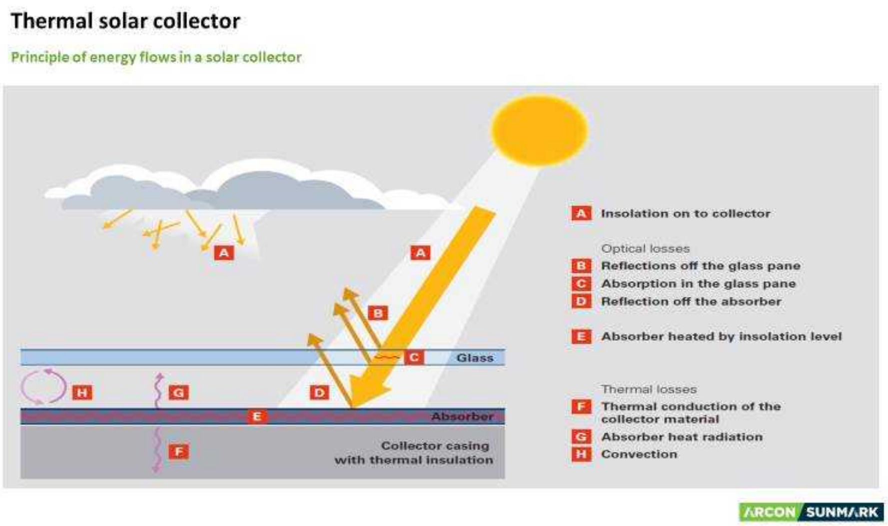


Figure 1: *The energy flows of the energy emitted from the sun and the capturing in a solar thermal collector. 95% of the heat is absorbed, 5% is reflected*

Quite often Photovoltaic panels (PV-panels or solar panels) and solar thermal collectors are confused with each other. Photovoltaic means electricity and usually refers to the production of electricity through the sun. Photovoltaic panels are referred to as 'solar panels' whereas solar thermal collecting panels are referred to as solar collectors. Solar panels work by allowing photons from the sun 'knock' electrons free from atoms and thus creating a current (Cummings, 1992). Solar thermal collection means the collection of heat from the sun and is explained above. This mistake is often made and although the mix-up might seem small, the technologies are very different.

9.1.2 What are solar thermal collectors?

In order to capture the emitted heat from the sun, a solar thermal collector is required. A solar thermal collector is a device that collects heat by absorbing sunlight and transferring the heat to a working fluid that flows inside the collector. A solar thermal collector consists of a glass cover plate, an absorber plate and a working fluid (Buker & Riffat, 2015). The absorber consists of a material with a high heat conductance. The solar radiation enters the device through the glass plate, heats the absorber, the absorber transfers the heat to the working fluid and the heated fluid leaves the device. The most common working fluids are water and air, however, glycerol and mineral oils can also be used as working fluids(Tripanagnostopoulos et al., 2004). Furthermore, a solar thermal collector also uses antifreeze to prevent the working fluid from freezing during the winter. If air is used, the solar thermal collector will not have antifreeze. (Buker & Riffat, 2015).

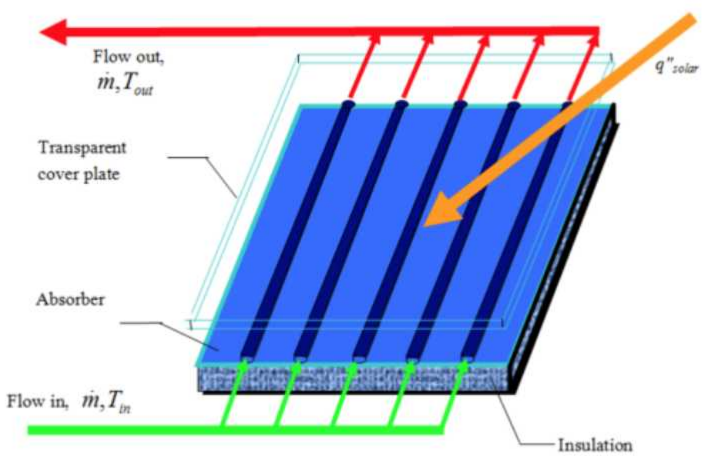


Figure 2: *A model with the workings of a solar collector. The green arrows represent the inflow of water with a temperature T, in and indicated with m. The orange arrow represents the solar rays that reach the solar collector, with an amount of heat indicated by q''. The red arrows represent the outflow of the water with a temperature $Tout$ and indicated with m*

.

Solar thermal collectors can be distinguished in two different kinds: The non-concentrating collectors and the concentrating collectors. The non-concentrating collectors are as described above and are used for low- and middle- temperature applications. The concentrating collectors reflect all the captured radiation and focuses it on a small absorber plate. Concentrating collectors are used for middle- and high- temperature applications (Pandey & Chaurasiya, 2017). In general, the three operating temperatures are the following:

- Low temperature (<100°C)
- Medium temperature (> 100°C and <400°C)
- High temperature(>400)

For domestic heating, only low temperature can be utilized and therefore, only non-concentrating collectors are used (Pandey & Chaurasiya, 2017).

9.1.3 What is required to use solar thermal heat?

After having captured the heat emitted by the sun, it can not be utilized immediately. For large scale heating, a DHN is required to distribute and use the heat. As mentioned in section 2, a DHN is an underground network of insulated pipes which supply heat to houses. A DHN consist of a central heating plant, a heat distribution network and, if necessary, heat transfer substations in the connected buildings (Schmidt et al., 2004). The fundamental idea of DH is the recycling of heat that would be wasted otherwise (Persson & Werner, 2011). The five biggest heat supplies in European countries are:

- Biomass fuels,
- geothermal heat,
- combined heat and power(CHP),
- excess heat from high energy industrial processes
- waste-to-energy (WTE) plants.

Note that solar thermal heat is not in the list of five biggest heat supplies in European countries. Countries such as Denmark and Germany have adopted solar thermal heat on a large scale, however, other European countries have not adopted solar thermal heat on a large scale. The main sources of the Netherlands are biomass and rest heat. A DHN also allows for heat sources that have not been developed yet to be connected (Roos & Manussen, 2011).

9.1.4 What is a solar thermal park?

As stated in section 9.1.1, solar thermal collection can be performed in two ways, small scale and large scale. For the heating of houses and the distribution being performed by a DHN, a solar thermal park is used. A solar thermal park is the collection of solar thermal heat on a large scale. The solar thermal collectors are connected in series to collector rows and the collector rows are connected in parallel to each other (Schmidt et al., 2004).

9.1.5 What are the different type of parks?

Described in section 9.1.4 is what a solar thermal park is, however, variations exist in whether a park uses storage or not. The heat that is collected through the sun can be used in 3 ways, directly heat the DHN, transfer the heat to the diurnal (daily) storage or transfer the heat to the seasonal storage. Supplying the collected heat directly to the DHN, will result in a heat demand coverage of 1-2% per year (Schmidt et al., 2004). The utilization of a daily storage increases the heat demand coverage to 10-20% (Schmidt et al., 2004). A daily storage is a large cylindrical tank that is filled with the excess heat that can not enter the DHN due to the DHN being satisfied at that certain moment. When the demand of the DHN increases and the supply cannot cover the demand (during the evening), the daily storage tank will be used to cover the increased demand. A Seasonal storage is the same principal as the daily storage, however, it stores the excess heat in the summer in a large artificial pond and distributes the heat during the winter. This method can cover the heat demand of a DHN up to 50% per year (Schmidt et al., 2004) . The variations that exist in a solar park are determined by the type of storage they use. A park without storage, a park with daily storage and a park with seasonal storage are the 3 variations a solar thermal park can have. This is further explained in Appendix B.4.

9.2 Energy transition in the Netherlands

In 2011 the Netherlands stated to aim for an 85-90 % reduction of CO2 emissions which should be achieved by 2050 (Rotmans, 2011). Combined with the climate agreement, in which is stated that 7 million households have to be heated independent of natural gas by 2050, a shift towards more sustainable heating has started in the Netherlands (EUDP, 2019). Especially in densely populated areas, according to (ARUP, 2016) 66 % of the population will live in urban areas by 2050. In 2017, the Netherlands produced 6,6 % of the total generated energy through sustainable sources (EUROSTAT, 2019)

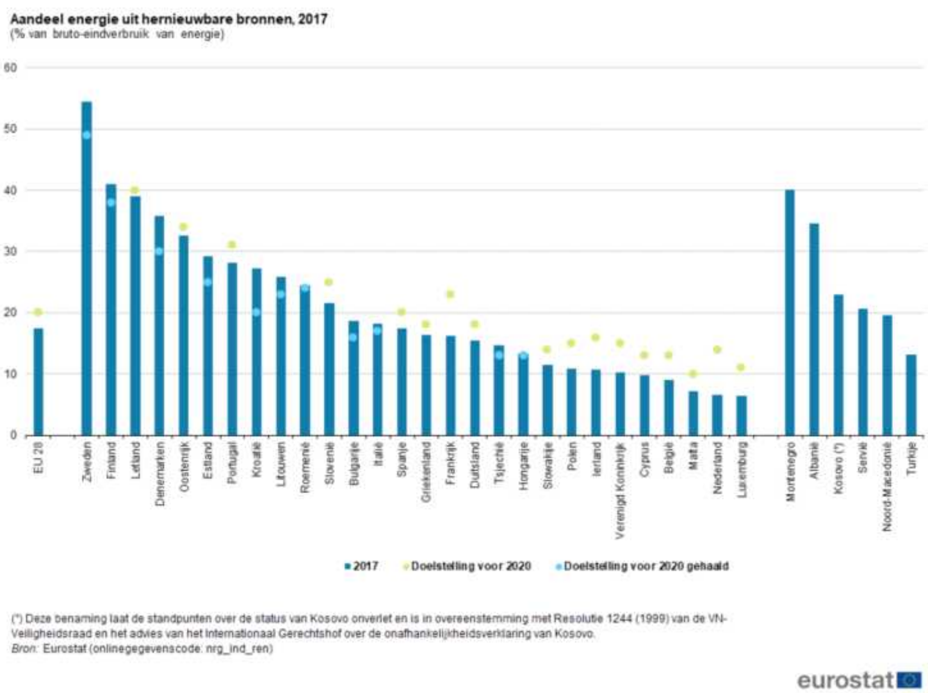


Figure 3: *A comparison of EU countries with the shares of energy from renewable sources. The blue bar indicates the current %, the yellow dot is the goal for 2020 and the blue dot indicates at what percentage the goal has been reached (EUROSTAT, 2019)*

As can be seen in figure 1, only Luxembourg is performing worse. In order to try to reach the 2020 goal of 14 % and the 2050 goal, the energy transition has to be accelerated. In 2018 the Netherlands increased its sustainable energy generation to 7,4 % (Segers et al., 2019).

9.3 Solar heat collection in the Netherlands

Currently there is only one solar thermal park in the Netherlands, this park is called ''Het Zoneiland" and is located in Almere. This solar thermal park is 1.5 hectare big, contains 7000m2 and supplies 10% of the energy demand of 2700 households (Bezemer & Bezemer Communicatie, 2010). The largest solar thermal park is located in Silkeborg, Denmark. It has 156.694 m2 of solar collectors and produces 80.000 MWh per year, which covers 20 % of the heat demand of 40.000 inhabitants (SDH, 2017). In Denmark around 63 % of the heat demand of households connected to a heat network is supplied with solar heat collected through solar thermal parks (Furbo et al., 2018). The second largest solar thermal park is in Vojens, Denmark, has a size of 70.000 m2 and produces 28000 MWh per year, which is around 45 % of the heat demand of the town (SDH, 2017).

10 Results

The following section will cover the results of the research committed. The results are presented per sub-question. The results have been acquired through interviews and the literature research committed.

10.1 Sub-question 1: What are the financial benefits and the costs of implementing a solar thermal park?

To give a numerical value to the benefits and the costs of a solar thermal park is not possible, due to being dependent on multiple parameters. During the development of a solar thermal park, the project developer will perform a business case. The business case will determine the NPV, the IRR, the cash flow, the amount of subsidy that will be granted and the amount of loan required to fund the park against what percentage of interest. This results in how much will the park cost and what will it revenue. The parameters on which the price of a solar thermal park depends are the following: The size of the park, the type of park, the amount of collectors, the amount of heat it will generate, the number of households to be heated, the heat demand of the households, the efficiency of the park, number of sun hours, solar fraction, the temperature of the inflow and the outflow, the mounting system of the collectors, price of the location (rent, lease), maintenance costs, tillage and size of the heat storage. Because these parameters are so different per situation, there is not a model that applies to all parks. However, to give an indication of what the prices of a solar thermal park will be, a model has been made in Chapter D of the appendix based on desk research, literature research and interviews to give a rough estimation of what the price of a park will be and how much gas and CO_2 will be saved. All of the above mentioned parameters should be taken into account for a more exact price indication of a solar thermal park.

