Catalogue of Local Energy Solutions

Autonomous Oosterwold

01.07.20

Faculty of Architecture and the Built Environment
Master Track: Urbanism
Studio: Urban Metabolism

Charlotte von Meijenfeldt
4209990

First Mentor: Ulf Hackauf
Second Mentor: Ellen van Bueren

TU Delft
Department of Architecture Engineering +Technology
BK Bouwkunde

Reading Guide

As explained in chapter XX, this catalogue is an overview of the systems that were found in literature and in practice that are applicable for energy provision in Oosterwold. The systems are separated according to their function: energy production, energy transport and energy storage. All three functions are necessary in order to produce a fully functioning local energy system. Since energy production and energy storage are both important aspects of spatial planning, they are evaluated for their land-use, environmental impact and environmental risks. Additionally, the system structure, landscape integration and reliability are analysed as this information is necessary in order to calculate and integrate essential services within the built environment. In other words, this information is necessary for the maximization studies in chapter 8 and could prove valuable for spatial planners working with local energy provision systems. Energy production and storage systems that are not applicable in Oosterwold are only discussed in general terms for completeness to limit the scope of this catalogue and provide in-depth information on the systems that matter. According to the following principles systems are excluded from research:

- *The system is novel and not yet applied in practice*
- *When it is not possible to generate or store enough energy to be self-sufficient considering the resources and production of energy for a single household in Oosterwold with a plot size of 1600 square meters*
- *If policies or the environment of Oosterwold prohibits the implementation of the system (with the exception of wind turbines)*

Techniques are found using different sources. First and far most respectable sources are used. These are literature from universities (TU Delft), the government (RVO) and research institutions (TNO, CE Delft). But, because the consequences of land-use intensity, environmental impact and risks on spatial planning is a relatively new research subject, other sources are used as well. The internet is searched for installation companies and published work of consultants (Sweco). For some specific information contact is made with the installation company or users of the technique.

Table of content

Images

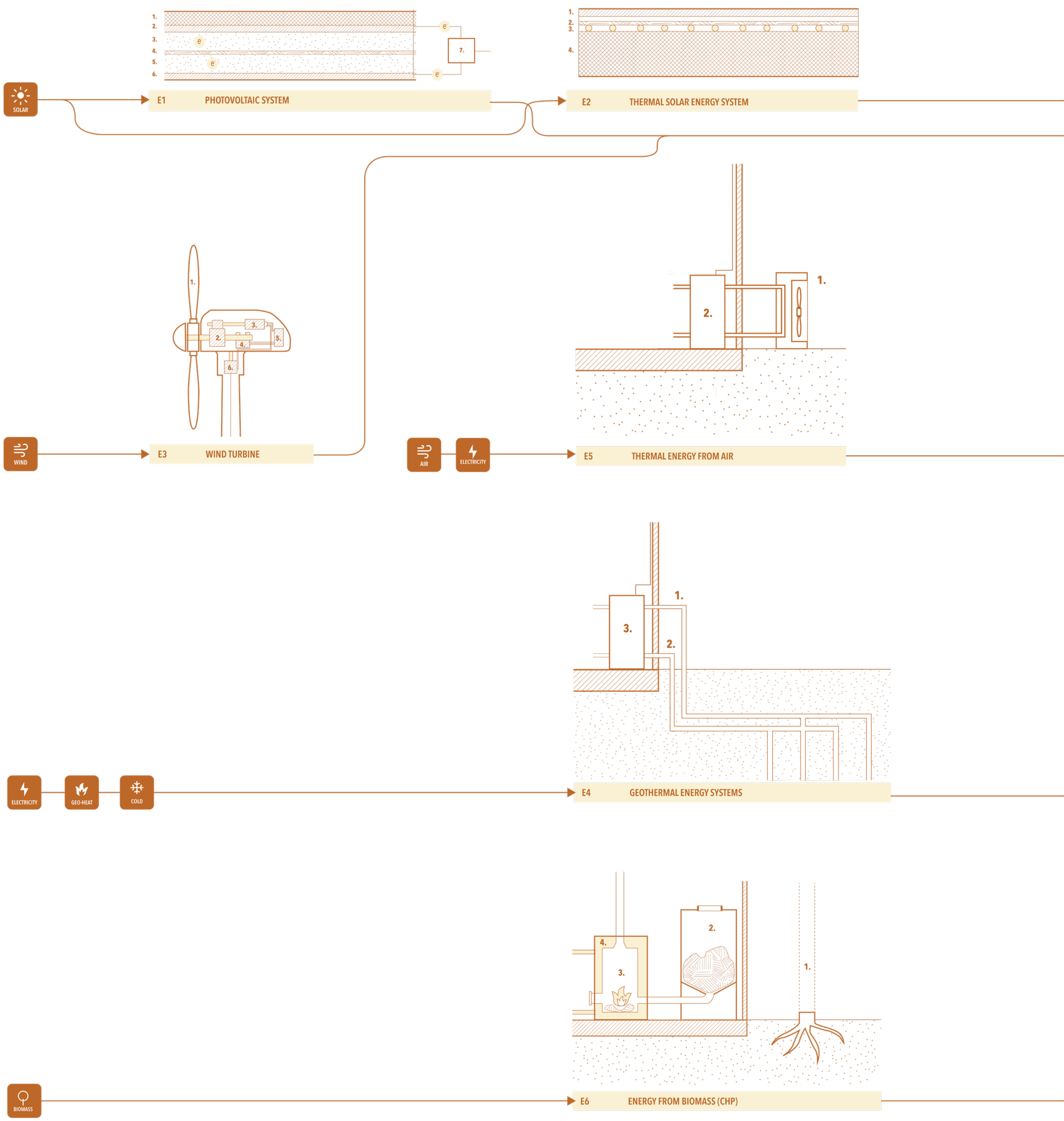
Figures

Overview of local energy systems

Production

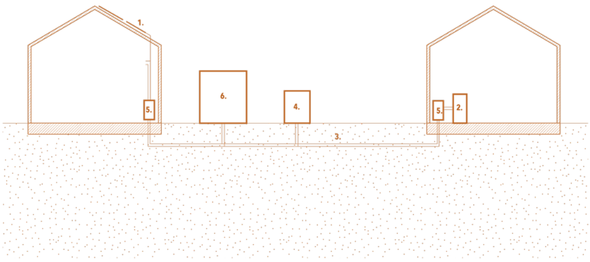
electricity

heat

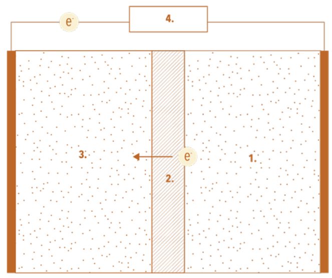


Transport

Storage

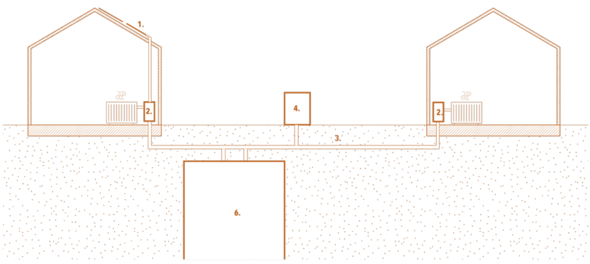


E12 (SMART) LOW-VOLTAGE ELECTRICITY GRID



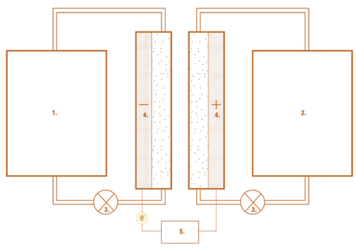
E7 LITHIUM-ION BATTERY

ELECTRICITY



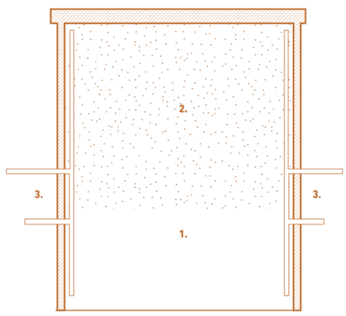
E13 (SMART) LOW-TEMPERATURE HEAT GRID

HEAT



E8 VANADIUM-REDOX FLOW BATTERY

ELECTRICITY



E 10 SEASONAL THERMAL ENERGY STORAGE

COLD

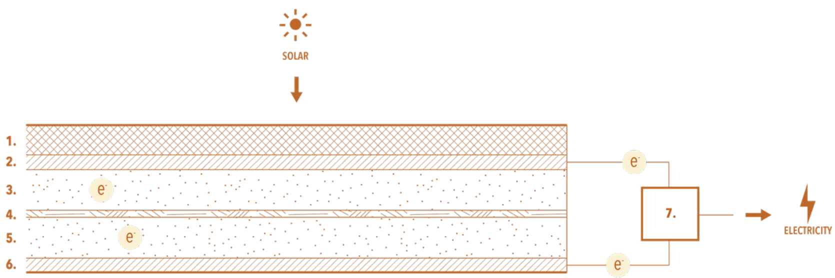
HEAT

E1 Photovoltaic panels

Photovoltaic panels produce energy by converting sunlight into electricity. This is done through the use of two thin layers of semiconductors with properties intermediate between those of metals and insulators of which silicon is the most commonly applied material (Green, 2000). The top layer has a surplus of electrons and is therefore negatively charged (n-type) while the bottom layer is positively charged due to a lack of electrons (p-type). Sunlight pushes part of the surplus electrons into the positively charged material at the bottom creating a current and generating a DC current. Average commercial panels can transfer from 17% of primary energy from sunlight into usable energy (ISE, 2019).

1.1 System structure

Above the first layer of silicon a protective layer of glass, adhesive and anti-reflective coating is applied (1.). The front contact connects the top layer of silicon with the bottom layer of silicon in order to create a current (2.). The next layer consists of the n-type semiconductor (3.) and a p-type semiconductor (5.) with a p-n junction separating both conductors (4.). On the bottom a 'back contact' catches surplus electrons (6.) creating the electric current. Since this current is a DC current it still has to be transformed to an AC current using an inverter (7.). Commercial inverters have an efficiency of around 98% (ISE, 2019). The production of electricity depends on the amount of sunlight reaching the surface of the earth. In the Netherlands this is highly dependent on the seasons (Velds, 1980). The input and output are therefore variable.