The payback time can be assessed. Every park that is built, is designed to have the fastest payback period, which is 15 years. After the 15 years, the capex and the loan will have been paid off. The only costs associated to the solar thermal park at that point are only the maintenance costs, which are €1 per produced MW/h. Meaning that after 15 years, the park will make profit. The cash flow starting at day one of building the park, until the end of the 15 years , is positive because of the subsidy. The subsidy lasts for 15 years, in those 15 years the park will have covered the capex and the loan. The cash flow will still be positive afterwards because of the profit made from the heat generation and the low maintenance costs. The subsidy is further elaborated on in Appendix C.2.3

10.2 Sub-question 2: What are the ecological benefits of implementing a solar thermal park?

The ecological benefits are defined as the amount of CO_2 saved with the use of a solar thermal park and the amount of natural gas saved. Furthermore, the ecological footprint is calculated according to (Stöglehner, 2003).

The combustion of 1 m^3 natural gas produces 0.00189 ton CO_2 (Envirometer, 2016). The amount of gas and CO_2 saved is dependent on the amount of solar collectors a park has. In Appendix E, the amount of heat generated per solar collector is calculated to be 5,066 MWh per year. The combustion of 1 m^3 gas yields 0,009769MWh Appendix E. Therefore, the amount of gas saved per year by using 1 solar collector is 518,58 m^3. This is equal to 0,98 ton CO_2 per year, or 980 Kg per year. Note that this number is not exact, due to the amount of heat generated per year of 1 solar collector is estimated in appendix H, it is not the exact number. The ecological footprint is defined as a simple comprehensible indicator that shows the effect of society's actions on the environment in terms of land used (Stöglehner, 2003). The ecological footprint calculates the land used for all sources of energy, for this thesis only the land will be calculated for heating in Groningen and the amount of land that can be saved by implementing solar thermal heat. (Stöglehner, 2003) defines the ecological footprint table as the following:

	Yield in MJ/m^2	Land need in m^2/MJ
Electricity photovoltaik	440	0.0023
Electricity wind	900	0.0011
Electricity water power	100	0.01
Solar heating	1200	0.0008
Wood extensive	7.3	0.1370
Wood intensive	18.79	0.0702
Straw as by-product	4.3	0.2326
Miscanthus	25.39	0.0394
Rape oil	5.81	0.1721
Methyl ester of rapeseed	4.72	0.2119
Ethanol from sugar cane	9.3	0.1705
Ethanol from sugar beet	8.0	0.125
Ethanol from wood	4.6	0.2174
Ethanol from wheat	4.61	0.2169
Ethanol from maize	1.59	0.6289
Methanol from wood	11.67	0.0857
Biogas, digestor gas, landfill gas	4.98	0.2008
Coal	0.05	20
Fuels	0.0834	11.99
Natural gas	0.096	10.42

Table 1: *Ecological footprint*

From the table can be seen that solar heating has a high yield compared to the other sources. In 2017, the entire energy demand of the province Groningen was 75.138 TJ, households were responsible for 15.941 TJ. Furthermore, 6.3% of the energy demand was generated with renewable sources (biomass, wood intensive) for heat. The remaining 16% of the energy demand was electricity and 77.7% of the energy demand was natural gas for heat. Finally, it is assumed that the 6.3% renewable source is biomass. Then the following table can be constructed:

Source	heat generated (TJ)	land used (km^2)
Natural gas	12.386,16	129063,79
Biomass	1004,28	70,5
Sum	13390,44	129134,29

Table 2: *Ecological footprint of Groningen*

The area of the province Groningen is 2960 km^2, the ecological footstep Groningen in 2017 had was 43,6 times its size. Note that the data from table 1 is the yield in 2003, the yield on gas is most likely to be higher now. Now it is assumed that solar heat will provide the same share of TJ as biomass. This gives the following table:

Source	heat generated (TJ)	land used (km^2)
Natural gas	11381,88	116550,451
Biomass	1004,28	70,5
Solar heat	1004,28	0,803
Sum	13390,44	116621,75

Table 3: *Ecological footprint of Groningen with solar heat*

Now the ecological footprint has been reduced to 39,4 times the size of Groningen. Renewable sources in general, but solar heat specifically, have a very positive influence on the ecological footprint.

10.3 Sub-question 3: What are the prospects of solar thermal heat in terms of output and demand?

The demand in renewable heat sources is increasing, since the Netherlands needs to heat 7 million houses independent of gas by 2050 (EUDP, 2019). Throughout Europe, 122 parks have been realized between 2010 and 2020. Between 2000 and 2010 only 44 parks have been realized (SDH, 2017). In the Netherlands, only one solar thermal park is in existence, however, in 2022 a second park will be realized in Groningen. It can be concluded that the demand for renewable sources, but also solar thermal parks, will only increase further in the coming years. This is because of the climate agreement and because the taxes on gas will only increase in the coming years. This results in heat generated through renewable sources becoming cheaper than heat generated through gas (Rijksoverheid, 2020). The output of a solar thermal park is dependent on a lot of different factors. These factors include: The type of collector, amount of collectors, sun hours per year, solar fraction, type and size of storage and the temperature inflow and outflow. The number of sun hours per year and solar fraction can not be influenced. In Appendix B.4, the different type of parks are explained and the influence of of heat storage on the output of a solar thermal park. The influence of the inflow and outflow temperature is explained in Appendix C.4.4 the technological advancement of using the same inflow multiple times will greatly increase the output of a solar thermal park. The technology of the solar thermal collector has improved since it was invented in 1977 (Lightfoot, 1977). Three types of collectors can be identified: flat-plate collector (FPC), evacuated tube collector (ETC) and parabolic collector (PC). The details of these collectors are shown in appendix B. The output of a solar thermal park is expressed in one value, instead of the storage output and the collector output. Therefore, the increase of output over the years can not be calculated. However, the output is believed to only further increase because of improved storage technology, higher absorption rates of the collectors and multiple use of the same inflow.

10.4 Sub-question 4: What parameters have to be taken into account during the development of a solar thermal park?

The development of a solar thermal park can be divided in 4 stages and the parameters can be divided in the following categories:

- financial parameters
- design parameters

The financial parameters are subsidy, loan, investment costs, maintenance costs. The subsidy for a solar thermal park is provided by the RVO and is called the SDE+ subsidy. This subsidy is granted for 15 years. The subsidy consists of a fixed price per produced kWh and a number of full load hours per year. Currently, the provided funds per produced kWh is €0,59 and the number of full load hours is 700 (RVO, 2019). However, the preliminary 2020 SDE+ subsidy states that it will be reduced to €0,54 per produced kW and 600 full load hours. The effect of this on the solar parks is that the subsidy granted will be less. However, most of the parks built in Europe do not reach the 600 full load hours per year (Interview with Theo Venema, Appendix A.3) (Interview with Peter Eijbergen, Appendix A.2). Figure 11,12 and 13 are an example of how the subsidy is calculated and an example of the subsidy granted. For the development of a solar thermal park, almost always a loan is required. The loan of the solar thermal park in Groningen covers around 80% of the total costs of the park. This might not be for every park, but it serves as an indication. The aim of the park is to profitable such that the loan can be payed off after 15 years, including interest. The investment costs consist of all the costs required to start developing the park. The costs of the location, collectors, storage, installation and technical building. The maintenance costs are €1 per produced MWh (Interview with Jelmer Pijlman, Appendix A.1) (Interview with Peter Eijbergen, Appendix A.2). This covers all the maintenance required to the park, breakage of collector or a fault in the system, but also the electricity required to operate the park. The financial parameters are shown in Appendix C.2.4, Appendix C.3.8, Appendix C.4.7 in Appendix E of the guide.

The design parameters The design parameters consists of the type of collector, amount of collectors, type of park, size of park, size of storage, location, type of mounting, temperature of inflow and outflow, amount of heat to be generated and amount of households to be heated. There are three type of collectors, the flat-plate collector, the evacuated tube collector and the parabolic collector. All three collect heat from the sun, however, only the flat-plate and evacuated tube collector are able to be used for the heating of households. Section B.1 describes the differences between these collectors and the operating temperatures. The amount of collectors is dependent on the amount of heat to be generated and the amount of households to be heated. It is important that an energy balance is made that shows the amount of TJ or MWh used by a municipality per year. After the balance is made, it can be determined what % of the total energy balance the park wants to cover. Once the share has been determined, the type of park has to be determined. Appendix B.4 describes the differences between the parks. The decision on the type of park is dependent on funds available, ground available and amount of heat to generate. The park type combined with the type of collector, type of storage and size of storage allow for the number of collectors to be calculated. Once the type of park, size of storage and number of collectors have been determined, the mounting has to be assessed. There are two ways to mount a solar thermal collector for large-scale purposes, these are described in Appendix B.2. Furthermore, the temperature of the inflow and outflow have to be calculated. The effect of this on the solar thermal park is described in Appendix C.4.4 The lower the inflow temperature and outflow temperature, the more efficient. There are a lot of parameters that have to be taken into account when developing a solar thermal park. There might be more parameters that will be taken into account when developing a specific solar thermal park. However, these are the core parameters that are taken into consideration during the development of a solar thermal park.

10.5 Sub-question 5: What parties are involved during the development of a solar thermal park

The parties involved are: solar park project developer, DHN managing party, decision making party within the municipality, local residents, land owning party and safety parties. The solar park project developer is the one of the main parties involved during the development of a solar thermal park. All the calculations required, the layout of the park, the design of the park and more will be performed by them. Furthermore, the maintenance and visual checks will also be performed by them. The DHN manager will work in close collaboration with the project developer to ensure that the temperatures supplied are not too high or too low, help calculate the amount of households to be heated and help with the calculations for the size of the park. The decision making party within the municipality is responsible for giving approval for continuing with the next step of the development process. At the end of each stage, a report should be composed that accurately describes all the parameters that have been taken into account during that phase, on what parameters decisions have been made and what will happen in the following stage of the process. For the local residents and for the sake of the project, it is important to actively involve the local residents during the project. By actively listening to the local residents and taking their wants and needs into account, results in a good cooperation. Ignoring the local residents may result in legal action being taken by the local residents to stop the park from developing. The importance of the local residents is further described in appendix D3.19. The land owning party can differ per park, the land can be owned by the municipality, but also privately owned. It is important to keep the land owning party closely involved with the progress of the park. The safety parties are involved to make sure no calamities arise during the development of the solar thermal park, but also when it is operating. The safety parties consists of the police, ambulances and fire brigade. The solar park project developer will do everything to make the park as safe as possible, but the safety parties are there to help with evacuation plans and calamity plans. The role of the parties involved and why they should be involved are further described per stage in C.2.6 C.3.8 C.4.8.

11 Conclusion and further research

11.1 Conclusion

This thesis is centered around finding the question to the two main research questions:

1. *What does the development process of a solar thermal park look like in terms of parameters and timeline?*

2. *What are the pros and cons of a solar thermal park?*

To answer these questions, desk research, literature research and interviews have been conducted. The main questions have been answered by providing the answers to the sub-questions formulated in section 5
The financial benefits and the costs of implementing a solar thermal park are stated in Appendix E. A price calculation model was developed to give a quick indication on what solar thermal heating can do.
The ecological benefits have been described in two ways, in terms of the ecological footprint and in terms of CO_2 saved. The ecological footprint shows the amount of land a municipality uses to generate the energy required. The CO_2 saved is integrated in the price calculation model to help show what solar thermal heating can do.
The prospects of solar thermal heat in terms of output and demand have been elaborated on by showing the growth in solar thermal parks in 1990-2010. The prospects for the output could not be determined, however, advances in the solar collector technology, improved storage technology and multiple use of the same inflow will result in the output of the solar thermal parks only increasing.
The parameters that need to be taken into account when developing a solar thermal park have been divided in two categories: the financial parameters and the design parameters. The financial parameters regard the costs, subsidy and gas saved. The design parameters regard the temperature of the inflow and outflow, type of park and type of collector. The parameters and what their influence is on the development have been stated per stage in the guide that is developed.

The parties that are involved during the development of a solar thermal park, all have different roles. Because they have different roles, they have different influences on the development. Therefore, they should be incorporated during different stages. A close cooperation between these parties results in a peaceful cooperation.

With the answers to the sub-questions, the main questions were answered and the guide was developed. The guide presents the development of a solar thermal plant. The main objectives are to provide the reader with the knowledge regarding solar thermal parks, guide the reader through the development of a solar thermal park, developing a SWOT analysis that shows the pros and cons of a solar thermal park and provide a financial analysis. The process of the development of a solar thermal park has been divided in four different stages to better understand the process. The four stages all have a goal that wants to be reached during that stage and the first three stages have important decision making moments. The SWOT analysis has been performed to showcase the pros and cons of a solar thermal park. Appendix D.6 shows the reader what influence the combinations of the different aspects have on the future of solar thermal parks. It is for the reader to develop an opinion on whether to implement a solar thermal park or not at the end of this section. The main research questions have been answered and the goal has been met.