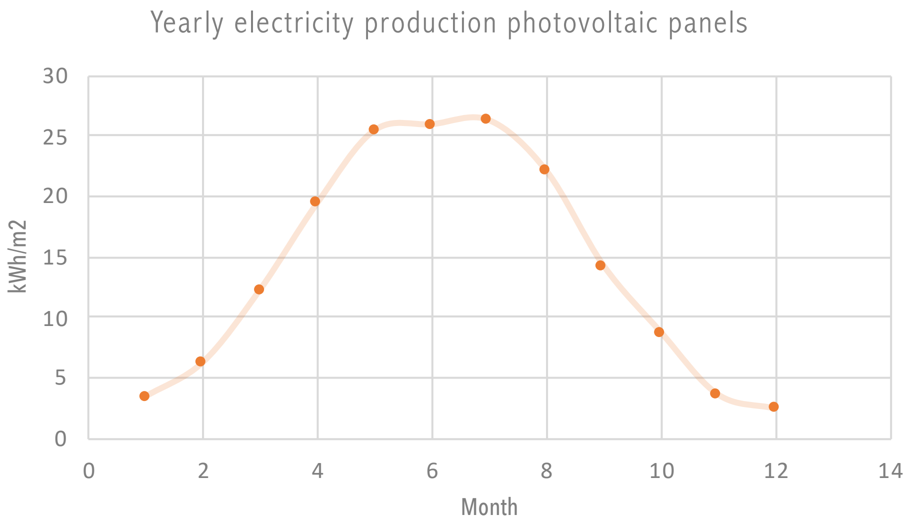
1. System structure of photovoltaic panels

1.2 Land-use and land-use intensity

The land-use and land-use intensity of photovoltaic panels is determined by the efficiency of the panel to transmit light into electricity (which differs per brand), their relative position to the sun and the availability of sunlight. As mentioned, on average panels can transfer 17% of the total solar energy into electricity. The relative position to the sun determines the amount of light that reaches the panel. The most productive position is determined by a specific location as the position of the sun is different in different parts of the world. In the Netherlands the most optimal position is southward and with an

A. Photovoltaic-termal panels (photo by author, Buiksloterham) ▶

inclination between 20 and 50 degrees (Milieu Centraal, 2019). If shading occurs on the panel (in the case of obstructions such as snow, trees or other buildings) the amount of light that reaches the panel and the production of electricity will decline. Lastly, the availability of sunlight depends on climatic conditions such as the position of the sun, the daily duration of solar power and the formation of clouds. Due to these reasons the amount of available sunlight in the Netherlands corresponds with the seasons as sunlight is scarce in winter while there is an abundance of sunlight in summer. Assuming there is no shading and panels are optimally placed in position to the sun, diagram 4.1 describes the land-use intensity of a photovoltaic panel based on average seasonal variation of solar light as described by the Royal Dutch Meteorological Institute ('KNMI') (KNMI, 2019). The yearly average is around 14 kWh/m2 panel with a minimum of around 2 kWh per m2 and a maximum of around 26 kWh per m2.



2. Average electricity production photovoltaic panels based on Milieu Centraal and KNMI weather data

1.3 Landscape integration

Photovoltaic panels can be combined with buildings, agriculture, water and nature but are difficult to combine with road structures. Photovoltaic panels can be placed upon roofs where they typically produce the highest amount of electricity due to their optimal placement, however, it is also possible to integrate them within facades (both walls and windows) which often reduces the performance but increases multifunctional land-use (Agentschap NL, 2011). If a green roof is applied the efficiency of photovoltaic panels can be increased with around 8 % due to a cooling effect (Hui & Chan, 2011). Other additional structure such as a carport or shading can also be combined with photovoltaics. Agricultural activities can be combined with the production of electricity if (transparent) panels are mounted onto greenhouse structures or other structures necessary for the production of food (Zwart, Hemming, Ruijs, & Gieling, 2011). Photovoltaic panels can also be placed on top of water bodies as floating elements. Due to a cooling effect of the panels compared to panels on land this can increase the efficiency with around 11% (Choi, 2014). Photovoltaic panels can also be placed in nature as long as shadow due to vegetation such as trees does not hamper the transmission of sunlight. This means some natural landscapes (such as grass fields or a dune landscape) will function better in accordance with photovoltaic panels than other types of landscapes such as forests (Posad, 2018). Photovoltaic panels cannot be combined directly with roads as panels are not (yet) strong enough to carry large vehicles and sand or dust formation causes a large reduction in efficiency. It is possible to integrate photovoltaic panels on the side of roads, in biking paths or above roads supported by a structure even though dust formation can still cause a significant drop in efficiency (Borg & Jansen, 2001; Hooimeijer, et al., 2017).

1.4 Environmental impact

Photovoltaic panels are best integrated with buildings when looking at the different levels of environmental impact on the different landscapes.

Landscape	Impact	Explanation
Road	Not applicable	-
Buildings	Low	If photovoltaic panels are integrated into a building during the design phase the visible presence of panels is low. This can differ in a situation where photovoltaic panels are added onto a building in a later phase. Photovoltaic panels do not emit noise, pollutants or smell that can cause nuisance for inhabitants.
Agriculture	High	Photovoltaic panels and the production of food are both in need of sunlight in order to function properly. Even if transparent photovoltaic panels are used on greenhouse structures this has a direct negative effect on the growth rate of crops. It is therefore best to grow crops in need of shadow (Zwart, Hemming, Ruijs, & Gieling, 2011).
Water	Medium	Photovoltaic panels can have a negative effect on the rate of biodiversity in water bodies as water insects can mistake the panels for places to lay their eggs reducing certain insect populations (Horvath, Blaho, Egri, & Kriska, 2010). Panels are relatively visible when placed on water bodies.
Nature	Medium	The placement of photovoltaic panels in a natural area can cause excessive land transformation to prevent shadow formation. These landscapes are not necessarily low in biodiversity but can create monotone landscapes prohibiting the landscape diversity that is necessary to sustain a high rate of biodiversity (Montag, Parker, & Clarkson, 2016). On top of that, a similar ecological problem can occur where insects instinctively mistake panels for water.

3. Landscape integration of photovoltaic panels

1.5 Reliability

The reliability of a steady production of electricity by photovoltaic panels is in general low as the production fully depends on weather patterns. This jeopardizes the reliability of the system to provide electricity. Possible mitigation strategies are the installation of electricity storage, trading of electricity through a local smart-grid or two-way national grid, or the combination of photovoltaic systems with other energy techniques. Extensive monitoring is necessary in order to respond in the demand for electricity or apply these methods (Agentschap NL, 2011).

Time period	Fluctuations	Explanation
Hourly	Always	The position of the sun and formation of clouds during the day and the general absence of light at night create variations in the hourly production of electricity.
Daily	Common	Due to daily weather patterns, such as cloud formation, the daily production of electricity can vary.
Seasonal	Always	Due to the changing position of the sun in different seasons the availability of sunlight differs greatly resulting in a varying production of electricity.

4. Reliability of photovoltaic panels

1.6 Environmental hazards

The following risks should be taken into account when using photovoltaic panels (Agentschap NL, 2011). Most of these risks are low if a photovoltaic system is properly designed considering the stability of the construction, reachability for installation and maintenance, the existing surface on which panels are placed and a new functioning panel is used.

Hazard	Risk	Explanation
Panels falling off (roof) structures	Low	Due to strong winds, snow or other mechanical loads panels can fall of structures causing damage to buildings or people. [1]
Panels causing damage to (roof) structures	Low	Photovoltaic panels can damage roof structure by causing leakage. [1]
Injuries during installation, maintenance or repair.	Low	The position and placement of photovoltaic panels determines their reachability and can cause difficulties or injuries during installation, maintenance or repair. [1]
Functional failure of the system	Low	Most panels function without failure for a duration of at least 25 years. [1]

[1] (Agentschap NL, 2011)

5. Environmental risks of photovoltaic panels

1.7 Photovoltaics in Oosterwold

Opportunities:

- *Large availability of land leaves room for photovoltaic panels as land-use is relatively high*
- *Integration of photovoltaic panels during the design phase*
- *Ability to integrate a two-way grid or smart grid mitigating variations in production by enabling trade or sharing of electricity*
- *Large availability of land*

Challenges:

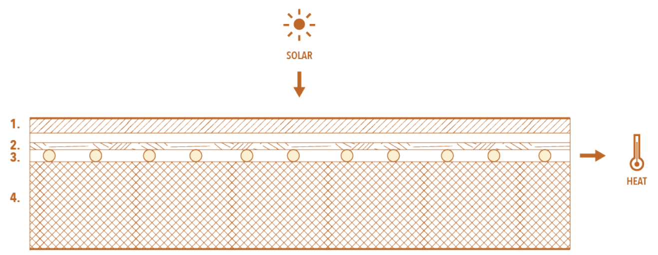
- *Trees or other elements can cause shadow formation on panels as the area is a natural landscape*
- *The implementation of electricity storage or combination with other production techniques to improve overall reliability*

E2 Thermal solar energy systems

Thermal solar energy systems produce thermal energy through the absorption of warmth from the sun. In a solar energy system, a network of small pipes transports liquid (often water) or air through a surface, such as a panel, to absorb heat from sunlight. This is first collected by a material with good conducting properties, such as aluminium, to create an efficient heat abstraction process unless pipes are integrated within an existing surface (Sarbu & Sebarchievici, 2017). Key is to draw as much heat into the piping system and release as little as possible to the environment.

2.1 System structure

Most thermal solar systems are produced as panels, but it is also possible to develop a simple piping system in surfaced which are easily warmed by the sun. In a typical panel, the first layer consists of a glass plate to protect the panel against the weather (1.). The second layer is an absorber surface which absorbs heat from the sun (2.) and transfers it to the underlying pipes that transport (mostly) liquid or air (3.). The last layer consists of an insulator to keep as much heat as possible inside the panel (4.). The efficiency of thermal panels is on average around 60 percent in the Netherlands (Energy for Sustainability, 2013).

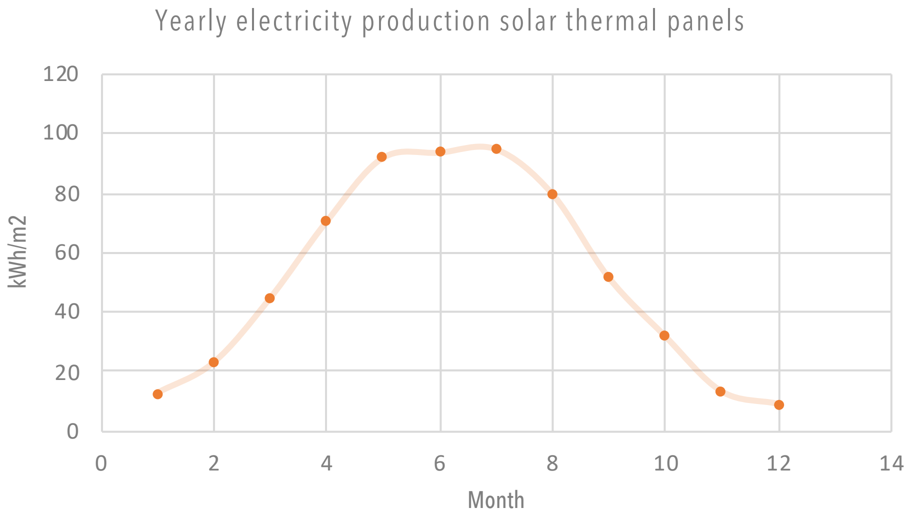


6. System structure of a solar thermal panel

2.2 Land-use and land-use intensity

The land-use of solar thermal energy systems depends on their efficiency to collect solar heat. A normal solar thermal panel has an efficiency of around 60% as explained in the introduction, however, if a solar thermal energy system is integrated within a building structure or within the soil the efficiency is only around 20% of a conventional panel which means the total efficiency is around 12 % (Weijers & Groot, 2007). This is also due to the general sub-optimal position of these surfaces. As with photovoltaic systems a thermal solar energy system is also benefitted from an optimal position

towards the sun and subject to the availability of solar energy or light (see ‘photovoltaic panels’) creating similar fluctuations in land-use intensity. On average a solar thermal panel produces around 51 kWh per m2 with a minimum of around 9 kWh per m2 and a maximum of around 95 kWh per m2 and for integrated solar thermal systems this is 80% lower.



7. Electricity production of solar thermal panels per m2

2.3 Landscape integration

As mentioned before, solar thermal energy can be collected by using a panel or through integrating a piping system in an existing surface which makes their integration with other functions more flexible. Thermal solar energy systems can be combined with all functions (road structures, buildings, agriculture, water and nature. A thermal solar energy system can be combined with road structures by installing a piping system close to the road surface (around 13 cm deep) (Weijers & Groot, 2007). Thermal solar panels and piping systems are easily combined with buildings as their surfaces often collect warmth which can be harvested by such systems. Here solar thermal energy panels are commonly combined with a photovoltaic system as both benefit from a similar position towards the sun and can exist in symbiosis (the thermal system harvests warmth and cools down the panel which increases the efficiency of the photovoltaic system). This also minimizes land-use. Furthermore, piping can be installed under roofs or integrated within facades or terraces. In agriculture, solar thermal systems can be installed within greenhouses to collect heat in summer (Zwart, Hemming, Ruijs, & Gieling, 2011). It is not possible to integrate them within the soil as the ploughing of land can damage piping. This is possible when integrated with natural systems which are generally left untouched. Here caution should be taken with large roots that might damage pipes. Lastly, it is possible to obtain solar thermal energy from surface water. This is often done through an open system which collects surface water instead of through the integration of piping in water (Stowa; Ministerie van Infrastructuur en Waterstaat; Unie van Waterschappen, 2017).

◄ B. Solar thermal energy system on a roof (phot by author, Oosterewold)

2.4 Environmental impact

Thermal solar panels are best integrated with road structures, buildings or within water bodies.

Landscape	Impact	Explanation
Road	Not applicable	-
Buildings	Low	If photovoltaic panels are integrated into a building during the design phase the visible presence of panels is low. This can differ in a situation where photovoltaic panels are added onto a building in a later phase. Photovoltaic panels do not emit noise, pollutants or smell that can cause nuisance for inhabitants.
Agriculture	High	Photovoltaic panels and the production of food are both in need of sunlight in order to function properly. Even if transparent photovoltaic panels are used on greenhouse structures this has a direct negative effect on the growth rate of crops. It is therefore best to grow crops in need of shadow (Zwart, Hemming, Ruijs, & Gieling, 2011).
Water	Medium	Photovoltaic panels can have a negative effect on the rate of biodiversity in water bodies as water insects can mistake the panels for places to lay their eggs reducing certain insect populations (Horvath, Blaho, Egri, & Kriska, 2010). Panels are relatively visible when placed on water bodies.
Nature	Medium	The placement of photovoltaic panels in a natural area can cause excessive land transformation to prevent shadow formation. These landscapes are not necessarily low in biodiversity but can create monotone landscapes prohibiting the landscape diversity that is necessary to sustain a high rate of biodiversity (Montag, Parker, & Clarkson, 2016). On top of that, a similar ecological problem can occur where insects instinctively mistake panels for water.

8. Environmental impact of solar thermal panels

2.5 Reliability

The reliability of a steady production of energy with solar thermal energy systems is low as the production depends on weather patterns. This jeopardizes the reliability of the system to provide heat. Moreover, most heat is produced in summer and needed in winter apart from hot tap water. Possible mitigation strategies are the installation of heat storage or the combination of solar thermal energy with other (more reliable) heat sources.

Time period	Fluctuations	Explanation
Hourly	Always	The position of the sun and formation of clouds during the day and the general absence of light at night create variations in the hourly production of electricity.
Daily	Common	Due to daily weather patterns, such as cloud formation, the daily production of electricity can vary.
Seasonal	Always	Due to the changing position of the sun in different seasons the availability of sunlight differs greatly resulting in a varying production of electricity.

9. Reliability of solar thermal panels

2.6 Environmental Risks

For panels mounted to the roof similar risks apply as with photovoltaic panels. Most of these risks are low if a solar thermal energy system is properly designed considering the stability of the construction, reachability for installation and maintenance and good quality panels are used.

Hazard	Risk	Explanation
Panels falling off (roof) structures	Low	Due to strong winds, snow or other mechanical loads panels can fall of structures causing damage to buildings or people. [1]
Panels causing damage to (roof) structures	Low	Photovoltaic panels can damage roof structure by causing leakage. [1]
Injuries during installation, maintenance or repair.	Low	The position and placement of photovoltaic panels determines their reachability and can cause difficulties or injuries during installation, maintenance or repair. [1]
Functional failure of the system	Low	Most panels function without failure for a duration of at least 25 years. [1]

[1] (Agentschap NL, 2011)

10. Environmental risks due to solar thermal panels

2.7 Thermal solar energy in Oosterwold

There is no additional legislation considering thermal solar energy in Oosterwold.

Opportunities

- *There is enough land available for the abstraction of solar thermal energy in all sorts*
- *Solar thermal energy systems can be taken into account during the design phase.*
- *All roads are still in construction, this creates opportunities for the integration of thermal solar energy*

Challenges

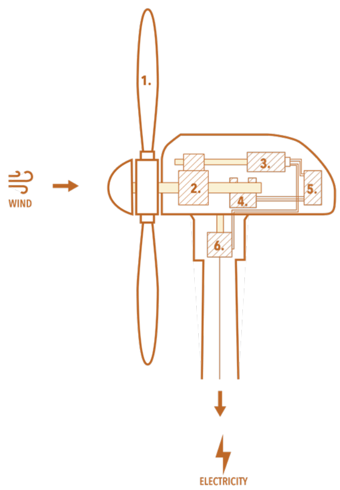
- *Solar collectors in road structures are generally difficult since different parties need to align their interests within the design phase*

E3 Wind turbine

A wind turbine harvests wind energy to generates electricity. This is done by using the kinetic energy from moving air and transforming this into rotational energy through the usage of blades (Loganathan, Chowdhury, Mustary, Rana, & Alam, 2019). Different types of wind turbines exist using different techniques and operating on different scales. Evidently, only the commonly used horizontal axis turbine has proven to be an efficient and well-tested type of wind turbine and therefore other techniques (bladeless, airborne, diffuser-augmented or vertical axis windturbines) are not considered (Bosch & van Rijn, 2018).

3.1 System structure

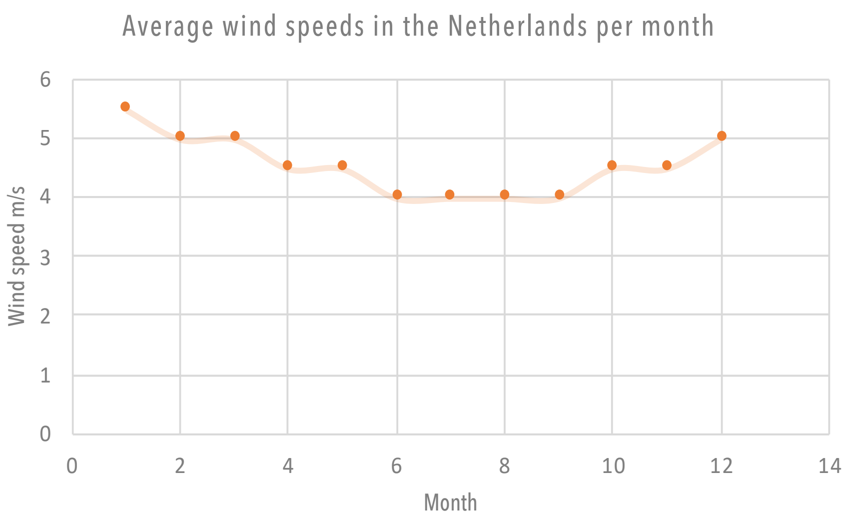
Horizontal axis wind turbines have large blades attached to a rotor (1.) that harness kinetic energy from wind. In the gearbox (2.) the relatively low rotor speed is transformed to a high rotor speed. This rotor is attached to a generator (3.) which transforms the kinetic energy into electric energy through the use of magnets. A computer (5.) keeps track of the wind speed and direction to make sure the wind turbine stops turning in case of heavy winds through the use of a brake (4.) and is positioned optimally through the use of a yaw motor (6.) (Chemviews, 2012). In general, the efficiency of wind turbines increases exponentially when the rotor diameter or height increases (Cace, 2010).



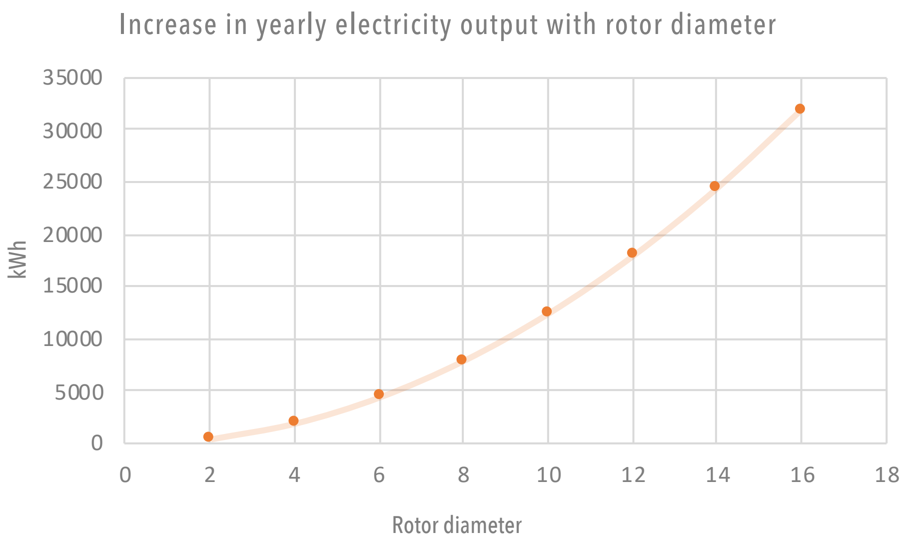
11. System structure of wind turbine

3.2 Land-use and land-use intensity

The direct land-use of wind turbines solely consists of their tower footprint. Since this is relatively small, especially when considering small-scale wind turbines, the land-use is often neglected. The output of wind turbines and therefore their land-use intensity depends on their rotor diameter as well as the average wind speed. Larger blades directly correspond with a higher power as doubling the rotor diameter will result in a quadrupling of the electricity output. The total wind speed is important as the electricity output increases with a third power of the total wind speed (Cace, 2010). Placing wind turbines in generally 'empty' landscapes and obtaining a maximum altitude will increase the wind speed and consistency of wind.