11.2 Future research

To further improve the guide, it is advised to investigate the exact influences of the temperature inflow and outflow on the output of a solar thermal park. Furthermore, expanding the financial analysis by including installation prices, material prices and the exact price of solar collectors and heat storage will make the guide more effective by giving a more precise cost indication. By conducting research on the decision making inside a municipality, the guide can be adjusted and be more specific towards the decision making moments that municipalities face. Finally, the output of the solar collectors were estimated. If research is conducted to the output of one collector, the amount of gas saved, CO_2 saved and money saved can be better estimated and finally will help in the decision making.

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A Appendix A: Interviews

A.1 A.1 Interview with Peter Eijbergen

Peter Eijbergen is managing director at Arcon Sunmark, one of the biggest solar thermal park developers in Europe. The following questions have been asked to Peter:

- What is the cost of the development of one solar collector?
- Who does the maintenance and what are the costs?
- What are the emissions of the development of one solar collector?
- In how many years does a solar collector 'earn' itself back in terms of emission?
- What is the advantage of solar thermal heat as to other renewable sources?
- How did the danish people react when the first solar thermal park was being built and what is their current opinion on solar thermal heat?
- Will the output of solar collectors increase if they can rotate with the sun?
- How will solar collectors perform in the future? Will they out perform other renewable sources?
- What are the main advantages of solar thermal heat?
- What are the main disadvantages of solar thermal heat?

What is the cost of the development of one solar collector? The cost of one solar collector can not be given a price tag due to the price depending on a lot of parameters. When developing a solar thermal park, a business case is performed. The cash inflow and outflow are calculated, capex, maintenance during the time that the park is active, how much the heat generated will sell for, the efficiency of the park, loans with interest and more. It is hard to put a price tag on a solar collector because of all the variables possible in the mentioned parameters. The same goes for a park, it is hard to calculate exactly beforehand what a solar thermal park will cost.

Of course an indication can be made in the beginning based on previously built parks with roughly the same size, however, the exact price will almost always vary. It is important to note that the cash flow is positive from day one. Because of the subsidy and the fact that the park earns itself back in 15 years. After those 15 years, the park will start making profit and still be cash flow positive.

Who does the maintenance and what are the costs? The maintenance will be performed by the party that develops the park. In the case of Groningen, Solarfields is managing the project and Arcon Sunmark will produce the solar collectors and perform the maintenance. The costs of the maintenance are €1 per produced MW/h. The €1 covers everything, the maintenance but also the electricity for the pumps. The maintenance that the developing party performs starts at the solar thermal park and ends where it is connected to the DHN. From that moment on, the maintenance that has to be performed will be the duty of the DHN managing party.

What are the emissions of the development of one solar collector? The exact number in CO_2 is unknown to me, however, after 1 year of operating, the solar collector will have 'earned' itself back in terms of CO_2. Furthermore, the solar collector can be removed from the park and reinstalled in another park. In Exceter in London, a solar thermal park was built on an abandoned airplane runway, however, the project had to be moved. They have moved the entire solar thermal park, because the collectors can be removed and reinstalled easily. It is also possible to break down the collector to its components and sell the individual parts. A solar collector consists of aluminum, rubber, glass, copper and isolating material. The costs of the breaking down can be covered with the revenues gained from the selling of the parts.

In how many years does a solar collector 'earn' itself back in terms of emission? As said before, it takes one year for a solar collector to save the amount of CO_2 as it costs to produce one.

What is the advantage of solar thermal heat as to other renewable sources? The main advantage of solar thermal heat is that it is more efficient than other renewable sources. Solar thermal heat is 50-60x more efficient as to biomass, even with the most advanced biomass plant, solar thermal heat came out 37 times as efficient. Even when comparing solar thermal heat to PV, solar thermal heat is still 3-4 times as efficient. Furthermore, an other big advantage is that a solar thermal park will generate heat for at least 25 years. The oldest park is 31 years old, however, Arcon Sunmark guarantees at least 25 years of operation, but this is usually more due to no park that has been built being out of order.

How did the danish people react when the first solar thermal park was being built and what is their current opinion on solar thermal heat? In 1973 during the oil crisis, Denmark decided to be less dependent of other countries regarding the import of fossil fuels, gas, oil etc. This is when they started to invest in the development of DHN and in renewable energies. The government started taxing gas and this resulted in heat from renewable sources being cheaper. The first reaction of the danish people was positive because of the cheap heat it would produce and currently their opinion on solar thermal heat is still positive. They currently have over 1.3 million m^2 in solar thermal collectors and 66% of all the households are connected to a DHN. In Copenhagen around 99% is connected to a DHN.

Will the output of solar collectors increase if they can rotate with the sun? So this is an interesting question, in short: No. The current solar thermal collectors are based on the fact that they do not move. In 2016, a company approached us to start investigating in the possibility for the tracking of the sun with solar collectors. However, after looking into it, we decided not to continue the project due to us believing it would not be profitable. A different solar thermal developing company did engage in the project, however, the project is currently stopped due to not working and being to pricey. The reason that it is not working is because the collectors are not designed to move, the warm and cold water will mix if the collectors start to rotate and this will negatively influence the output. If such a system were to be designed, it should be made from scratch and not based on the existing model.

How will solar collectors perform in the future? Will they out perform other renewable sources? As said before, solar thermal heat is already out performing other sources. It is important to note that in an optimal future, the entire heat demand will never be covered by one renewable source. It will always be a combination of different renewable heat sources.

A solar collector is a relatively 'young' technology. It was patented in the late 70's, meaning that improvements to the system are always possible. However, the efficiency of a solar thermal park is dependent on the inflow and outflow temperature of the DHN. If this temperature can be optimized, the park will perform better too.

What are the main advantages of solar thermal heat? The main advantage is that the heat of the sun is completely free, only a DHN is required to transport the heat. Furthermore, it is currently the most efficient renewable source available in the world.

What are the main disadvantages of solar thermal heat? The information available on solar thermal parks is relatively low, in Denmark the awareness is high, however, in the Netherlands the awareness is very low. People do not know the difference between solar thermal heat and PV. Furthermore, the larger the park the better, but the smaller the park the less heat it will generate. A solar thermal park is expensive, but not more expensive than other renewable sources and the solar collectors perform significantly less when it is cloudy. They do operate when it is cloudy, but not near as good as when the sun is shining.

A.2 interview with Jelmer Pijlman

Jelmer Pijlman is the director at Solarfields, a solar thermal park project developer that is currently managing the development of the solar thermal park coming in Dorkwerd in 2022. The following questions have been asked to Jelmer:

- What are the costs of the development of a solar thermal park?
- What will the ROI be on the park?
- How much in subsidies is required to develop the solar thermal park?
- Who does the maintenance and what does it cost?
- What are the solar collectors positioned on and does it influence the nature?

- If the residents of Dorkwerd did not take legal actions, would the nature have been 'neglected' more?
- Are there any requirements to the implementation of the solar thermal park to the DHN?
- What is the general opinion of the residents around the to be built solar thermal park?
- How will the legal steps that have been undertaken by the residents be resolved?
- How long does the development of a solar thermal park take with the beginning being the idea and the end being the park?
- What are the parameters that have to be taken into account when developing a solar thermal park?
- What parameters are important for the municipalities when developing a solar thermal park?

What are the costs of the development of a solar thermal park? The costs are hard to determine, it is all based on a business case that will be performed in which all the cash flows are taken into consideration, capex and maintenance over the years. For every park it is very different and therefore, it can not be answered with a number per m^2. The park in Dorkwerd will cost around €25.000.000. In order to pay for everything, subsidies are required, a loan for about 80% of the costs will be needed and assets are used. The aim is that after 15 years, the park will earned the capex back and the loan paid off. Then the only costs that the park will have are the maintenance costs which are very low.

What will the return of investment be on the park? As said before, the return of investment aims to be after 15 years. After 15 years everything that the park produces, is considered profit.

How much in subsidies is required to develop the solar thermal park? Putting a number on how much is required is difficult, the only subsidy available for solar thermal parks right now is the SDE+ subsidy. They calculate a price based on how much heat the park will produce. This subsidy is granted for 15 years, however, withing 3 years of the granting of the subsidy, the park has to be realized or else the subsidy will be revoked.

Who does the maintenance and what does it cost? The maintenance in Dorkwerd will be performed by Arcon Sunmark, this is maintenance such as when a collector is broken or the antifreeze needs to be replaced. However, optical checks are also performed and these will be performed by us personally or by drones controlled by us. The chance that a collector breaks is very small, the biggest threat to collectors are very sharp rocks. Furthermore, the antifreeze does not need to be replaced theoretically, however, checks are still performed to be sure.

What are the solar collectors positioned on and does it influence the nature? There are two ways to mount the solar collectors to the ground. It is by either using profiles or using concrete strips. The profiles are the preferred method due to being the cheapest, most reliable and being the best for the nature. The profiles are placed in the ground and attached to the solar collectors. Push and pull tests are performed to calculate how deep the profiles need to go. Usually around 1 meter to 1.20 meters deep, however, in some cases it might be more. The other method to mount solar collectors is by placing them on concrete strips. This method is only used when the park is positioned upon a former dredge depot, or there is something in the ground that is not allowed to be pierced. For example, if a park is positioned on a former dump, the dump will be sealed with a certain seal and the profiles would breach this seal. The concrete strips do not. However, the concrete strips are relatively worse for the nature than profiles ,the actual impact of the concrete strips on the ground is near to nothing.

Are there any requirements to the implementation of the solar thermal park to the DHN? No, the only thing required to use the heat generated is a DHN. The park needs to be attached to the DHN and then the heat can be used.

What is the general opinion of the residents around the to be built solar thermal park? Both positive and negative. They think it is a good step forward in the energy transition, however, the residents living next to the park are negative. They think that the nature will be ruined by the collectors. The problem is that the residents are not actively trying to better understand how the park will look like in the end. Therefore, we have organised meetings for the local residents, a landscape architect has been hired to make a 3d sketch of how the park will look like. After seeing this, the residents are already more positive about the park because it will not be as big of an 'eyesore' as they think. The collectors will be placed 40cm apart from each other and the nature will be preserved. Goats and sheep will roam the area to prevent the grass from overgrowing and only once a month a visual check has to be performed. But as said before, these can be performed with a drone.

How will the legal steps that have been undertaken by the residents be resolved? The initial size of the project was a solar thermal park of 20 *ha*. After having had multiple meetings with the local residents, we have decided to reduce the size of the park to 11 *ha*. Furthermore, they feared that the nature would be ruined, therefore, we hired a biologist to perform a research in which every bird, animal, insect and flower were mapped. Then we did research on what the influence would be of the park on the habitat of those and the conclusion was that there would be no noticeable influence.

How long does the development of a solar thermal park take with the beginning being the idea and the end being the park? Usually, the entire process takes 3-5 years. 3 years are made possible to build the park once the subsidy is granted. But before the subsidy is granted, 99% of the park has to already be designed. The granting of the subsidy should be the starting shot for the building of the park. The building of the park can take less than 3 years, some only take 1 year. We expect that the building of the park in Dorkwerd will take 2-2.5 years.

What are the parameters that have to be taken into account when developing a solar thermal park? When developing a solar thermal park, a lot of parameters have to be taken into account. The development starts with a pre-feasibility study being performed. Here parameters such as location, ground, what finances are available, size of DHN and more are assessed. Then a feasibility study will be performed, the parameters are similar but some extra are added such as possible heat generation and tillage. Once the municipality agrees on that a solar thermal park is going to be built, the design is made. The amount of collectors are calculated, what type of park is it going to be, size of heat storage, amount of heat, costs etc. Once this all has been performed, the park will be built once the subsidy is granted.

What parameters are important for the municipalities when developing a solar thermal park? When a municipality approaches us for a solar thermal park, they always have the following points: They want to participate in the energy transition and have considered solar thermal heat as a viable option. The price of the park is the most important factor to them and after the price, the safety chain is important to them. The safety chain meaning the guarantee that the projected heat generation also will be distributed. The price for them is important in terms of NPV and IRR. These are calculated according to the business case that is performed for them.

A.3 Interview with Theo Venema

Theo is projectmanager at Warmtestad. Warmtestad is the owner and manager of the DHN in Groningen. The following questions have been asked to Theo:

- What is a district heat network?
- How much does heat generated by solar thermal parks cost compared to other renewable sources?
- Will the amount of DHNs in the Netherlands increase due to the climate agreement?
- If the amount of heat generated by renewable sources drastically increase, will the DHNs have to change to cope with the increased supply?
- Are there any functional requirements for the implementation of a solar thermal park to an existing DHN?
- Are there any requirements for the households?
- Is it mainly focused on flat buildings currently? Will the near future provide feasible solutions for the heat distribution for houses that are further apart?

- What are the current developments regarding heat storage?
- What is the current composition of heat supplied? (% of heat from what source)

What is a district heat network? In short, a DHN is a network of underground tubes that transport warm water from different sources to buildings. Once the heat has been discharged, the cold water is disposed of via a different tube. The tubes consist of a steel inner tube, an isolating layer consisting of pur and then covered with waterproof polyethylene. On average, the tubes last around 50 years.