12. Average wind speed in the Netherlands per month which results in fluctuating electricity production (KNMI, 2019)



13. Rough indication of yearly electricity output as a result of the rotor diameter and based on an overview of current small-scale wind turbines made by (Cace, 2010)

3.3 Landscape integration

To maximize electricity production in a certain location, it is important to regard the exact position of wind turbines and decrease the influence of other objects that might slow down wind speeds. Firstly, wind turbines should be placed at a distance from each in order to prevent them from influencing each other. As a rule of thumb small wind turbines are placed at least three times their rotor diameter (for large wind turbine this distance is larger: at least five times their rotor diameter) (Cace, 2010). On top of that, large objects such as buildings or trees, should be taken into account when considering the right position for a wind turbine. In general, the prevailing wind directions should be free of any obstacles which can be difficult when integrating wind turbines in the build environment. When there are obstacles that can hamper the (prevailing) wind, the wind turbine should be placed at a distance of around 10 time the height of that obstacle (Cace, 2010). Wind turbines can be combined with buildings, agriculture, water and nature and cannot be combined with road structures. In the case of buildings and specifically households, wind turbines can be mounted on roofs or façades. Care should be taken considering the effect of the building on the wind speed and wind stability. It is relatively easy to integrate wind turbine into an agricultural landscape if this landscape consists of a simple crop landscape. When fruit trees or greenhouses are used extra care needs to be taken considering the wind alteration. Wind turbines can also be placed in water with little concern for wind obstructions of water bodies are large enough. Lastly, wind turbines can be placed within natural areas if these areas are generally free of obstructions such as trees. In general wind turbines cannot be placed directly on roads, however, it is possible to place wind turbines alongside roads or on structures above roads (Weijers & Groot, 2007).

3.4 Environmental impact

Landscape	Impact	Explanation
Road	Not applicable	-
Buildings	Low – High	Depending on the size of a wind turbine, inhabitants can be subjected to moving shadows and noise pollution. Wind turbines with a rotor diameter up to 2,5 meters do not create moving shadows but with larger wind turbines caution should be taken. To prevent shadow, wind turbines have to be placed at a distance of at least 12 times their rotor diameter. For noise pollution a wind turbine cannot produce more than 47 dB on average during the year (Rijksdienst voor Ondernemend Nederland , 2019). This can be mitigated by reducing the sound contact of a wind turbine and a built structure. Furthermore, wind turbines are relatively visible on roof structures which can be viewed as a disturbance especially in a historic built environment (Cace, 2010).
Agriculture	Low	The placement of wind turbines within an agricultural landscape has no registered impact on the landscape.
Water	Low	The placement of wind turbines within water bodies only has negative effects on biodiversity or quality of water during construction. During operation wind turbines can both exert positive and negative effects on the biodiversity of water bodies (Bergström, et al., 2014)
Nature	Low	There is a minor impact on wildlife, with in particular birds, when these collide with blades but mortality numbers are low (R.Saidur, N.A.Rahim, M.R.Islam, & K.H.Solangi, 2011).

14. Environmental impact of wind turbines

3.5 Reliability

Wind turbines are not a reliable source of electricity as wind speeds can change every hour and every day. When wind speeds are too low or too high wind turbines can even halt any production of electricity (Cace, 2010). On the other hand, seasonal changes are rare as average wind speeds do not change immensely (see diagram 4.8). To further increase reliability and availability of wind, wind turbines can be placed at a higher altitude. Other mitigation strategies include the combination with other techniques or placement of turbines at different wind positions.

Time period	Fluctuations	Explanation
Hourly	Common	Wind speeds can vary on an hourly basis as a result of weather patterns.
Daily	Common	Wind speeds can also vary from day to day depending on the weather patterns.
Seasonal	Possible	Seasonal fluctuations are relatively low windspeed only fluctuates with around 1 m/s. This means wind turbines are a relatively stable source of electricity through the seasons.

15. Reliability of wind turbines

3.6 Environmental Risks

Hazard	Risk	Explanation
Moving shadows	Low	Shadow formation depends on the placement and height of the wind turbine. Moving shadows are seen as bothersome by many people and can cause epileptic attacks. If wind turbines produce moving shadows near a household window for more than 17 days per year they have to be shut down. Wind turbines with a rotor diameter of less than 2,5 meters do not form shadows and are therefore exempt from legislation (Rijksdienst voor Ondernemend Nederland , 2019).
Ice formation	Low	Ice formation on blades from wind turbines can create risks for inhabitants and damage surrounding structures. This is mainly a problem with larger wind turbines but can also occur with smaller wind turbines. This risk occurs around 2 to 7 days per year in the Netherlands (Vries, 2018).
Technical failure	Low	Small wind turbines are not yet produced on a large scale which means technical failures are still relatively common (Cace, 2010).

16. Environmental risks of wind turbines

3.7 Wind turbines in Oosterwold

In Oosterwold only small wind turbines are allowed. The following rules apply:

Wind turbines…

1 … should be attached to the roof or facades of the main building;

2 … cannot be 3 + meters higher than the main building;

3 … have a maximum rotor diameter of 2 m (Gemeente Almere, 2018).

Opportunities

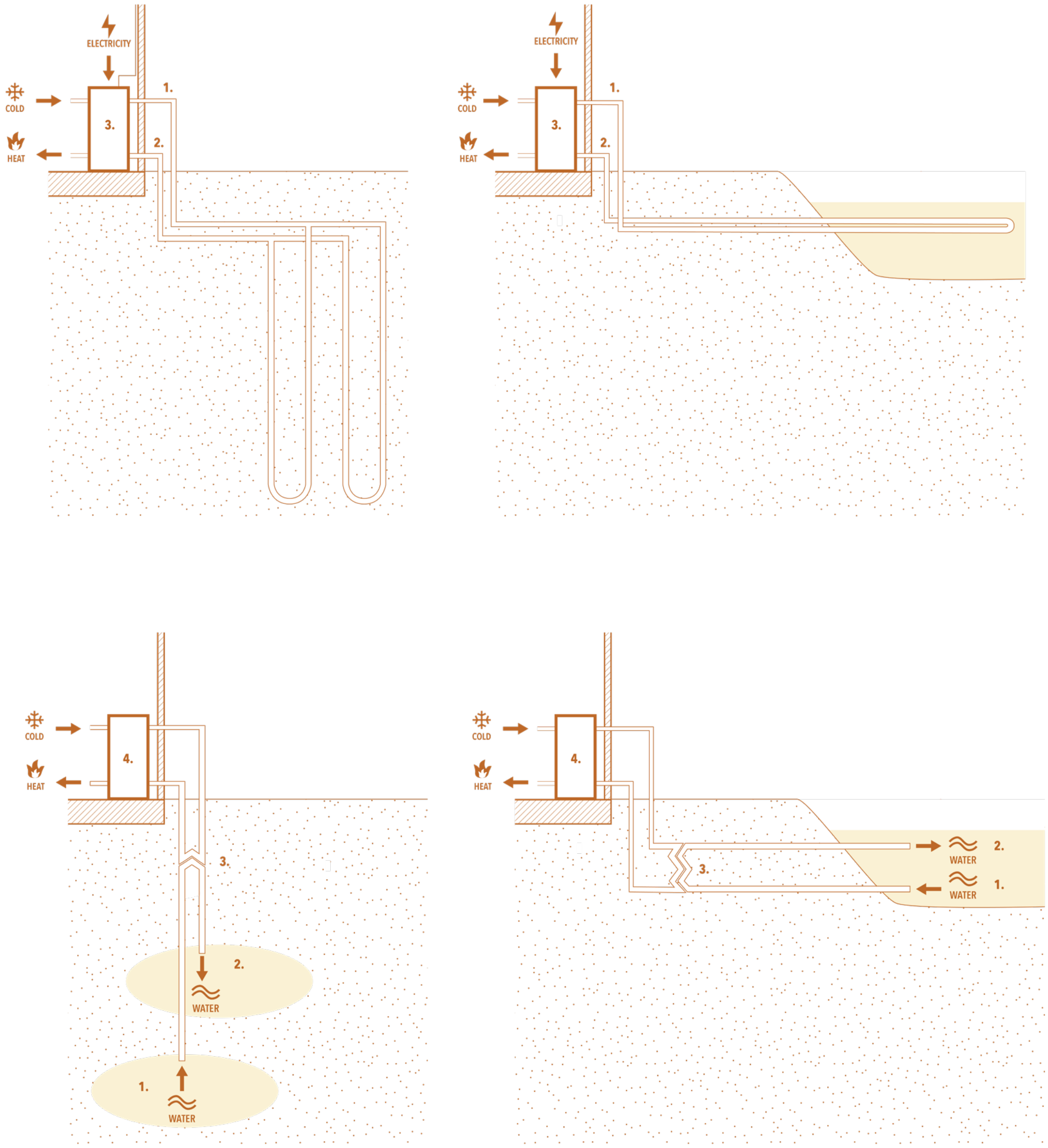
- *Due to the low density of household which are often only a single story high and the general agricultural landscape, obstacles that can hamper wind speeds are minimal (even though they still need to be taken into account) which benefits the electricity production from small wind turbines.*

Challenges

- *Since wind turbines have to be mounted on roofs and photovoltaic panels are generally best placed on roofs, wind turbines might hamper the production of electricity from photovoltaics due to shadow creation.*

E4 Geothermal energy systems

Geothermal energy systems use heat from the ground, ground water or surface water, which is relatively stable, as a source for the heating and cooling of buildings or hot water. Large-scale geothermal heat systems (2500+ households) abstract heat from the earth crust which can be found from around 500 meters deep in the Netherlands and is not considered in this thesis. Small-scale geothermal heat systems use heat that indirectly originated from the sun. The sun warms the upper layer of the earth and surface water which then penetrates up to around 200 meters deep via ground water networks (Milieucentraal, 2019). There are roughly two main types of geothermal energy systems: closed systems and open systems. Closed systems pump liquid (water, glycol or beet juice) through the ground which warms or cools (depending on the season) the liquid. Open systems directly pump water from an underground water source or use surface water. Closed systems and open systems can generate between 30 – 80% of the heat required (depending on location, preferences and vertical or horizontal placement) but open systems can generally store more heat or cold and therefore reach higher efficiencies (European Copper Institute, 2018; Bodemenergie NL, 2020). Both systems can also function as storage for both heat or cold and therefore provide cooling in summer or heating in winter. This is not possible when surface water is used (Bodemenergie NL, 2020).



17. Systen structure of a closed (top) and open (bottom) system both vertical (left) and horizontal (right)

4.1 System structure

Depending on the conditions and preferences, either a closed or open geothermal energy system is chosen. Usually in both cases a vertical system is chosen considering the significant land-use of a horizontal system and the increase in fluctuations due to the smaller proximity towards the surface.