How much does the heat generated by solar thermal parks cost compared to other renewable sources? This is a difficult question to answer, the price is based on different factors such as the size of the park, the efficiency, output etc. Because the park being built currently in Groningen is not generating heat yet, it is still difficult to assess this. The heat that will be supplied to the households will have a fixed price. This is not influenced by whether solar thermal heat was larger in output than biomass during that period or whatsoever. But since solar thermal heat is more efficient than other sources, it can be assumed that the price per MW might be lower.

Will the amount of DHNs in the Netherlands increase due to the climate agreement? So the energy transition in the Netherlands is interesting. More municipalities are looking into alternative ways to generate heat. With the climate agreement and the Paris agreement, an acceleration is forced. In order to use the alternative/renewable sources for heat generation, a DHN is required. So yes, I think that the amount of DHNs in the Netherlands will increase. We have noticed it already here in Groningen.

If the amount of heat generated by renewable sources drastically increase, will the DHNs have to change to cope with the increased supply? So if the amount of heat generated would increase, in theory the DHN would not have to be changed. If the supply increases, the storage should be able to cope with the excess heat, else it is just lost heat. The amount of heat that is demanded by the households is relatively the same throughout the years. It might deviate with a few %. However, if a DHN expands, the heat demand will increase and then the supply should in turn also be able to increase. So for example, with the solar thermal park that will come in Groningen, the temperature of the inflow will be around 70 °C and the outflow will be around 50°C. The DHN of paddepoel has been expanded to use the heat that will be generated.

Are there any functional requirements for the implementation of a solar thermal park to an existing DHN? No, once a solar thermal park has been developed, it can be connected to the DHN and then the heat can immediately be distributed. There are no requirements to the network or to the park required.

Are there any requirements for the households? The only requirement for a household to use the heat supplied by the DHN is a heat exchanger. A heat exchanger is a device that keeps the hot inflow and the cold outflow separate, but enables the usage of the heat. There is a small loss in heat, in Groningen 75°C is supplied and 73 °C is actually used. Currently, only flat buildings are heated with the DHN. Normally, every household would have to have a heat exchanger, but in the case of a flat building, only one heat exchanger for the entire building is required.

Is it mainly focused on flat buildings currently Will the near future provide feasible solutions for the heat distribution for houses that are further apart? Currently, as said before, only flat buildings are heated. This is because the heat loss when connecting houses that are more than 4 meters apart, is too big currently. The near future does provide feasible solutions, Denmark is far ahead in the development of their DHNs. Around 60-70% of all households are connected to a DHN. This also includes remote houses, so yes there are solutions possible. Furthermore, it is required for new residential areas, that the houses built there are connected to a DHN. And there also might be a possibility that the Dutch government will tax the natural gas, just like Denmark did, to increase the price of natural gas and reducing the price of the other renewable sources. What is difficult is that the development and expansion of a DHN costs a lot of money, but if you make the DHN too big and the heat from renewable sources can not supply the heat demand, it gets even more expensive. It is key to find an optimum in the amount of heat that is supplied, the heat that is demanded and what will follow in the future.

What are the current developments regarding heat storage? The developments of the heat storage are mainly focused on whether the storage can cope with the heat generation peaks, such that it can be evenly distributed afterwards when the demand is higher. If the peaks can not be coped with, the heat will be lost. We use a 'WKO' storage, a hot and cold storage. This is a system that uses the excess heat in the summer to heat up ground water and in the winter when the heat demand is higher, we use the heated ground water to heat the households.

What is the current composition of heat supplied? (% of heat from what source) So currently, we are awaiting the development of a sustainable power plant. So therefore, the current composition is a natural gas powered engine that produces electricity and residual heat. When the power plant has been developed and the solar thermal park has been realized, the composition will be a combination of solar thermal heat and residual heat from a data centre.

B Appendix B

B.1 Different type of solar collectors

Described below are the three different kind of solar heat collectors that can be utilized for heat generation and supply to a DHN. However, $> 99\%$ of the solar heat collectors used are flat plate collectors because of certainty, safety and lowest € per MW/h (Pandey & Chaurasiya, 2017).

B.1.1 Flat plate collectors

The solar energy is transformed into heat by the absorber which is located in the inside of the solar collector. It absorbs the solar heat and transmits it to a frost-resisting liquid which circulates in a system of pipes. The heated liquid is lead to a warm water tank, store tank or a separate heat exchanger. Temperature range: 0-120°C

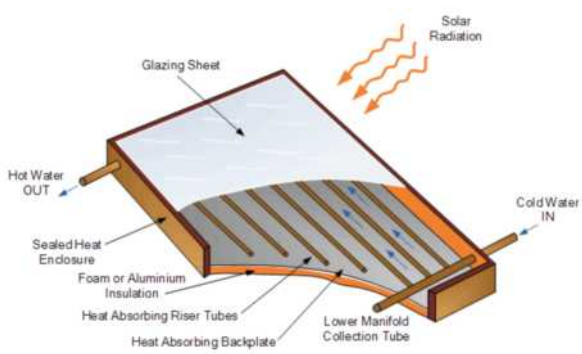

Figure 4: *A graphic representation of a flat plate collector*

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B.1.2 Evacuated tubes

Evacuated heat pipe tubes are composed of multiple evacuated glass tubes each containing an absorber plate fused to a heat pipe. The heat from the hot end of the heat pipes is transferred to the transfer fluid of a domestic hot water or hydronic space heating system in a heat exchanger called a ‘’manifold”. The EVT is preferred in domestic heating (Sabiha et al., 2015). Temperature range: 0-150°C

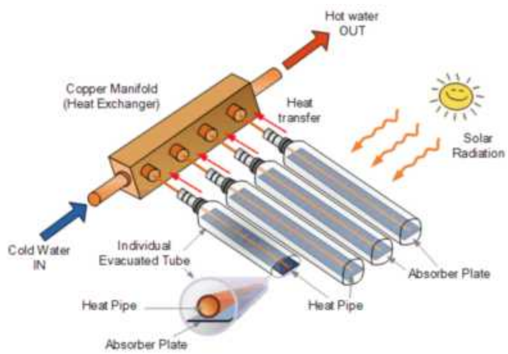

Figure 5: *A graphic representation of an evacuated tube collector*

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B.1.3 Parabolic

A trough-shaped parabolic reflector is used to concentrate sunlight on an insulated tube (Dewar tube) or heat pipe, placed at the focal point, containing coolant which transfers heat from the collectors to the boilers in the power station Temperature range 0-400°C.

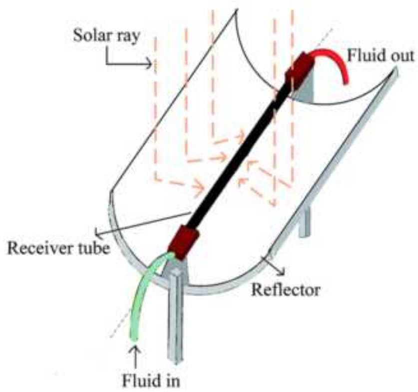

Figure 6: *A graphic representation of a parabolic collector*

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B.2 Mounting systems

There are two ways to mount the solar collectors to the ground:

- Profiles
- Concrete strips

Profiles are long metal 'spikes' that are inserted into the ground. Profiles are the preferred method to mount the solar collectors due to being cheaper and they preserve the nature more than the concrete strips.

Figure 7: *Solar collectors mounted using profiles*

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The other method to mount solar collectors, is by making concrete strips that keep the solar collectors on the ground. Concrete strips are used in a few specific situations: When the park is situated for example on a former garbage heap, dump or dredge depot. When there is a foil situated on the land that may not be pierced, concrete strips are used.

Figure 8: *Solar collectors mounted using concrete strips*

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In addition to the mounting systems, the solar collectors can not track (Sabiha et al., 2015). Tracking means following the sun. The reason that this is not possible is due to the movements of the collectors allowing contamination of the cold water inflow and the hot water outflow. The entire mechanism of the current solar collectors is based on not being able to move, in order to try to make it possible major adjustments have to be made to the existing model. In Brive-La-Gaillarde, France, there is a solar thermal project investigating the possibility of tracking with solar collectors. They use 3024 $m2$ of solar collectors on tracking systems, however, the project is currently ceased due to technical issues that have arisen because of the tracking (Interview with Peter Eijbergen, Appendix A.2).

B.3 Heat storage

During the daytime, most heat is generated and the demand is lower and during the night the heat generation is lower and the demand of heat is higher. In the summer, more heat is generated and the demand is lower and in the winter the heat generated is less and the demand is higher. In order to compensate for these differences, heat storage is being utilized. Note that not every park has heat storage. There are two forms of storage: Day storage and Seasonal storage. In Day storage, a large cylindrical storage unit is placed near the solar thermal park. The capacity of this storage unit is calculated depending on the size of the park and the heat demand. Water is transported from the solar thermal park to the households connected to the DHN. If the generation of heat in the summer is larger than the demand, the excess heat will be stored in the day storage. Once the heat demand rises, usually in the evening and night, the stored heat will be provided to the households (More on this in Appendix B.4 (Type 2 park).

Figure 9: *A cylindrical daily storage tank*

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Seasonal storage is the storing of heat that is generated during the summer and then distributed during the winter. Seasonal storage can be done in two ways. The first possible way is by storing through hot- and cold storage, also called a ''WKO", Warmte- koud opslag. This system uses the heat generated in the summer, to heat groundwater up to a certain degrees centigrade and when in the winter the demand is higher uses the heated groundwater to heat the households. This is the preferred method in the Netherlands.

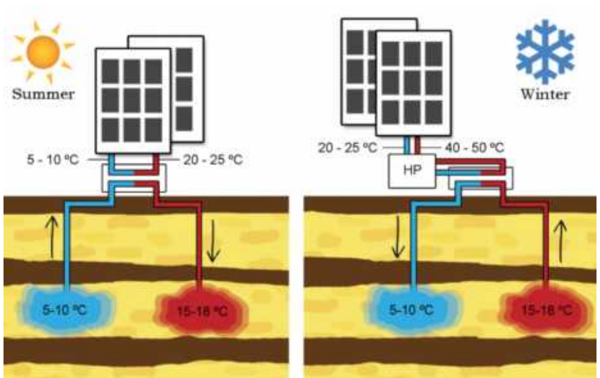

Figure 10: *a graphical representation of the WKO seasonal storage*

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The other option is to use an artificial pond. This pond usually has a depth of around 70cm, an insulating layer is placed on the ground and then filled with water. The water will be heated during the summer with the excess heat and in the winter this heat will be distributed to the households Appendix B.4 (Type 3 park). This is the preferred method in Denmark.

Figure 11: *A 60.000* m^3 *seasonal storage in the construction phase. located in Dronninglund, Denmark*

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B.4 Different types of solar thermal parks

Currently there are three different types of solar thermal parks that are being utilized throughout the world. The parks throughout the world vary in whether they utilize storage or not. Because of this there are currently three types of possible solar thermal parks:

B.4.1 Type 1

The first type is the simplest, it consists of a large field of solar collectors, they collect heat and then the heat is transferred to the heat network through a heat exchanger. The heat is then transported to the households connected to the heat network. This type of solar park is able to supply the heat network with around 1 % or 2 % of the heat demand (Schmidt et al., 2004).

B.4.2 Type 2

The second type uses a technical building and a storage tank. The technical building is a construction where all the calculations by computers are done to optimize the heat collection. The heat is collected, is transported to the technical building, enters the heat network and supplies the heat. Afterwards the heat is returned to the tank and stored there, also called 'daily storage'. The size of the tank will be calculated depending on the size of the collector field, amount of heat that will be generated and on the land it is situated on (Interview with Peter Eijbergen, Appendix A.2). The type 2 solar thermal park covers up to 20% of the heat demand. (Schmidt et al., 2004)

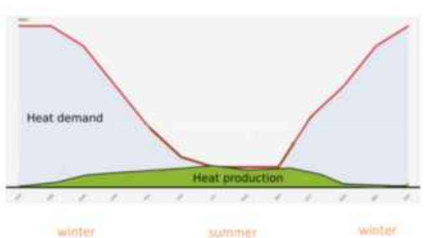

Figure 12: *A representation of the heat produced and the heat demand. Note that the production in the winter is very low, whereas the demand during that period is very high compared to the summer (Arcon Sunmark 2019).*

B.4.3 Type 3

The third type is quite similar to the second version. It is bigger and has daystorage, but also a seasonal storage. A big pond has been dug and covered with foil and an insulating layer. The heat is collected, transported to the technical building, enters the network and supplies the heat. Excess heat will be transported to the daystorage. During the summer, when the daystorage is filled and the demand of the DHN has been satisfied, the excess heat will be transferred to the seasonal storage. When the demand is higher than the supply (usually in the winter), heat can be transferred from the pond to the heat network. This type of park also works with the ''WKO" as described in Appendix B.3. This type of solar thermal park can supply around 50-55 % of the yearly demand (Schmidt et al., 2004)).

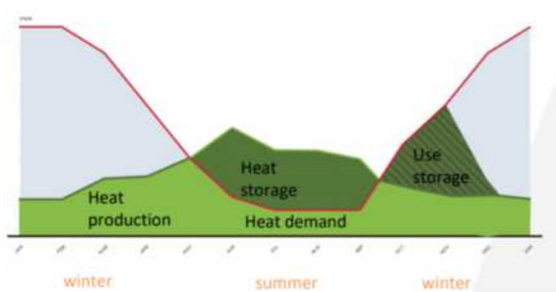

Figure 13: *A representation of the heat produced and the heat demand. Note that the excess heat that is stored during the summer is utilized during the winter. The seasonal storage system covers a large part of the demand during the cold period after the summer (Arcon Sunmark 2019).*

C Appendix C: The guide

In the following appendices, the guide to large-scale solar heat collection is presented. The guide consists of first showing a timeline of the development of a solar thermal park. The timeline shows the different stages and decision making moments. The pre-feasibility stage, the feasibility stage, the design stage and the implementation stage. Afterwards a SWOT analysis is performed to showcase the pros and cons of a solar thermal park. Finally, a financial analysis is performed in order to give an indication on what a solar thermal park will cost and what the financial benefits and ecological benefits will be. The guide is split up in 3 parts, the development, SWOT analysis and Financial analysis. This is done such that the reader can easily switch between each part.

C.1 Timeline of the development of a solar thermal park

A timeline will be presented that provides the lay-out of the development and implementation of a solar thermal park. The development will be divided into 4 stages: The pre-feasibility stage (Appendix C.2) , the feasibility stage (Appendix C.3), the design stage (Appendix C.4) and the implementation stage (Appendix C.5). Between every stage, a decision making moment will take place, the course of events differ per municipality. At the decision making moment, a report will be presented to the decision making party with the parameters taken into consideration, decisions that need to be made and what will happen in the next stage. This guide will provide what the contents of the report should require which will be presented to the decision making party. This is done in order for the decision making party to make a decision without them having no knowledge of important aspects of that particular stage. The timeline will show the different stages and decision moments that a municipality will face during the process. At the end of the implementation stage, the solar thermal park will be completed and ready to start collecting heat. The duration of the first three stages can differ, there is no time limit on the duration. However, the maximum duration of the implementation stage is 3 years in the Netherlands due to the subsidy regulations. This is elaborated on in Appendix C.2.4 .

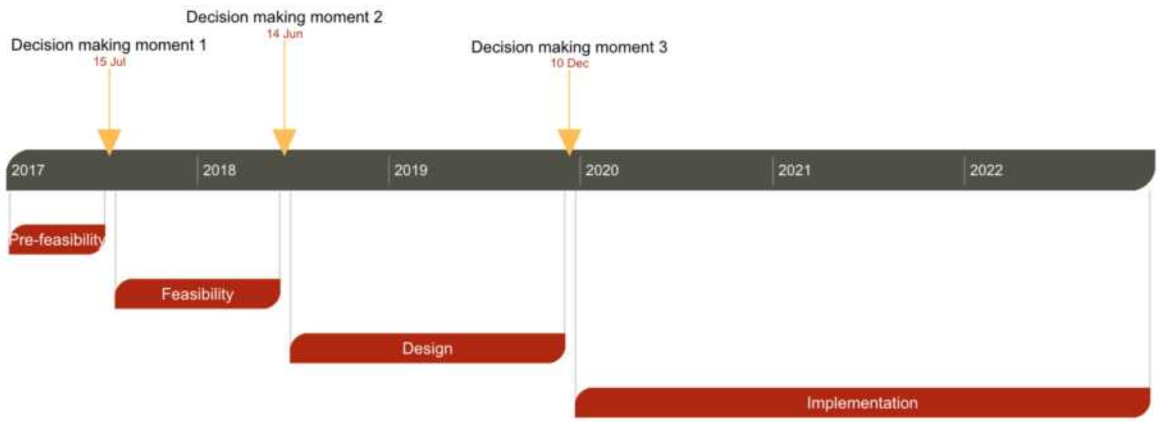

Figure 14: *Timeline of the entire process. The red task bars represent the stages of the entire process. The yellow indicate the decision making moments, the added dates are as an example.*

C.2 Stage 1: The Pre-feasibility stage

The first stage of developing a solar thermal park can be considered as the pre-feasibility stage. This is the stage where a solar thermal park is being considered and a rough idea of what this would entail is going to be presented to the municipality board. Some parameters are considered in this stage in order to provide sufficient information such that a decision can be made on whether to continue with the development or not. This stage includes the following elements:

- Locations
- Ground
- Budget and financing
- Presence of a DHN
- What type of park?

The parameters will be elaborated on individually at each stage, because after every stage the parameters change or the existing parameter is deepened in. The goal of the pre-feasibility stage is to gather the information to check whether a solar thermal park is feasible in broad lines. By making a report with the parameters said above, the decision making party should be able to make a decision on the continuing of developing the solar thermal park.

C.2.1 Location

The first parameter that should be considered is the possible locations where a solar thermal park can be placed. Available pieces of land should be mapped, this could be locations owned by the municipality and managed by a third party, or private owned lands. It is advised that mainly land owned by the municipality is mapped, because privately owned lands will require either the purchasing of the land or a deal to be made. The identification is done by looking at large areas of land, that currently have no particular function. Examples of such locations are former dredge depots and land that is not being used for agricultural purposes, but also nature reserves can be used, since the land where the park is placed on has no influence on the nature and its inhabitants.

C.2.2 Ground

Once the locations have been mapped, it is necessary to identify what sort of soil the location mainly consists of. The different types of soil have an influence on the placement of the potential solar collectors as described in appendix A and also if the placement of solar collectors is even possible. It is not necessary to come up with an exact composition of the soil, however, the main component should be identified. Most municipalities have a map containing the main component of soil of every location in its municipality, identification should not be a big obstacle. When developing a solar thermal park, differences in height are not an issue. Every sort of landscape can be used for a solar thermal park, however, the differences in height may have to be accounted for. Some parts will be reduced in height whereas other parts will be heightened. This is not a problem, however, this does have costs associated with it. Therefore, the identification of height differences in the potential locations is strongly advised, since this may already exclude certain potential locations.

C.2.3 Budget and Financing

The development of a solar thermal park is expensive. Not only size affects the price of the park, but also the type of park, storage. However, this is elaborated on in Appendix E. Currently, in the Netherlands, the RVO extends subsidies for the development of solar thermal parks. This subsidy, called the SDE+, is calculated according to the amount of kW the park produces. The formula for the thermal capacity of the park is:

$$A * 0.7 = T_c \tag{1}$$

Where A is the area of the solar collectors in m^2 and T_c is the thermal capacity in kW. The subsidy is only available for solar thermal parks that produce more than 140 kW (RVO, 2019). The subsidy is then calculated according to the following table:

	Phase 1 from 29/10/2019, 09.00h until 04/11/2019, 17.00h	Phase 2 from 4/11/2019, 17.00h until 11/11/2019, 17.00h	Phase 3 from 11/11/2019, 17.00h until 14/11/2019, 17.00h	Basic energy price	Provisional correction amount 2019	Max. full load hours per year	Max. duration subsidy (years)	Commissioning deadline at the latest (years)
Sun	Maximum basic amount / phase amount (€/kWh)	Maximum basic amount / phase amount (€/kWh)	Maximum basic amount / phase amount (€/kWh)	(€/kWh)	(€/kWh)			
Solar thermal Thermal capacity:								
- ≥ 140 kW and < 1 MW	0,090	0,098	0,098	0,025	0,032	700	15	3
- ≥ 1 MW	0,085	0,085	0,085	0,019	0,026	700	15	3

Figure 15: *SDE+ calculation table. The figure shows the difference in subsidy granted per phase.*

In order to clarify the table, an example is presented:

Maximum phase amount phase 1 (free catagory)	8,5 €ct/kWh
Maximum basis amount from phase 2	8,5 €ct/kWh
Provisional correction amount 2019	2,6 €ct/kWh
Provisional subsidy SDE+ 2019 With phase 1 request at 9,0 €ct/kWh	8,5 – 2,6 = 5,9 €ct/kWh = 59 €/MWh
Provisional subsidy SDE+ 2019 With phase 2 request at 9,8 €ct/kWh	8,5 – 2,6 = 5,9 €ct/kWh = 59 €/MWh
Max. full load hours per year	700
Thermal capacity of an installation with a total collector surface of 11000 m²	11000 * 0,7 = 7700 kW
Max. eligible yearly production with a thermal capacity of 7700 kW	7700 * 700 = 5390000 kWh = 5390 MWh
Provisional subsidy SDE+ 2019 With phase 1 request at 9,0 €ct/kWh	59 €/MWh * 5390 MWh = € 318.010
Provisional subsidy SDE+ 2019 With phase 2 request at 9,8 €ct/kWh	59 €/MWh * 5390 MWh = € 318.010

Figure 16: *Example of a solar thermal park with a capacity of 7700 kW. The table shows the amount of subsidy that will be granted in the different phases described in figure 9, however, for parks above 140 kW the price is the same in both phases as shown in figure 10.*

Note that the subsidy is granted for 15 years, however, the commissioning deadline is 3 years. This results in that the project has to be realized within 3 years in order for the subsidy to be fully granted. Furthermore, potential investors and banks that are able to provide loans should be identified.

As of 2020, a change to the current SDE+ as described in figure 9 and shown in figure 10 will change. The changes are not official yet, however, the provisional changes have been published. The phase amount in 2020 will change from 8,5€ct/kWh to 8,0€ct/kWh and the amount of max. full load hours per year will change from 700 to 600.

Maximum phase amount 2020(preliminary for parks >1MWth)	8,0 €ct/kWh
Provisional subsidy SDE+ 2020 With phase 1 request at 8,0 €ct/kWh	8,0 – 2,6 = 5,4 €ct/kWh = 54 €/MWh
Max. full load hours per year	600
Thermal capacity of an installation with a total collector surface of 11000 m²	11000*0,7=7700 kW
Max. eligible yearly production with a thermal capacity of 7700 kW	7700 * 600 = 4620000 kWh = 4620 MWh
Provisional subsidy SDE+ 2020 (preliminary for parks >1 MWth)	54 €/MWh *4620 MWh = €249.480

Figure 17: *Example of a solar thermal park with a capacity of 7700 kW. The table shows the amount of subsidy that will be granted in 2020 according to the provisional changes.*

C.2.4 Availability of district heat network

As stated in the introduction, the availability of a DHN is an option to utilize the solar heat. The distance of the solar thermal park to the DHN should be minimized if possible. Heat is lost when transporting from the solar heat park to the DHN. This heat loss is usually very small, around 2 % (Interview with Theo Venema, Appendix A.3), however, the further the distance, the bigger the heat loss. Whilst mapping the availability of the DHN, it is also important to determine the amount of households connected to the DHN. This can easily be determined by requesting the information at the DHN manager. Once having determined the amount of connected households, the municipality can start thinking about the percentage of households connected to this DHN they wish to heat with the solar thermal park.

C.2.5 Type of park

As stated in section 2.9, three types of park are available for development:

- No storage (type 1)
- Daily storage (type 2)
- Seasonal storage (type 3)

During the first stage, the type of park that the municipality wants to be built should be considered. The amount of households connected to the DHN that the municipality wishes to provide with solar heat has an influence on which type of park might be the most suitable. Factors such as available funds and size of the location also have an influence on which type of park can be built.

C.2.6 Participants during pre-feasibility

The following section will focus on the parties involved in the first stage. The first stage can also be seen as an exploratory stage. The designated party wants to see if solar thermal is more than just an idea for their municipality and therefore starts by exploring, identifying and mapping certain parameters. During this stage, it is advised that the following parties are involved. Their expertise will result in good understanding of the parameters. Collaborating from the beginning will result in better mutual understanding of the project in later stages. The parties involved during this stage are:

- District heat network manager
- Potential location owners/managers
- Potential project developers

The district heat network manager should be involved at this stage due to having data on the DHN such as number of households and average heat demand per household. This is of importance because this has an influence on the size of the to be developed park. Without this information it is not possible to assess the amount of heat that has to be produced. The location owners or managers should be involved because if a park is to be developed, this will result in changes to their property. The location is the most important aspect of the first stage, without a location there is no possibility that the park can be developed. The owners or managers should be informed actively on the potential changes to the land. Potential project developers should be involved at this stage because of their expertise. They can already at this stage give advice on what type of park would be the best fit for the amount of households the municipality possibly wants to heat and help assess potential locations.