Closed

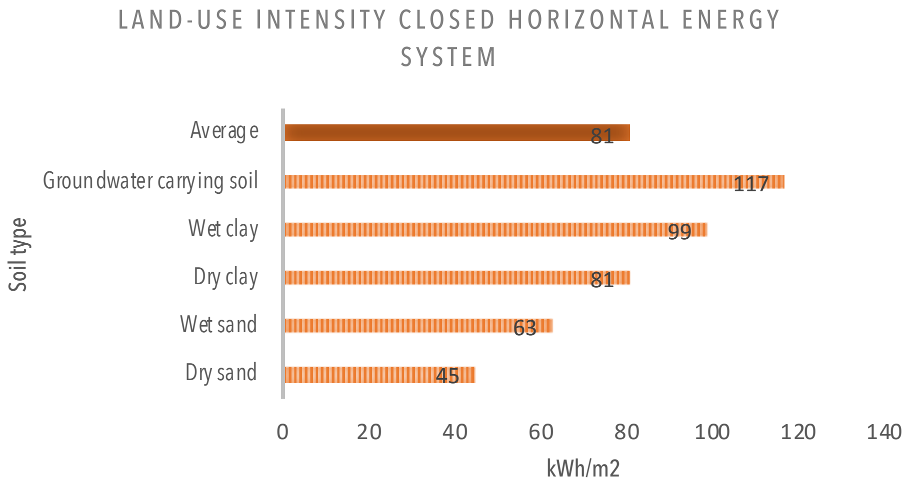
In a closed system, a set of pipes either travels horizontally or vertically into the ground, groundwater or surface water. Cold water is fed into the piping system (1.) which is warmed (2.) and returned to the source. Here its connected to a heat pump (3.) which can generate the desired temperature using electricity.

Open

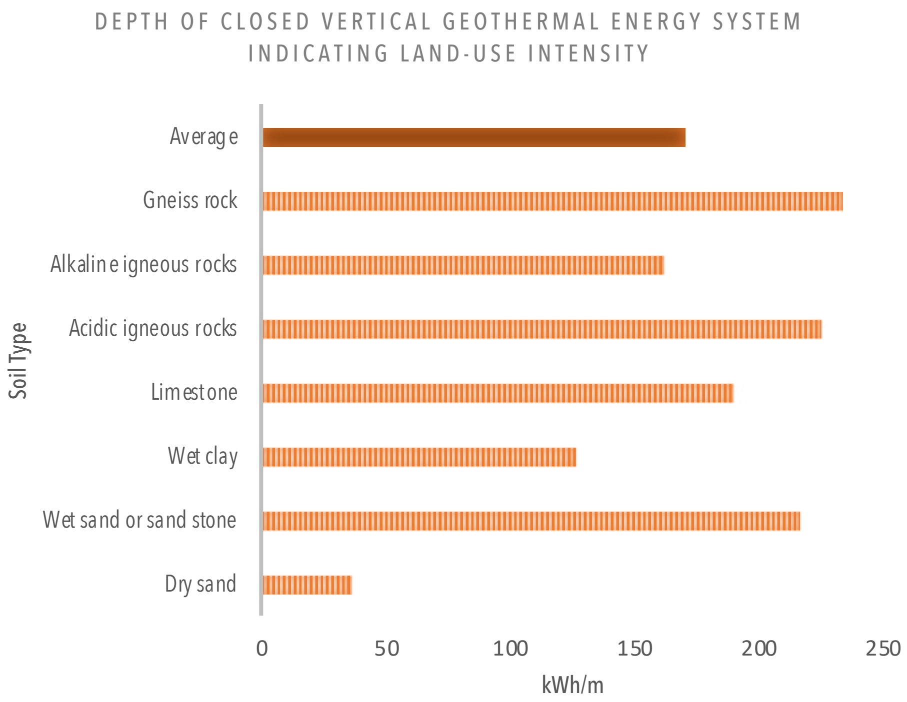
In an open system an underground or above ground water source is used in order to generate heat. Water is extracted through a pipe (1.), heat is transferred to a second set of piping (3.) and released into the environment (2.). In this way the system can also function as a storage for hot or cold when combined with other (heat) sources. A heat pump (4.) can produce the correct temperature water. Water can also be abstracted from surface water even though efficiencies are generally lower due to the temperature changes within the water (Kleiwegt, Opstall, & Budding, 2017).

4.2 Land-use and land-use intensity

All geothermal systems use underground space with only heat pumps and connections visible above the ground. Geothermal systems are therefore generally more easily to integrate as there is enough space underground. This, however, is not the case in areas where the underground space is already crowded with cables and piping such as in cities (Kleiwegt, Opstall, & Budding, 2017). Due to this fact, land-use is still an important factor in the choice for a geothermal system. Closed systems, especially when applied horizontally, require more space than open systems due to the increase in piping. A closed horizontal system can generate around 40 – 120 kWh/m2 depending on the soil type and assuming the system functions around 2000 hours per year and is placed at a depth of at least 1,5 meters (Bodemenergie NL, 2020). This means on average the land-use intensity of a closed horizontal system is around 80 kWh/m2. A vertical system can generate between 25-30 W per meter (Bodemenergie NL, 2020). The land-use intensity for vertical closed systems therefore depends on the acquired depth of the pipes. For open geothermal energy the capacity for heating or cooling depends on the size of the source. Underground aquifers can be heated until 25 degrees warm or cooled until 5 degrees cold (Todorova, Alannea, Virtanena, & Kosonen, 2020). This means that per m3 of water around 0,83 GJ is available which amounts to around 231 kWh per m3 if we take into account a season of around 5 months. For surface water this is less as surface water can only be heated or cooled with a maximum of 3 degrees. Following similar calculations this amounts to around 69 kWh per m3. Apart from the space needed for the installations, extra space needs to be calculated to provide the necessary electricity. Geothermal heat pumps use around 1 part of electricity for every 4 parts of geothermal heat they can abstract (a 'COP' of 5) regarding low temperature heating (Klimaatexpert, 2019). For horizontal geothermal energy systems or systems that use surface water this can deviate due to fluctuating temperatures as these systems are usually more effect by seasonal changes. For hot (potable) water this is around 1 out of 3 (a 'COP' of 3) (Klimaatexpert, 2019).



18. Land-use intensity of a closed horizontal system dependent on the soil type (Bodemenergie)



19. Land-use intensity of a closed vertical system dependent on the soil type (Bodemenergie)

4.3 Landscape integration

Geothermal systems are relatively easy to integrate within the landscape. It is possible to place geothermal systems under any type of surface as long as the visible structures (heat pumps) have a place. It is important to consider surrounding geothermal energy systems as using similar sources can hamper the efficiency and potential of geothermal energy. Geothermal energy systems can be combined with road structures, buildings, agriculture, water and nature. Road structures or other structures such as buildings is not possible in combination with horizontal piping. It is possible to integrate vertical piping (open or closed) as these can be placed at an inclination. For agriculture and nature, it is important to place horizontal geothermal systems at a depth of at least 1,5 meters to prevent ruptures in piping due to agricultural activities or large (tree) roots. For horizontal parts of vertical systems (for connections to households) similar integration rules apply. Surface water can be integrated as a source of heat or cold and therefore these can be easily combined.

4.4 Environmental impact

Geothermal energy systems have little environmental impact: they are generally not visible or excrete odour and have little impact on natural systems if properly designed.

Landscape	Impact	Explanation
Road	Low	No direct impact on road structures were found.
Buildings	Low	No direct impact on buildings or other structures were found.
Agriculture	Low	No direct impact on agricultre was found.
Water	Low - High	The impact of a closed system on the water quality is low. An open system will also not cause a large impact on water quality or ecology if water is flowing (such as in rivers) or the water body is large enough (such as in lakes), however, for smaller water bodies open geothermal systems can impact the flow of the water body or create a short circuit in the system (Deltares, 2018). In other words, the thermal capacity of waterbodies and their flow should be considered in comparison to the preferred thermal capacity to reduce environmental impact.
Nature	Low	Adjusting the heat in underground aquifers has little influence on the geochemical processes, however, it can slightly affect underground bacteria growth and therefore care should be taken during the design and placement regarding nearby potable water sources.

20. Environmental impact of geothermal energy sources

4.5 Reliability

The reliability of geothermal energy systems is relatively high but depends on the type of system (e.g. closed horizontal, closed vertical, open vertical or open surface water). In general, the closer to the surface the system is located, the more fluctuations it will experience due changes in temperature or the warming of the sun.

Time period	Fluctuations	Explanation
Hourly	Not present	-
Daily	Not present	-
Seasonal	Possible	Closed horizontal systems or open surface water systems can be afflicted to seasonal changes due to the warming or cooling of surfaces. Vertical geothermal energy systems experience less to no fluctuations especially when considerable depth is created (Lieten, et al., 2012).

21. Reliability of a geothermal energy source

4.6 Risks

The main risks of applying geothermal energy systems is the disturbance of the underground. This can result in contamination which can have a negative effect on the groundwater quality. The risk of this happening is however relatively low. One of the most important mitigation strategies is to monitor systems consistently. This can detect hazards and prevent a long-term decrease in efficiency, damage of the system or possible groundwater pollution.

Hazard	Risk	Explanation
Warming of the groundwater or surface water	Depends	For groundwater a minimum temperature of 5 and maximum temperature of 25 should be maintained to prevent the growth of bacteria and resulting contamination of groundwater (Todorova, Alannea, Virtanena, & Kosonen, 2020). For surface water the maximum temperature change is 3 degrees as this is part of a larger ecosystem (Kleiwegt, Opstall, & Budding, 2017).
Pollution of groundwater due to leakage or spread of chemicals	Low	In closed systems an antifreeze liquid is pumped around to abstract thermal energy. When the system breaks this fluid can leak into groundwater sources and cause contamination, however, the chances of this happening are relatively low. Furthermore, geothermal energy systems penetrate different layers of earth and can spread pollution if the top ground layer is polluted (Lieten, et al., 2012).
Congestion of open sources	Low	5-10% of open source geothermal energy systems deals with congestion in the supply chain but this is often easily dealt with (Lieten, et al., 2012).

22. Environmental risks of geothermal energy sources

4.7 Geothermal energy in Oosterwold

In Oosterwold it is not possible to implement geothermal systems deeper than 27 meters under the ground level due to possible contamination risks of the groundwater which is used as a potable water source. For this reason, open geothermal energy systems making use of aquifers are prohibited within the area (Gemeente Almere, 2018). In Oosterwold the main soil type is dry clay which means horizontal closed sources can produce around 80 kWh/m2. If vertical closed systems are used at a total length

D. Air heat pump (photo by author, Oosterwold) ▶

of 27 meters this amounts to a maximum of 5 kW per drill (TNO, 2016). Taking into account the total distance of pipes this amount to around 150 kWh/m2.

Opportunities

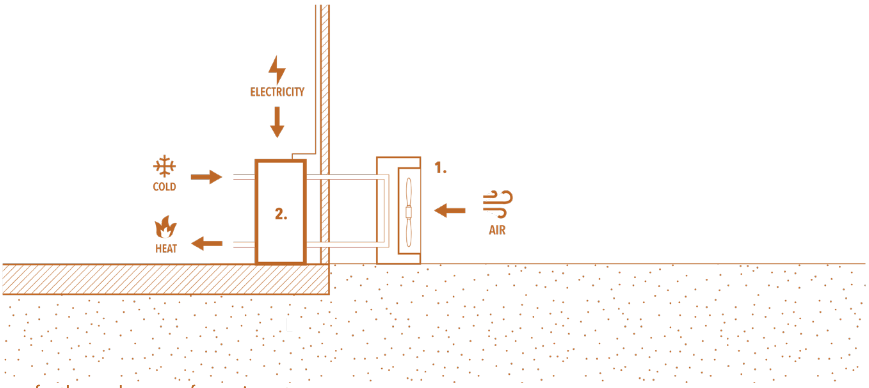
- *There is an abundance of space which can cater vertical and horizontal closed geothermal energy systems.*
- *Geothermal energy systems can provide both cooling and heating for households.*

Challenges

- *There are no large surface water bodies in Oosterwold which makes it impossible to apply open geothermal energy systems in combination with surface water.*
- *Extra caution needs to be taken with the risk of leakages when systems fail as this might contaminate the underlying potable water source.*

E5 Thermal energy from air

Through the application of heat pumps, thermal energy can be abstracted from air. These systems are therefore commonly called 'air heat pumps'. This thermal energy can be abstracted from interior air (inside a building) or exterior air. On top of that, air heat pumps can transmit thermal energy from air to water (or another type of liquid) or to air. In this catalogue we only consider exterior air heat pumps which abstract heat from air to water. This is because interior air heat pumps are generally directed towards an increase in comfort and do not save energy, and air to air heat pumps are not able to provide hot (potable) water.