C.2.7 First decision making moment

At the end of the pre-feasibility stage is the first decision making moment. This is the moment that a report has been developed which consists of the parameters described above supported with expertise from the involved parties. The report can have different forms, this is up to the presenting party to decide which form is the best for their targeted audience, however, the report should have the following contents:

- Economical risk analysis
- Location
- Project developer

An economical risk analysis should be performed, at this stage there are still a lot of factors unknown which will influence the price of the park, but it is important that the economical risk is assessed broadly. This should contain an indication of the payback period, potential financing options and potential banks for loans. The price of the park can not be exactly determined at this stage, however, the prices of previously built solar thermal parks can give an indication on the final price. Note that when using data on other parks, differences in for example solar fraction and solar hours Appendix C.3.3 should always be accounted for. The numbers should always be in ratio. Furthermore, a decision should have been made on the location as well as on the project developer and should be included in the report. It is important to include the parameters in the report because it will show the decision making party the size the development. If the report contains the elements stated above, it should be presented to the local council. They will have to decide whether to continue with the development of the solar thermal park. Once the local council has decided on the continuation of the development, the next stage can be entered, which is the ''Feasibility" stage.

C.3 Stage 2: The feasibility stage

In the second stage of the development of a solar thermal park, a feasibility study has to be performed. At the end of the stage a report with the feasibility study will be presented to the decision making party. During this feasibility study, the following parameters are of key importance and should be included. The parameters are:

- Solar fraction
- Possible heat generation
- The amount of households to be heated
- Tillage
- Type of park
- Decision on location
- The subsidies and loans required.

These parameters should be included because they show the amount of collectors that will be required, the size of the project and how it will be financed. This will make it possible for the decision making party to visualize the project better. The following section will individually elaborate on the parameters to provide the information required to conduct the feasibility stage.

C.3.1 Location

At this stage, the location for the solar thermal park should be determined. This is required in order to further investigate the amount of heat that can be generated and the amount of households that will be heated with this amount. It is also important that the location is determined because of potential tillage activities which are needed to perform. The location selection should be done together with the DHN manager and the project developer, with their expertise the correct location can be chosen. Once the location has been determined, the solar fraction, possible heat generation and amount of households to be heated can be determined as well as what type of park it will be and the costs associated with it.

C.3.2 Solar fraction

As stated in section 2.3, solar heat collection is the harvesting of the sun's heat and supplying it to the connected households. The annual load factor covered by solar energy compared to the total annual thermal load is called the Solar fraction. This can be calculated with the following equation:

$$F = \frac{(L - Laux)}{L} \tag{2}$$

Where F is the force, L is the annual energy required by the load (GJ) and $Laux$ is the annual energy required by the auxiliary (GJ). In other words, F is a ratio between the useful solar energy supplied to the system and the energy required to heat the water or the building space if no solar energy is used (Kalogirou, 2013). Although a country such as the Netherlands is relatively small, the yearly number of sun hours differs with more than 10%. For example: Groningen has around 1450 hours of sun every year, whereas Texel has up to 1650 hours of sun per year (T. RVO, 2019). Therefore, the solar fraction calculation has to be performed and also the amount of sun hours per year have to be determined. This calculation and determination will be performed by the project developer, combined with the amount of heat to be generated and the amount of households to be heated.

C.3.3 Amount of households to be heated

The heat generated by the solar thermal park will replace or compensate for a reduction in a different heat source. In order to calculate the amount of households that will need to be heated, the following will be done: The DHN manager will first remove or reduce the heat generation from a different source (As stated in section 2.1, heating through gas will most likely be reduced/removed), the reduction in heat capacity will be calculated and this amount will have to be generated through the solar thermal park. For example: City A has a DHN that utilizes gas, biomass and rest heat. The DHN has a demand of 1000 MW/h and this can be supplied with the current composition. However, City A decides to implement a solar thermal park. The gas is removed from the DHN, the demand is still 1000 MW/h, but the DHN can only supply 750 MW/h with the current composition. Therefore, the solar thermal park has to supply 250 MW/h in order to meet the demands. The DHN manager can convert the ''missing" 250 MW/h in amount of households that have to be heated with the solar thermal park. Calculating the amount of households that need to be heated is important for the heat generation, the size of the park and the type of park.

C.3.4 Possible heat generation

After having chosen a location and calculating the solar fraction, the number of solar hours per year and the amount of households to be heated, the size of the park can be determined. This will be done by the developer of the solar park and the DHN manager. The DHN manager is involved because the distance from the solar heat park to the DHN influences the amount of heat that is preserved and the temperature at which the heat enters the system and exits the system has an influence on the efficiency. The solar park developer will calculate the maximum amount of heat that can be generated by combining the size of the location, solar fraction, solar hours, distance to the DHN, the inflow and outflow temperature and the amount of households to be heated. The size of the park will be determined based on the size of the location and the heat that will be generated.

C.3.5 Type of park

Section 2.9 describes three parks and their differences compared to each other and in section 3.1.5 a short description of factors that influence the choice of park have been highlighted. The three parks differ in the storage system. The seasonal storage makes it possible to store heat in the summer and use it in the winter. This kind of system has the possibility to supply the most heat. The type of parks differ in price, no storage is the cheapest and seasonal storage is the most expensive. The type of park will have to be determined together with the solar park developer. The expertise they possess, combined with the amount of households to be heated, the available funds and size of the location will result in a decision on which type of park would be the best fit.

C.3.6 Tillage

A thorough investigation has to be performed on the ground of the location and whether any tillage is required. As stated in appendix A, the solar collectors can be mounted in two ways:

- Profiles
- Concrete strips

A decision has to be made on whether concrete strips will be used or profiles. The preferred mounting system is profiles since it is cheaper and uses less ground, however, if this is not possible due to factors described in section 2.5, concrete strips should be considered. If the mounting system is decided on, it is necessary to investigate the ground. The mounting systems do not require the ground to be level, however, large differences in height have to be accounted for. The investigation will be performed by the solar thermal park developer and a third party that specializes in tillage.

C.3.7 Subsidies and loans

After having calculated the amount of houses that need to be heated, the amount of heat the park will generate (in MW/h) and the type of park, the subsidy can be calculated. Currently the RVO is the only instance that provides subsidies for solar thermal parks, called the SDE+ (described in section 3.1.3). The calculation for the amount of subsidy that will be granted can be performed according to figure 1 and figure 2 in section 3.1.3. After the SDE+ subsidy has been calculated, the remaining costs will need to be covered. In order to cover the remaining costs, a loan is required and if the loan does not cover all the costs, assets can be used to cover the rest. At the beginning of the park, the costs will be higher due to the interest, however, after 15 years the park will have yielded enough to cover the initial expenses and then the costs will be far lower due to no interest having to be paid anymore and only maintenance being an expenditure. The costs of maintenance is elaborated on in section 5.1.5 and section 6.1

C.3.8 Participants during feasibility stage

The following section will cover the parties involved during the second stage of the development of a solar thermal park. Where stage 1 was more exploratory, the second stage is meant to perform a feasibility study for the solar thermal park development. The following parties are advised to be incorporated in this stage. The parties are able to perform skills that a municipality on its own would not be able to perform. The parties are:

- Project developer
- District heat network manager
- Ground/tillage expert
- Loan granting parties

The project developer is included because its expertise is required to come up with the optimal solar thermal park. The district heat network manager is now also actively involved in the development because the amount of heat generated and the temperature of the inflow and outflow influences the price of the heat. A ground/tillage expert is required to inspect the ground and to come up with a report containing information on what kind of activities are required. The last party is stated as the loan granting parties, this is because per situation this changes. In some situations a bank will provide the loan and in other cases this will be done by private companies or with equity. The subsidy granting instance is also included in the loan granting parties. A landscape expert can be hired to visualize the upcoming project for the local residents. This is not required, however, local residents often have trouble visualizing the solar thermal park. A solar thermal park can be designed in two ways: the first way is by showing it to the world ('Het zoneiland' is an example of this, they have a busroute through the solar thermal park) and the second way is by hiding it (the solar thermal park to be developed in Groningen is going to be hid away by a tall hedge around the perimeter of the park). It is up to the municipality whether the park will be visible or not, the landscape expert will visualize this for local residents. This will help in preventing legal actions being undertaken to potentially obstruct the development.

C.3.9 Second decision making moment

At the end of the feasibility stage is the second decision making moment. The report that will be presented should have the same form as the first report, again, the form should be decided on by the presenting party. The report should at least contain the following elements:

- A clear outline of the solar thermal park
- Which DHN to be heated
- Financial overview

. The outline of the park should include the size of the park, the amount of collectors, type of park, the amount of heat that will be generated, the temperature inflow and outflow and size of the storage (if a type 2 or type 3 park is chosen). In the report it should be made clear which DHN it will heat, what the new composition of the DHN will be and how many households will be heated. In order to come up with a clear design, the following flowchart has been made to simplify the process. A financial overview should be included in the report, containing the costs of the park as well as the amount of subsidy and the loans. But also containing the internal rate of return (IRR) and the net present value (NPV). The IRR and NPV are two important factors and not including these in the report will increase the chance of the decision makers not continuing the development of the solar thermal park. Once the report has at least the following elements, it can be presented. Per municipality it can differ which parties are involved in the decision making, however, most likely it will be the local council, a councilor, the mayor and the fire department and police. The last parties are always involved with big projects in order to provide safety regulations. When the decision parties have decided on the continuation of the development, the third stage can be entered, which is the ''Design" stage.

C.4 Stage 3: The design stage

In the third stage of the development of a solar thermal park, the entire design of the park will be made. Where the first stage was exploratory and the second stage was to check whether its feasible, the third stage is meant to design the solar thermal park in detail. In this stage, the majority of the tasks will be performed by the project developer, however, a close cooperation should be maintained in order to prevent mistakes and miscommunications. The report that will be presented at the end of the third stage should at least contain the following elements:

- The type of park
- Calculations to be performed
- The amount of heat (in MW/h)
- Costs
- Subsidies and financing
- Local residents

C.4.1 Amount of collectors

As stated in Appendix C.2.3, the amount of collectors is dependent on the thermal capacity. The exact amount of collectors will be calculated by the project developer, however, recall Appendix C.2.3 that the formula for the thermal capacity is :

$$A * 0.7 = T_c. \tag{1}$$

Therefore, if the thermal capacity is known (this has been calculated in the feasibility stage by the project developer and the district heat network manager), then the amount of collectors can be calculated with the following:

$$A = \frac{T_c}{0.7} \tag{3}$$

There is a chance that the amount of collectors, calculated according to the equation above, will differ with the final amount determined by the project developer. This can be due to all of the factors described in the feasibility stage, but also because of local residents. This shall be elaborated on in Appendix C.4.7

C.4.2 Type of park

As described in Appendix C.3.5sections 3.1.5 andAppendix C.4.5, the types of park differ in size and storage. At this stage, it should be evident which park is going to be opted. The main elements to keep in mind are the price of the park and the amount of heat to generate. However, if a thorough economical risk analysis has been performed during stage 1 and during stage 2 the subsidies have been calculated and the loans have been identified, it should not be a problem. Furthermore, the layout of the park can also be assessed during this stage. This will be done in cooperation with the project developer. However, it is recommended to actively think about locations, size of storage and about the mounting system. For example: are all the collectors going to be mounted with profiles, or concrete strips, or a combination of both? The optimal combination will be calculated by the project developer, but remaining active during the process will result in good cooperation.

C.4.3 Calculations to be performed

As the designing of the solar thermal park has been started, a lot of calculations have to be performed. These are:

- Ground pressure
- Temperature of inflow and outflow

The ground pressure is the amount of force exerted over a certain amount of area. The formula is the following:

$$P = \frac{F}{A} \tag{4}$$

Where P is the pressure in Pa, F is the force in N and A is the area in m^2. It is important that the amount of pressure is calculated, a too high force exerted on the available area will result in slippage of the area or topsoil compaction. The project developer will perform push pull tests with the profiles that will determine the length of the profiles. Other calculations include: The distance between the solar collectors, the temperature inflow and outflow of the system and the amount of tubes (in m) required to transport the heat from the collectors to the DHN. The distance between the solar collectors is usually 70 cm, however, different factors such as the lay of the land, available ground and input from local residents Appendix C.4.7 can influence the distance between the solar collectors and therefore, the optimal distance has to be calculated.

The temperature at which the inflow will enter the DHN and the outflow leaves the DHN has to be calculated. As previously mentioned, the inflow temperature and outflow temperature influence the efficiency of the solar thermal park and therefore, influence the price of the heat. When heat enters the DHN at a temperature of 90 °C and leaves the DHN at 70°C, the difference (Δ) is 20 °C, however, if heat enters the DHN at 70 °C and leaves the DHN at 50 °C, the Δ is still 20 but the overall system is more efficient. The reason for this is because the temperature difference between the inflow and the outside air will always result in cooling down of the inflow. However, if the temperature difference is larger, the cooling down will also be larger. Thus, the more energy it takes to maintain the inflow at the set temperature. The key to the most efficient system is to aim for the highest possible Δ at a low temperature (around 20 °C). The inflow and outflow temperatures are influenced by the amount of heat that will be generated, insulation, heat capacity of the heat network and demand of DHN. The calculations will be performed by the project developer in close cooperation with the district heat network manager. The amount of tubes to be calculated is dependant on distance between the solar collectors and the distance to the DHN (type 1 park) or distance to the technical building (type 2 and type 3 parks only). This calculation will be performed by the project developer.