23. System structure of a thermal energy from air system

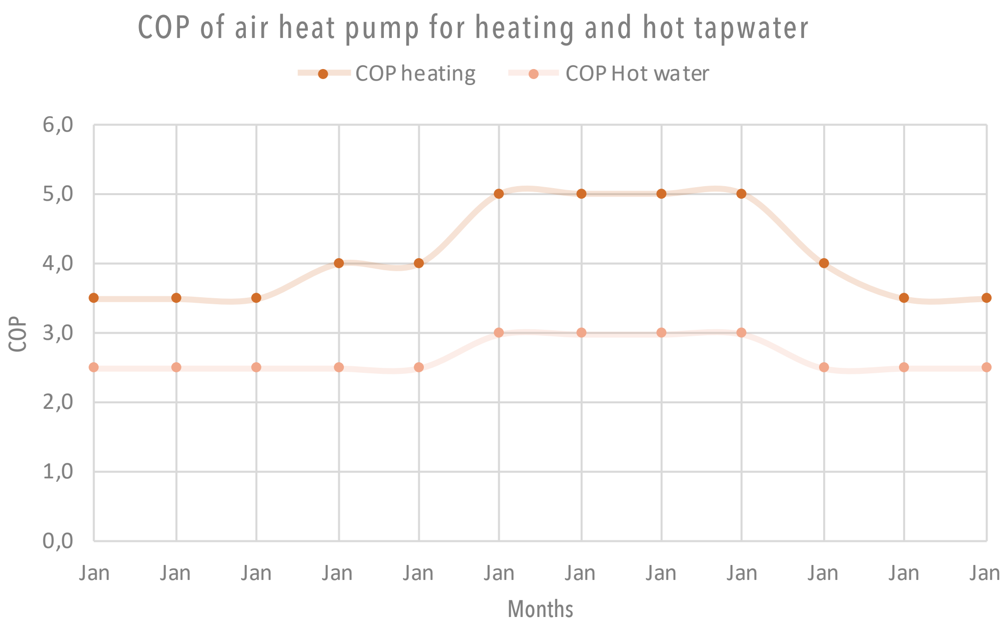
5.1 System structure

An air heat pump draws in air through a ventilator (1.). This air warms water that flows behind the ventilator which is further warmed by a heat pump (2.).

5.2 Land-use and land-use intensity

The land-use of an air heat-pump is dependent on the land-use for the complete installation. The land-use for air heat pumps is therefore almost negligible compared to other thermal energy systems.

However, when the production of electricity is also included as part of their footprint, their land-use will increase depending on the method of electricity production. This is essential for calculating the 'true' average land-use intensity. In general air-based heat pumps use between 2,5 and 4 parts of thermal energy from air compared to 1 part of electricity to generate low-temperature heating in the Netherlands (Klimaatexpert, 2019). This efficiency depends on seasonal changes as air becomes colder in winter and therefor more electricity is needed to provide enough heat. For hot (potable) water this ratio lies between 1 out of 2,5 and 1 out of 3 (Klimaatexpert, 2019).



24. COP (Coefficient of Performance) of an average air heat pump per month based on average outside temperature in the Netherlands, low-temperature heating and hot water production of 60 degrees

5.3 Landscape integration

An air heat pump can only be integrated within or next to buildings as it would directly obstruct vehicles on a road structure, agricultural activity, water or nature. Part of the air heat pump is placed outside of a building where is abstracts outside air while the rest of the installation is placed inside.

5.4 Environmental impact

Air heat pumps can create noise pollution but do not have any other major environmental impacts.

Landscape	Impact	Explanation
Road	Not applicable	-
Buildings	Low	Air heat pumps generally create a low amount of noise, around 35 to 40 decibels, but there are heat pumps (especially more powerful ones) that create a higher amount of decibel. This can lead to nuisance as a heat pump functions day and night. At the moment there are no noise restrictions, however, the Dutch foundation for noise nuisance recommends a maximum sound of 30 dB at 5-meter distance to prevent any nuisance. When this limit is reached, extra soundproof insulation can be used to decrease noise pollution or heat pumps should be placed at a larger distance (NSG, 2019). Furthermore, air heat pumps are, due to their outside placement, relatively visible but this can be reduced by integrating them within the design phase.
Agriculture	Not applicable	-
Water	Not applicable	-
Nature	Not applicable	-

25. Environmental impact of a thermal energy from air system

5.5 Reliability

In general, the reliability of an ai heat pump is high, however, their reliability is for a large part dependent on the reliability of electricity production. If the electricity production is not reliable this means air heat pumps are also less reliable. In the following table we consider the fluctuations in air temperature and therefore the fluctuations in the need for (more) electricity.

Time period	Fluctuations	Explanation
Hourly	Always	The air temperature during the day is dependent on the position and presence of the sun, at night and in the morning more electricity is needed to produce heat and hot water.
Daily	Common	Air temperatures commonly fluctuate from day to day.
Seasonal	Always	Average seasonal temperatures fluctuations due to the position of the sun which relates to fluctuations in electricity demand.

26. Reliability of a thermal energy from air system

5.6 Risks

No considerable risks or preventive legislation was found in literature or documents when it comes to operating air heat pumps. The only small risk is a possible leakage of chemicals from refrigerants or antifreeze liquids used within the heat pump. This can be mitigated by ensuring proper installation and maintenance (Klooster, 2018).

Hazard	Risk	Explanation
Leakage of chemicals	Low	Faulty installation can cause a leakage of refrigerant or antifreeze liquid which can contaminate the soil or air. The risk of this happening depends on a proper installation and maintenance and is generally low (Klooster, 2018).

27. Environmental risks of a thermal energy from air system

5.7 Air heat pump in Oosterwold

At the moment electricity is still provided in Oosterwold. The guarantee for electricity makes air heat pumps an attractive heating solution as this also provides a guarantee for heating, however, in case electricity is produced and used on location an air heat pump can be less efficient.

Opportunities

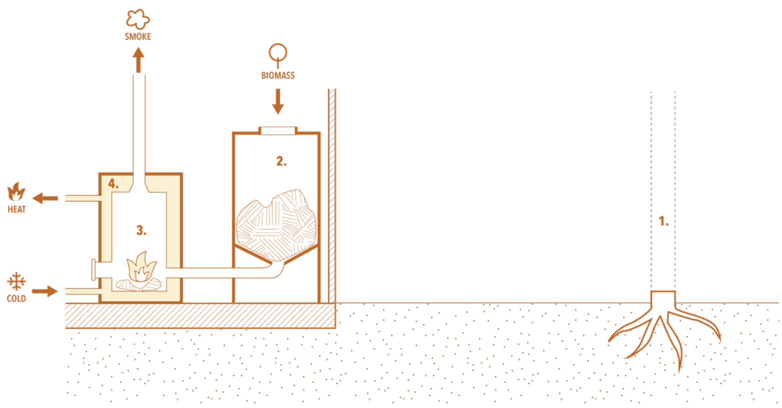
- *Low risk and little land-use*
- *The low household density will reduce the possibility of noise nuance from neighbor thermal energy from air systems*

Challenges

- *In case electricity is produced on site it might be more difficult to provide reliable heating if fluctuations in electricity occur*

E6 Energy from biomass (CHP)

Systems that produce energy from biomass use the calorific value that is contained in biomass to create thermal and/or electric energy. This is done by burning the biomass which can be in a solid, liquid or gas state (respectively ‘biomass’, ‘biofuel’ and ‘biogas’). Biomass is generally obtained from organic waste, sewage waste, gardening waste or vegetation (usually trees). The potential for energy from biomass is therefore directly linked to the potential for obtaining biomass as well as its calorific value. The different types of systems that can obtain energy from biomass are based on the type of biomass and the potential for electricity and/or heat production. This means there are biomass burners, biofuel burners and biogas burners that can either produce heat or a combination of heat and electricity. This last category is often denoted as ‘Combined Heat and Power’ (CHP) systems.



28. System structure of a biomass burner

6.1 System structure

The following system structure is a simplified version of a biomass installation as biomass installations exist in many different versions. The illustration resembles a biomass Essentially an outside source feeds the storage of biomass, gas or fuel (1.). This is then burned with the use of oxygen and used to heat water.

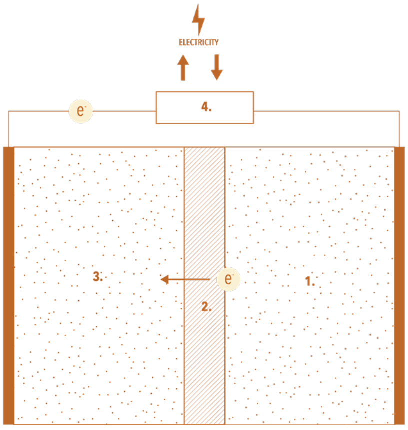
6.2 Biomass systems in Oosterwold

CHP cannot be used in Oosterwold in an autarkic setting due to the large amount of fuel required. Around 1 m3 of wood can be grown on a single plot per year.

E. Biomass burner outlet (photo by author, Oosterwold) ▶

E7 Lithium-ion battery

There are many electro-chemical batteries, but the lithium-ion battery is by far the most popular and commonly used battery. This is due to its relatively high capacity to store energy and long lifespan. The most popular and commonly used electro-chemical battery is the lithium-ion battery. There are also other electro-chemical batteries available but since lithium-ion is most commonly applied due to its relatively high energy density and long life span, only this battery is analysed.



29. System structure of a litium-ion battery

7.1 System structure

The first layer is the anode and is made from a lithium compound (1.). The second layer is the cathode and is made from graphite (3.). The third layer is called the insulator (2.), and it is located between the first and the second layer allowing electrons to pass and either generate or store energy (4.).

7.2 Land-use and land-use intensity

The land-use intensity of a lithium-ion battery depends on the energy density. For lithium-ion this is between 100-250 Wh/L. A conventional home battery has a capacity of around 13,5 kWh and uses around 0,1 square meters (Tesla, 2020).

7.3 Landscape integration

The land-use intensity of a lithium-ion battery depends on the energy density. For lithium-ion this is between 100-250 Wh/L. A conventional home battery has a capacity of around 13,5 kWh and uses around 0,1 square meters (Tesla, 2020).

7.4 Environmental impact

Landscape	Impact	Explanation
Road	Not applicable	There is no impact when lithium-ion batteries are integrated in cars.
Buildings	Low	Operating batteries do not emit sounds or noise.
Agriculture	Not applicable	-
Water	Not applicable	-
Nature	Not applicable	-

30. Environmental impact of a lithium-ion battery

7.5 Reliability

Lithium-ion batteries are relatively reliable batteries. In cold temperature heat needs to be added and in warm temperatures batteries need to be cooled in order to remain within safe operating temperatures (20-35 degrees Celcius). Furthermore lithium-ion batteries experience a power fade overtime which needs to be incorporated in the design for capacity (Gandoman, 2019).

7.6 Risks

Due to the increasing usage of lithium-ion batteries in the Netherlands, fires and other negative events have also increased. This has motivated the government to start writing regulations which will be published in 2020 and activated at the same time as the Environmental Law ('Omgevingswet' (Lepelaar, Meijer, & Berg, 2019). To mitigate the risk of fire a number of measures can be taken according to the the fire department of Rotterdam and the Hague (Lepelaar, Meijer, & Berg, 2019). These regulations concern batteries from cars or the storage of batteries larger than 500 kilograms. In this case outside storage is preferred. Depending on the fire delay of the applied insulation, the distance to other structures or living environment will be determined. If there is no insulation around 10 meters distance is necessary, if some insulation (30 minutes of fire resistance) is applied around 5 meters is necessary and if all fire resisting insulation is applied (60 minutes) then it is possible to place the batteries closer than 5 meters.

Hazard	Risk	Explanation
Fire or explosion releasing toxic gasses	Low	Lithium-ion batteries can be affected by thermal or electric overload or mechanical damage. These can cause a rise in temperature which can turn into a fire and the release of dangerous toxic gasses. These gasses are dangerous for the general health of nearby humans but also make battery fires difficult to extinguish since they react with water resulting in a higher danger of explosion. Only aerosol extinguishers or sand can extinguish these types of fires (Lepelaar, Meijer, & Berg, 2019). When one battery is placed near other batteries this can create a causal sequence.

31. Environmental risks of a lithium-ion battery

7.7 Lithium-ion battery in Oosterwold

Lithium-ion batteries are a good electricity storage techniques for Oosterwold.

Challenges

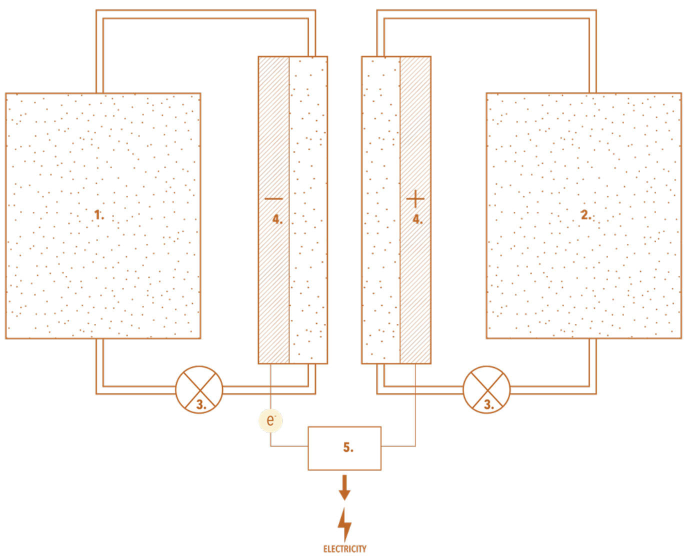
- *Safely integrating lithium-ion batteries due to the risk of fire or explosion*

Opportunities

- *Usage of lithium-ion batteries from cars*

E8 Vanadium Redox Flow Battery

A vanadium redox flow battery uses a redox reaction to create a current. An almost unlimited storage capacity could be created by just enlarging the basin for the electrolytes. The system is highly robust with minimum capacity loss per cycle (no material loss for 20 000 + cycles as compared to 5000 cycles for Lithium Ion), whilst complete discharging will not harm the electrodes. Also, they have very fast response times, not needing capacitors for quick ramp-up. A special development item is the membrane between the electrolytes, to prevent the Vanadium ions from passing and precipitating on the electrodes. The battery is inflammable due to its aqueous nature, making it inherently safe. The cost of the storage is considerably below comparable Lithium based batteries, whilst contrary to Lithium, Vanadium is widely available around the globe. On the downside the batteries take up more space and the Vanadium oxides are toxic needing special care during installation and decommissioning (Wageningen UR, 2019).



32. System structure of a vanadium redox flow battery

8.1 System structure

The system works using two barrels of vanadium, one positively charged (2.), the other negatively (1.). The substance is pushed through an electrochemical cel (4.) using pumps (3.). Here a current develops charging or storing electricity (5.).

8.2 Vanadium Redox Flow battery in Oosterwold

The vanadium redox flow battery is not yet available for domestic use, however, this is about to change in the near future. Large-scale installations have already been built in Hokkaido and Denmark but there are no small scale applications yet. Even though this battery is not yet available, due to its advantages over lithium-ion it deserves proper mentioning and considerations in the future for Oosterwold.

E9 Mechanical storage

Due to the very recent significant advances in battery storage, the different types of mechanical storage are becoming rapidly obsolete due to their higher capital and operating cost as compared to elektro-chemical batteries. They will therefore only be discussed in general terms for completeness.

9.1 Pumped Hydro Electricity Storage (PHES)

PSH is a type of Hydroelectric energy, whereby instead of using the energy of flowing rivers, water is pumped up to a high reservoir storing it as potential energy during low energy demand, which is released by allowing the water to drive a turbine during high demand. It is obvious that a large-scale application can only be made in undulating terrain, or by filling abandoned mineshafts.
Building a closed loop storage even for a single household will require a very large tank (50 m3) at a meaningful height (5-10m), which is not practicable in a typical Dutch neighbourhood or Oosterwold (Pérez-Díaz, 2015).

9.2 Compressed Air energy storage (CAES)

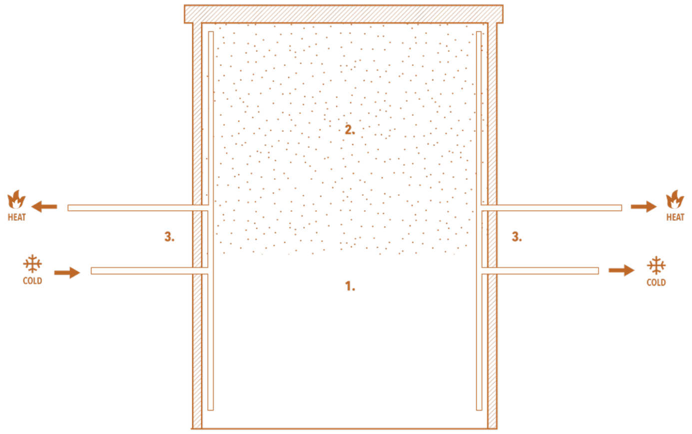
Air can be stored in a cavern or abandoned mine, using compressors to pump the air down during low power demand, whilst using the compressed air to drive a turbine generating electricity during times of high demand (Castellani, 2017). This type of storage is still relatively novel and generally uses a high amount of land making it a non-viable option for Oosterwold.

9.3 Flywheel storage

A rotor disk is accelerated during times of low energy demand, and the rotation preserves the kinetic energy. The energy is released during peak demand through driving a dynamo, whereby the rotation speed slowly reduces. Technological advances through use of magnetic bearings and carbon fibre materials have improved the response time and the efficiency, but due to the much greater progress in battery storage, most of the research around flywheels has been terminated by now (Wu, Yang, & Ye, 2020).

E10 Seasonal thermal energy storage (STES)

Seasonal thermal energy storage can signify a large range of types of heat storage. Many types of seasonal heat storage use underground aquifers for the storage of heat, however, this is not possible in Oosterwold due to the drilling restrictions in order to safeguard the quality of groundwater. There is one type of seasonal heat storage that is left which is the construction of an underground (or above ground) storage tank. This prevents the usage and pollution of groundwater but delivers similar or even better-quality heat storage. During summer energy is converted into warm water and stored underground, whilst in winter this warmer water is re-extracted to provide household heating.



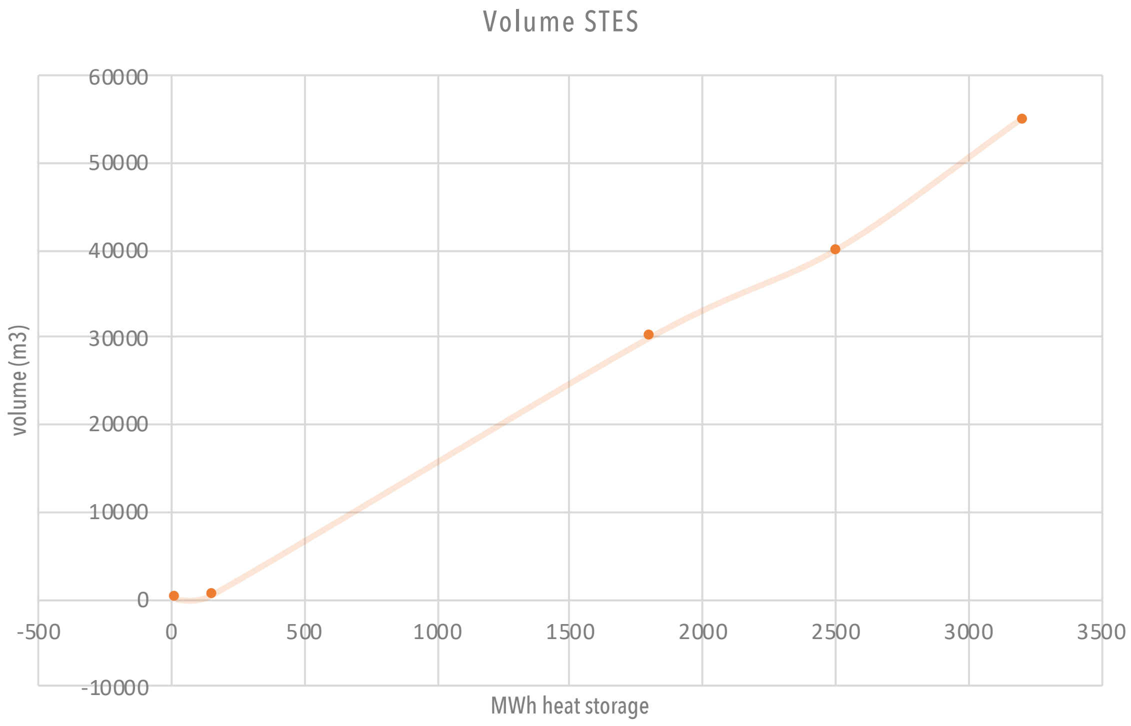
33. System structure of a seasonal energy storage system (based on the Ecovat technology)

10.1 System structure

A large tank is constructed underground with the necessary insulation (1.). When heat is added through the inlet and outlet system (3.), the top layer of the tank slowly becomes warmer. Since heat rises, the top layer of water in the tank can reach a temperature of 90 degrees while the bottom part is relatively cool. This allows the storing of heat and cooling of homes in summer as well as the abstraction of heat and storing of cool water in winter.