C.4.4 Amount of heat

The amount of heat that will be generated has been assessed in the feasibility stage, however, now that the amount of collectors have been calculated and the type of park is established, the heat can be calculated. As stated before, the thermal capacity equation:

$$A * 0.7 = T_c. \tag{1}$$

describes the relation between thermal capacity and solar collector surface area. However, this is for an ideal situation, in reality, irregularities always arise which influence the amount of heat that can be generated. The generated amount is a combination of the amount of solar collectors, solar fraction, sun hours and ambient temperature. The project developer will calculate this as exact as possible, however, the numbers might deviate with a very small percentage due to nature being irregular.

C.4.5 Costs

The following section will elaborate on the costs, this includes the costs of the solar thermal park and the maintenance costs. The costs of the solar thermal park are difficult to indicate due to the different factors that influence the price:

- Size,
- Heat capacity,
- Temperature of inflow and outflow

At this stage, the project developer and district heat network manager are able to make a complete overview of all the costs of the solar thermal park. This should include the costs of the hardware and operational costs, but also maintenance costs and tillage costs. The maintenance costs and the frequency in which something breaks is relatively low. The maintenance is €1 per produced Mw/h. Maintenance is elaborated on in Appendix D.1. The cost overview is important at this stage because it is very important to stay aware of the large investment that is being made.

C.4.6 Subsidies and financing

At this point in the design stage, the SDE+ subsidy should be recalculated according to Appendix C.2.3. Although the calculation has already been performed in the feasibility stage, it is important to recalculate it again with the exact number of solar collectors that will be placed in the solar thermal park and the heat that will be collected. The calculated amount of heat collectors during the design phase can differ from the amount that has been calculated in the feasibility stage. Once the amount of subsidy that will be granted has been recalculated, it is important to assess the amount of money that is required to be loaned from banks and how much will come from assets. The park will earn itself back in 15 years and then the costs of the park will be lower due to the loan being paid off and therefore, no interest is required to be paid anymore. The remaining costs will be the maintenance costs as described in Appendix C.4.5, but the associated costs are relatively low compared to the initial expenditures of the park.

C.4.7 Local residents

Local residents have not been included during the first two stages and both decision making moments due to no actual plans of developing a solar thermal park were present during those moments. However, in the design stage it is important to include local residents. They need to be made aware of the potential changes that are coming to the area near them. They should be heard and their opinions should be taken into account when continuing with the design and the development of the solar thermal park. After this point in the stage, if local residents are strongly opposed to the current plans, the design stage can be entered again, but this time with the arguments/demands of the local residents taken into account. It is also possible to ignore the arguments/demands of the local residents, however, this can lead to a very negative relation and this is not preferred. It is advised to hear the local residents out and try to take their opinions into account. If the local residents have very extreme idea's about the solar thermal park, it is advised to try to find a solution in the middle. The local residents will be satisfied due to being heard and this will result in a more peaceful cooperation.

C.4.8 Participants during design stage

As opposed to the previous stages, a new party has to be actively included in the progress of the solar thermal park, the local residents. As described in Appendix C.4.7, negative relations with the local residents can cause problems in the near future, therefore, it is important to actively involve them in this stage. Other parties that should be included are: Project developer, district heat network manager, ground/tillage expert and the bank that extends the loan. Furthermore, it is also possible that if a different company than the project developer will install the collectors, that this company is included in this stage as well as the supplier of the solar thermal collectors. However, this is not required. It is important that at this stage the entire project has been mapped out and it is clear for every party what will happen and what their tasks are if the decision making party decides on the continuation with the development.

C.4.9 Third decision making moment

The third decision making moment is the last decision making moment before the solar thermal park will start being built. In the previous decision making moments, both reports still had some unknown factors or included outlines. The report that will be presented to the decision making party should have no unknowns, everything in the report should be worked out and supported with calculations or other documentation. There can not be any unknowns because in the last stage the park will be built. The report should have the following contents:

- A risk analysis
- Number of collectors
- Type of collectors,
- Mounting system
- Type of park
- amount of heat
- financial over

This should be done in collaboration with the police and the fire department to make sure everything will be safe and what to do in case of calamities. Furthermore, an extensive financial overview should be constructed that shows the costs of the park (initial costs, but also maintenance costs and tillage costs), the revenue of the park, the size of the loan, the size of the subsidy and if assets are used, the size of the assets. This overview should also include a payback plan with the interest of the park and how long it will take to pay back the loan + interest and how much will be paid off per what time period. If the report contains the elements stated above, it should be presented to the decision making party. This will most likely consist of the local council, the mayor, a representative of the police, a representative of the fire department and a representative of the local residents. They will have to decide whether to continue with the development of the solar thermal park. Once the local council has decided on the continuation of the development, the final stage can be entered, the implementation stage.

C.5 Stage 4: Implementation stage

After the design stage, the final stage will be entered. In the implementation stage, the park will be built, connected to the DHN and at the end of the phase, the park will be up and running. At this point in the process of the development of a solar thermal park, all the parties that are involved and the timeline of the process have been assessed. Irregularities may arise during this final phase, however, these can not be predicted as per case it may differ what will happen. As stated before, the implementation stage can take up to a max. of 3 years to finalize. The subsidy will not be granted if the park can not be realized in 3 years.

D SWOT analysis

The SWOT analysis will be individually elaborated on, afterwards the combinations of Strengths Opportunities, Weaknesses Opportunities, Strengths Threats and Weaknesses Threats are considered. In table 1 an overview will be presented. Three points of each aspect shall be described, there might be more small strengths, weaknesses, opportunities and threats, however, these will not be stated. The SWOT analysis has been performed in an unbiased manner.

D.1 Strengths

1. The main strength of solar heat is that it is a proven technology, meaning that it has already shown that it is cheaper in terms of MW/h and more efficient than any other renewable source. During the development of a solar thermal park, the price of the heat per MW/h is calculated and is then fixed for the coming 25 years. Compared to biomass, solar heat is 50-60 times as effective, even with the most technologically advanced biomass installation, solar heat still generates 37 times more heat than biomass.

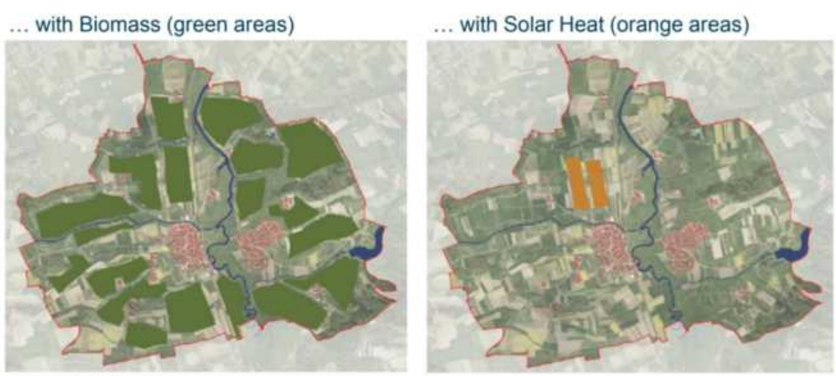

Figure 18: *A representation of the difference in land used between biomass and solar heat*

Compared to solar electricity (PV), if the heat generated with solar parks would be converted to electricity and be measured in kW/m^2 it will still be 3-4 times as effective as PV.

2. The sun has no emission and the harvesting of the sun's power also has no emission. The production of solar collectors does have a negative impact on nature in terms of CO_2, however, the amount of emissions is already compensated for after 1 year. The lifetime of a solar park is currently around 25 years. In addition to the quick compensation of the production emissions, a solar thermal park can be recycled in two ways. First, if it is decided that a park has to be transported to a different location, the solar collectors can be detached and transported to a new location and then be installed again. In Exeter, a solar thermal park was built on an old airport runway and is currently being broken down and transported to a different location. The second way to recycle a solar collector is by breaking it down to its raw materials. A solar collector contains aluminum, glass, copper, rubber and isolating material. The raw materials can then be used for different purposes or can be sold. The costs of breaking down the solar collectors can be covered with the profits gained from the selling of the raw materials.

3. The third strength of solar heat is that the maintenance of a park is very cheap. Usually the maintenance of a solar thermal park is around €1 per MW/h. This includes everything. Once or twice a year a visual check is required to look for damages. The purpose of the visual check is to look for damages done to the solar collectors, this can also be performed with drones. The land can be maintained by grazing sheep (Association, 2018). The only way for a solar collector to break is through impact of very sharp stones. Once a year the PH value of the antifreeze also has to be checked (Association, 2018). The lifespan of the antifreeze used in solar collectors is usually a lifetime, however, checks are performed for safekeeping.

D.2 Weaknesses

1. A big investment is required to develop a solar thermal park. In Vojens in January 2015 a park was built with 71.500 m^2 of solar collectors, the total development costs were $23.6 million. Due to the high costs of a solar thermal park, it is not possible to develop a solar thermal park without a subsidy and loans. Sometimes it is also the case that assets will be used in combination with a subsidy and loans to fund the park.

2. The efficiency of a solar thermal park is very dependent on the heat network it is connected to. The water with heat that is supplied to the heat network and the water that comes back from the heat network have different temperatures. The more distant these temperatures are, the more efficient the solar thermal park is (also described in Appendix C.4.3). Also, during the development of the solar thermal park the price of the heat will be calculated for 25 years. The price of the heat is more difficult to determine if in those 25 years major changes are being conducted to the heat network. In cases when the heat network is expanded majorly, this is often a difficult task to overcome.

3. The price of heat collected through the sun starts to compete with heat generated through natural gas when using a park of around 4000-5000 m^2 with a storage tank (Type 2 solar thermal park described in Appendix B.4. Meaning that any park below those dimensions will not have a heat price below that of gas.

D.3 Opportunities

1. The solar heat collector was first utilized in 1977, making the technology relatively young. This results in that the currently technology only can improve. Because the technology can only improve, the output is most likely to be better in the future. An acceleration in research being conducted to improve solar collectors will even further improve the output.

2. Shifting towards renewable sources is only becoming a bigger subject for municipalities. The demand for renewable sources that are very effective, cost and emission wise is, only increasing. However, in the future, to provide 100% of the households with renewable energy, a

combination of different renewable sources has to be made. It is very unlikely that only one renewable source will provide 100% of the heat demand. A type 3 Appendix B.4 solar thermal park has the potential to achieve the 100% coverage of the heat demand in combination with a biomass installation.

3. As described in Appendix C.4.3, the output of the solar thermal park is dependent on multiple factors, one of them is the inflow and outflow temperature. Reducing the temperatures whilst maintaining the same Δ will improve the efficiency of the solar thermal park. The output of a solar thermal park can improve without improving the park itself.

   Having the heated water that is entering the system to be used multiple times, can also greatly improve the output of the solar thermal park. If the inflow has a temperature of 100 °C and the outflow has a temperature of 70 °C, the Δ will be 30. However, if the outflow is then used again to re-enter the system, the inflow will now be 70 °C and the outflow will be 40 °C. This will result in that the total Δ of the original 100 °C water that entered the system, will be a Δ of 60. Making the park very efficient.

D.4 Threats

1. The biggest threat for solar thermal parks is the availability of land. As stated before, the price of heat through solar parks becomes competitive with heat through gas with a park of 4000-5000 m^2. In order to start heating a large amount of households, the park has to become significantly larger. As described in section 2.4, the biggest park is 156.694 m^2. This size of land is not always available. The lack of large amounts of area to be used for solar thermal parks is a large threat.

2. The amount of information available in the Netherlands regarding solar thermal parks is limited, but also the interest and awareness is at a low level. Due to the limited information and lack in interest, the decision making parties are more likely to opt for a different existing renewable heat source that they believe is more mature. Furthermore, the limited knowledge and lack of interest results in people not knowing the difference between PV and solar heat, or not even being aware of

the existence of solar thermal collection. These are all big threats to the future of solar thermal parks in the Netherlands.

3. The development of a solar thermal park is not possible without a subsidy, loans and potential use of assets as stated in Appendix C.2.3. If there would be a change in the availability or size of the subsidies provided for the development of solar thermal parks, it will become very hard for municipalities to develop these parks. An increase in interest on the loans will potentially result in solar thermal parks not being self-sufficient after 15 years. If a solar thermal park is not self-sufficient after 15 years, the interest on the loan and the maintenance will have to be paid from the revenues alone and not with the help of the subsidy (only lasts 15 years). Solar thermal parks will then be unable to break even or make profit.

D.5 SWOT matrix

SWOT		Strengths	Weaknesses
		1. Proven technology 2. No emission 3. Cheap maintenance	1. High investment 2. Dependent efficiency 3. At least 4000 m^2
Opportunities	1. Technology can only improve 2. Combination can provide 100% heat demand 3. Heat network improvements influence output	Appendix D.6.1	Appendix D.6.2
Threats	1. Availability of land 2. Awareness 3. Subsidy change	Appendix D.6.3	Appendix D.6.4

Figure 19: *A SWOT matrix has been made with an extra column and an extra row to showcase the interrelations between the different aspects of a SWOT, this is elaborated in the following sections*

D.6 Combinations in SWOT matrix

The following combinations occur in the SWOT matrix: Strengths and Opportunities, Strengths and Threats, Weaknesses and Opportunities and Weaknesses and Threats. These combinations shall be elaborated upon to show the influence of each part of the SWOT analysis to the system. The combinations can showcase potential future benefits and pitfalls.

D.6.1 Strengths and Opportunities

This section will describe how the strengths and opportunities combined will strengthen the future possibilities of solar thermal parks.

Although the solar collector is relatively young, it is already a proven technology. It is already more effective than other renewable sources such as biomass and PV and it can only improve. In 2050, all households in the Netherlands have to be free of gas. As stated in section 2.2, in order to supply heat from different sources to households, a DHN is required. The technology regarding DHN's will have to improve in the coming 30 years to be able to supply more and more households. As stated in Strengths section, the efficiency of a solar thermal park is dependent on the Δ between the inflow temperature and outflow temperature. Improvements in the DHN which will maintain the optimal Δ, but reduces the temperature of the inflow and outflow, or allows the water to enter the system multiple times, will further increase the output of a solar thermal park.

D.6.2 Strengths and Threats

The following section will describe how the strengths of a solar thermal park will overcome the threats it is currently facing.

The biggest threats for the solar thermal park is in terms of available land, information and in terms of money. If no land is available, no parks can be built. If the information in the Netherlands regarding solar thermal parks remains limited, the demand for the solar thermal parks will stay low and if the subsidies change is size or availability, the parks cannot be realized. However, if the solar thermal parks outperform other renewable sources, it is expected that these threats will be reduced. More land will be made available for solar thermal parks instead of other renewable sources, people will become more aware and interested in the technology, resulting in an increase in research conducted on the subject. If the parks show an overall better performance than other renewable sources, the subsidies will not be reduced in size or availability, it will most likely be the opposite way, it will increase in size and availability.

D.6.3 Weaknesses and Opportunities

The following section will describe how the weaknesses of solar thermal parks potentially counteract the opportunities that it has.

Although the demand in renewable sources is most likely to increase in the upcoming 30 years, it is still a very young technology. Currently, a park of at least 4000-5000 m^2 is required before it potentially competes with the price of natural gas. The price of such a park is very expensive, not every municipality is able to build such a park. Furthermore, the efficiency of solar thermal parks is very dependent on the temperatures of the in and outflow of a DHN. Increasing the size of a DHN is a very difficult task, it is most likely that DHN managers will give priority to increasing the size of the DHN before trying to reduce the inflow and outflow temperatures to increase the efficiency. When increasing the size of the DHN, the price of heat will also vary and will become harder to calculate prices when developing a solar thermal park.

D.6.4 Weaknesses and Threats

The last section will describe how the weaknesses and threats of a solar thermal park will result in the possible failure of the expansion of solar thermal parks in the Netherlands

The availability of land is a large threat for the expansion of solar thermal parks, this combined with that the area required has to be quite large before the heat prices starts to compete with natural gas and that the investment is big to develop such a park, are large obstacles to overcome if one wants to develop a solar thermal park. Because it is such a large investment, a change in subsidy size or availability will result in solar thermal parks not being able to be realized at all. If a subsidy change is implemented, the awareness and interest regarding solar thermal parks will even further reduce. The dependency of a solar thermal park on a DHN does not help, why would research be conducted in solar thermal parks if it is more important to improve the DHN's? The potential result can be that people are reluctant to invest in a solar thermal park until the DHN's are improved to have a constant Δ at a lower temperature.

E Financial analysis

In the following section, the parameters that have to be taken into account when calculating the price of a solar thermal park will be assessed. Furthermore, an example will be provided that shows the costs, CO_2 reduced and subsidy granted. The final costs and revenues are not exact due to the influence of heat storage, efficiency and mounting system on the costs and revenues.

E.1 Investment costs

The investment (or capex) of a solar thermal park consists of the following parameters that each will be elaborated on individually. Afterwards, a table is provided that allows for calculating whether a solar thermal park will be profitable or not. The aim is to provide an indication on the costs. The true costs will differ due to lack of data.

E.1.1 Solar collector price

The solar collectors that will be used for the financial analysis is the HT-HEATboost by Arcon Sunmark. This type of solar collector is used on all the latest solar thermal parks developed by Arcon Sunmark. The parameters are shown in Table 4.

Technical data	GK3133
Collector type	Large-size collector
Overall area $[m^2]$	13.57
Absorber area $[m^2]$	12.6
$L * W * H[mm]$	$5.960 * 2.270 * 140$
Weight$[kg]$	351
Weight$[kg]$ - no fluid	250
Housing	Al-frame
Surface	Al-natural
Backplate	Al-sheet
Absorber	Al, high selective vacuum coating
Absorption[%]	95
Emission[%]	5
Glass	3.2 mm tempered solar safety glass
Insulation	70mm mineral wool plate
Heat Transfer Medium	polypropylene glycol/water mixutre

Table 4: *The parameters of the HT-HEATboost collector (Dincerto, 2016)*

The prices of the collectors are dependent on a lot of parameters that influence the price per park and are not available. The following has been done to estimate the price of the solar thermal collector: The price of a solar collector used for small scale solar heat collection costs on average €610 per 2.5 m^2 ((Zonne-weetjes, 2019) and (HRsolar, 2019). the price per m^2 is then calculated to be €244. Therefore, the price of a solar collector of 12.6 m^2 will be: $244 * 12.6 = 3074, 4$. Note that these prices are an estimation.

E.1.2 Number of flat plate solar collectors

The output of one collector is based on the average of the output of the following parks and the number of collectors it has.

Park name	Output	Area of collectors	Number of collectors
Silkeborg	80000 MWh	156694m^2	12437
Vojens	28000 MWh	69991m^2	5555
Gram	20000 MWh	44836 m^2	3559

Table 5: *The 3 largest solar thermal parks in Denmark and their output*

The output of the parks combined is 128.000MWh, which is provided by 21.551 solar thermal collectors. The output per year of 1 solar thermal collector is then calculated to be 5,934 MWh per year. (Stöglehner, 2003) states that the yield per m^2 is 0.333 MWh per year, for 12.6 m^2 that would be 4.2 MWh per year. However, the source is from 2003 and the technology has much advanced since then. Therefore the average of the both has been taken for further calculations, which is 5,066 MWh This is an estimate, the total output of a solar thermal park has been used to calculate this, however, the output of a park also relies on the type of heat storage. The data of the actual output of 1 solar thermal collector is not available.

E.1.3 Location price

The price of the location varies a lot per municipality and per ground type. It is assumed that in the Netherlands, the solar thermal parks will be built on agricultural ground. There is also a difference in price between buildland and grassland. To simplify the prices of the locations in the Netherlands, the average has been taken of both prices and of all the municipalities. The average price in the Netherlands is €65000/ha or €65/m^2 (Silvis & Voskuilen, 2019).

E.1.4 Loan and interest

In order to cover the costs of a solar thermal park, a loan is required. For the park in Dorkwerd, Groningen the loan covers 80% of the total costs of the park. However, the information on the size of assets used for the development of the park is unavailable. Therefore, for the example, it is assumed that no assets are used for the development of a solar thermal park.

E.1.5 Gas needed

Burning 1 m^3 of gas yields 0,009769 MWh and produces 0,00189 tons of CO_2.The amount of gas that needs to be used can be calculated. This is an estimation, the yield on burning 1 m^3 natural gas might not have 100% yield. Furthermore, the price of 1 m^3 in 2020 is estimated at €0,77 (Rijksoverheid, 2020).

E.1.6 Price of seasonal storage

The prices of seasonal storage per m^3 of various large-scale solar thermal parks are described in the following graph:

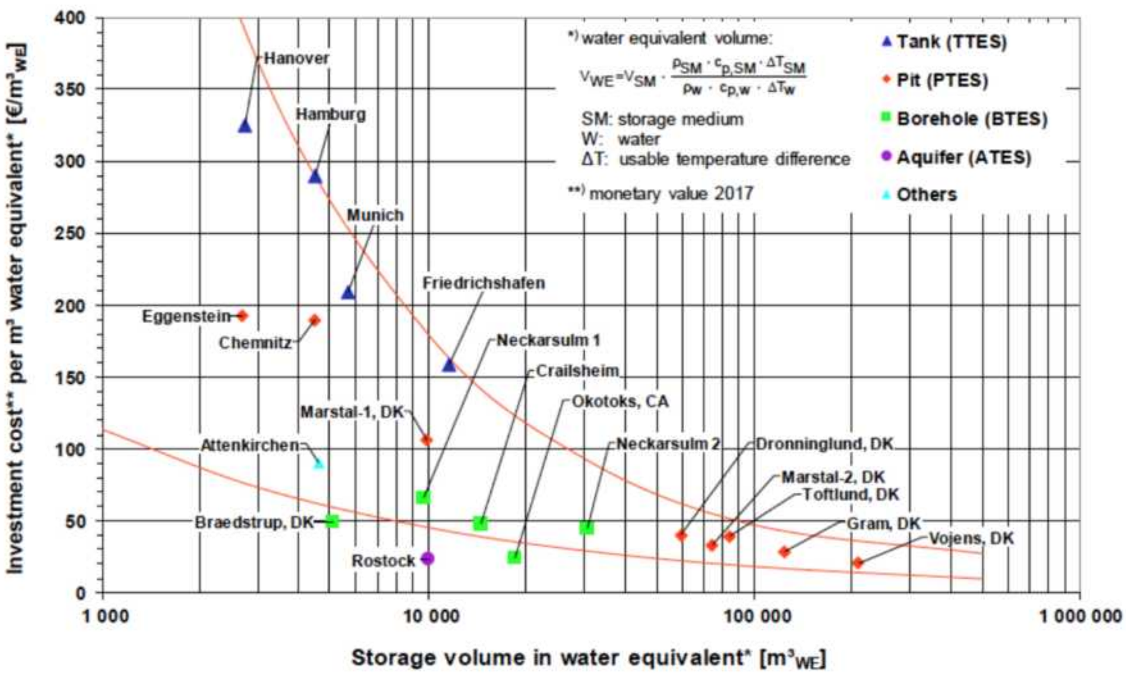

Figure 20: *graphical representation of the storage volume of seasonal storage against the price per* m^3

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As figure 16 shows, the larger the storage volume, the cheaper the price per m^3 becomes. The price per m^3 in Vojens was €24, in Gram €34 and in Toftlund €48. An average of €35.3 is payed per m^3 of seasonal storage. This amount will be used for the price calculation of a solar thermal park.

E.2 Example price calculation solar thermal park

In 2014, 3614 TJ was used to heat all the households in Groningen (Groningen, 2017). This is equal to 1.003.889 MWh per year.
In this example, a solar thermal park will be developed that covers 5% of the heat demand per year, which is 50.195 MWh. Furthermore, a seasonal storage pit will be developed that has a capacity of 12.000 MWh. The size of the seasonal storage is based on the storage of Vojens and Gram, which will be 175.000m^3 (ENERGINET, 2018)
.

Heat demand	50.195 MWh
Number of solar collectors	9.909
Size of solar collectors	124.853,4 m^2
Area needed	124.853,4 m^2
Size of storage	175.000 m^3
Price of solar collectors	€30.464.229,6
Price ground	€8.115.471
Price of storage	€6.177.500
Gas saved per year	5.138.192 m^3
CO_2 saved per year	9711,18 tons
Gas saved per year €	€3.956.407,84
Subsidy 2020 per year	€2.831.675,11

Table 6: *Example calculation solar thermal park*

The park will cost €44.757.200 and the subsidy granted will be €2.831.675,11 per year. A total subsidy of €42.475.126,6 will be granted over the course of 15 years. This would cover nearly all the costs of the entire park, however, this is not the case in reality. The costs of the heat storage are an estimation as well as the prices for the installing, technical building, all the materials needed and transportation and installing the park to the DHN. If this is included, a larger loan is required to cover the costs and an interest is paid over this loan. This example serves as an indication on the costs of a solar thermal park, but also what it will do in terms of CO_2 saved. The following template serves as a helping tool in gaining an indication on how large the solar thermal park has to be and how much the solar thermal park will cost.

Heat demand	x MWh
Number of solar collectors	Heat Demand/5,934
Size of solar collectors	Number of collectors*12,6 m^2
Area needed	Number of collectors*12,6 m^2
Price of storage	€35,3/m^3
Price of solar collectors	number of collectors * 3074,4
Price ground	area needed * 65/m^2
Gas saved per year	Heat demand/0,009769 m^3
CO_2 saved per year	Gas saved*0,00189 tons
Gas saved per year €	gas in m^3 * 0,77
Subsidy 2020 per year	use Figure 12

Table 7: *indication template*