10.2 Land-use and land-use intensity

Two known companies in the Netherlands operate these types of systems available from a household to a neighbourhood level. For a household the tank volume is around 83 m3. The size of the tank depends on the difference between the heating demand and capacity for heat production in winter.



34. The total volume of the STES dependent on the amount of necessary heat storage (based on data from Ecovat and Hocosto)

10.3 Landscape integration

The system is easy to integrate in a natural or agricultural landscape as it is located underground. For maintenance reasons it is not possible to place the system under a road or water body.

10.4 Environmental impact

Landscape	Impact	Explanation
Road	Not applicable	-
Buildings	Not applicable	-
Agriculture	Low	There is no known impact on agriculture.
Water	Not applicable	-
Nature	Low	There is no known impact on nature.

35. Environmental impact of STES

10.5 Reliability

The system loses around 25% of the total energy mainly due to pumping losses and in small part due to the conduction of heat to the ground (CE Delft, 2019). Other than that, the system is reliable as long as the sizing is done adequately.

10.6 Risks

There are no known risks of this technology (Ecovat, 2018). Construction mistakes could potentially lead to pollution of the groundwater but this has not happened so far.

10.7 STES in Oosterwold

Challenges

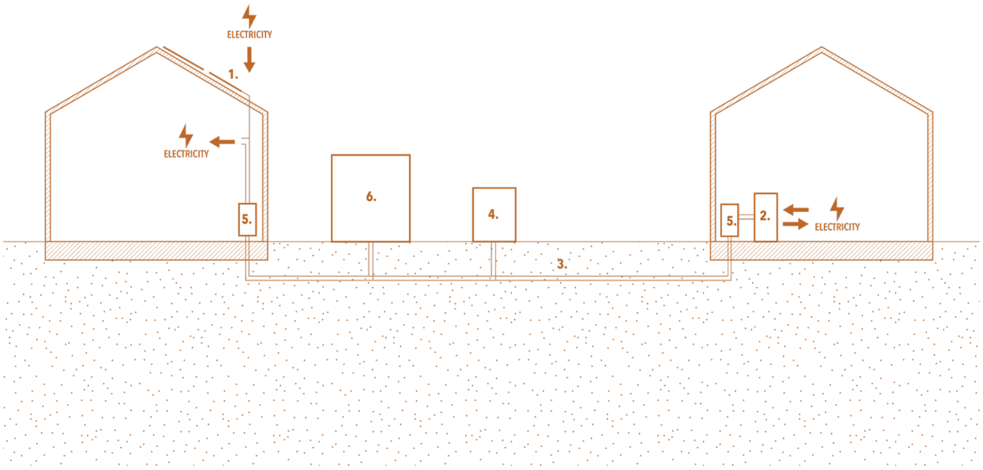
- *Integration of a heat network is necessary resulting in a loss of energy through pumping*

Opportunities

- *The demand for energy can be balanced significantly*
- *There is enough land to integrate the system underground*

E11 (Smart) Low-voltage electricity grid

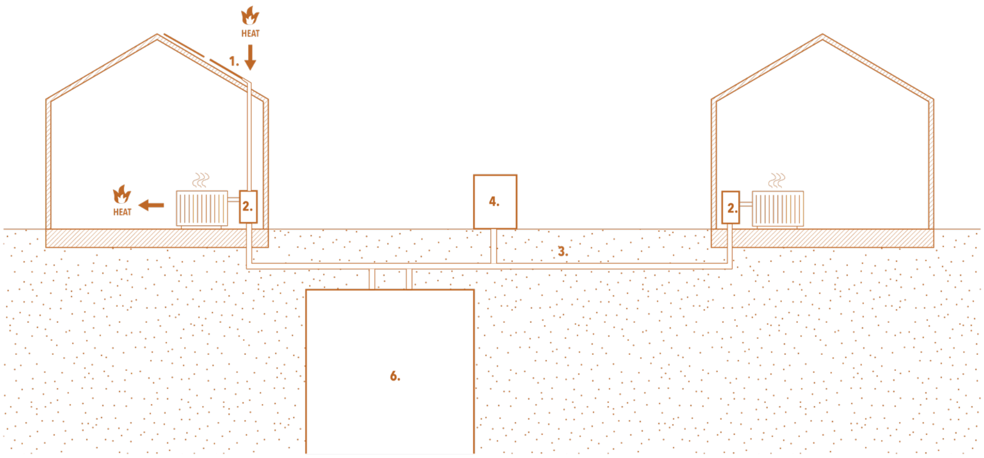
When electricity is produced (1. or 2.) it can be stored (5.) or exchanged via an electricity grid (3.). A computer functioning as control unit (4.) can facilitate the 'smart' exchange of electricity in order to increase the redundancy, resilience and efficiency of the entire energy network. This low voltage grid can be connected to a large-scale high-voltage grid by means of a transformer. The exchange of electricity does account for distribution losses. The voltage loss cannot be more than 5 percent of the total power or voltage according to NEN 1010. This is specifically for low-voltage networks. The loss of power depends on the diameter of the cable, the amount of power that needs to be transported, and the length of the cable. For calculations a maximum loss of 3% is used (Jongbloed, 2019).



36. System structure of a (smart) low-voltage electricity grid

E12 (Smart) Low temperature heat grid

A low temperature heat grid facilitates the transport of heat using hot water with a temperature between 30-50 degrees Celsius. Using a heat pump (1.), water is abstracted from heat storage (2.) or heat production (3.) and transported to households (ECW, 2019). A smart heat grid can also facilitate the exchange and storage of heat through a computerized control unit. The transport losses mainly depend on the electricity use for pumping and can reach up to around 15% of the total energy (CE Delft, 2019).



37. System structure of a (smart) low-temperature heat grid

References

Green, M. (2000). Photovoltaics: technology overview. Energy Policy, 989-998.

ISE. (2019). Photovoltaics Report. Freiburg: Fraunhofer Institute for Solar Energy Systems.

Velds, C. (1980). Zonnestraling in Nederland. Den Haag: KNMI.

Milieu Centraal. (2019, March 4). Zonnepanelen. Opgehaald van Milieu Centraal: https://www.milieucentraal.nl/energie-besparen/zonnepanelen/zonnepanelen-kopen/kunnen-zonnepanelen-op-mijn-dak/

KNMI. (2019, June 3). Weerstatistieken. Opgehaald van Weerstatistieken de Bilt: https://weerstatistieken.nl/

Agentschap NL. (2011, December 1). Gebouw integratie zonnestroomsystemen. Opgehaald van Ministerie van Economische zaken, Landbouw en Innovatie: https://www.rvo.nl/sites/default/files/bijlagen/Gebouwintegratie%20zonnestroomsystemen.pdf

Hui, S. C., & Chan, S. C. (2011). Integration of green roof and solar photovoltaic systems. Integrated Building Design in the New Era of Sustainability (pp. 1-12). Hong Kong: Joint Symposium 2011.

Zwart, F. d., Hemming, S., Ruijs, M., & Gieling, T. (2011). Benutting van zonne-energie in de tuinbouw . Wageningen: Wageningen University.

Choi, Y.-K. (2014). A Study on Power Generation Analysis of Floating PV System Considering Environmental Impact. International Journal of Software Engineering and Its Applications, 75-84.

Posad. (2018). Klimaat, Energie, Ruimte. Den Haag: Nederlandse Overheid.

Borg, N. v., & Jansen, M. (2001). Photovoltaic noise barrier at the A9-highwayin The Netherlands. Brussels: European Commission.

Hooimeijer, F., Rizzetto, F., Riches, F., LaFleur, F., Chastel, C., & Trinh, T.-T. (2017). Resilient Infrastructure and EnvironmentSpatial operation perspectiv. Delft: Delft University of Technology.

Horvath, G., Blaho, M., Egri, A., & Kriska, G. (2010). Reducing the Maladaptive Attractiveness of Solar Panels to Polarotactic Insects. Conservation Biology, 1644-1653.

Weijers, E., & Groot, G. d. (2007). Energiewinning uit weginfrastructuur. Den Haag: Rijkswaterstaat.

Stowa; Ministerie van Infrastructuur en Waterstaat; Unie van Waterschappen. (2017). Thermische energie uit oppervlaktewater. Den Haag: Ministerie van Infrastructuur en Waterstaat.

Agentschap NL. (2017). Zonthermische daken. Den Haag, the Netherlands: Ministerie Economische zaken.

Cace, J. (2010). Praktische toepassing van mini-windturbines. Utrecht: Agentschap NL.

Rijksdienst voor Ondernemend Nederland . (2019). Slagschaduw en windturbines. Utrecht: Ministerie van Economische Zaken en Klimaat .

Bergström, L., Kautsky, L., Malm, T., Rosenberg, R., Wahlberg, M., Capetillo, N. Å., & Wilhelmsson, D. (2014). Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environmental Research Letters, 1-12.

R.Saidur, N.A.Rahim, M.R.Islam, & K.H.Solangi. (2011). Environmental impact of wind energy. Renewable and Sustainable Energy Reviews, 2423-2430.

Vries, M. d. (2018). Veiligheidsprotocol IJsafzetting Windturbines. Utrecht: Nederlandse Wind Energie Associatie.

Gemeente Almere. (2018, Oktober 10). Regels. Opgehaald van Bestemmingsplan Oosterwold: http://www.ruimtelijkeplannen.nl/documents/NL.IMRO.0034.OP5alg01-vg01/r_NL.IMRO.0034.OP5alg01-vg01.html

Milieucentraal. (2019, March 12). Aardwarmte en bodemwarmte. Opgehaald van Milieucentraal: https://www.milieucentraal.nl/klimaat-en-aarde/energiebronnen/aardwarmte-en-bodemwarmte/

European Copper Institute. (2018). Heat Pumps: Integrating technologies to decarbonise heating and cooling. Brussels, Belgium: EHPA.

Bodemenergie NL. (2020, January 26). Keuze bodemenergiesysteem. Opgehaald van Bodemenergie NL: https://bodemenergienl.nl/

bodemenergie/keuze-bodemenergiesysteem/

Kleiwegt, E., Opstall, E. v., & Budding, B. (2017). Thermische energie uit oppervlaktewater. Amersfoort: Stowa.

Todorova, O., Alannea, K., Virtanena, M., & Kosonen, R. (2020). A method and analysis of aquifer thermal energy storage (ATES) system for district heating and cooling: A case study in Finland. Sustainable Cities and Society, 1-15.

Klimaatexpert. (2019, January 1). COP, SCOP en rendement van een warmtepomp . Opgehaald van Klimaatexpert: https://www.klimaatexpert.com/warmtepomp/technisch/cop-scop-en-rendement

Deltares. (2018). De potentie van TEO voor verduurzaming van de gebouwen van het Rijksvastgoedbedrijf en Rijkswaterstaat. Den Haag: Rijks Vastgoed Dienst.

Agentschap NL. (2013). Beheer Warmte Koude Opslag. Utrecht: Ministerie van Economische Zaken.

Lieten, S., Vries, E. d., Baaren, E. v., Bakr, M., Essink, G. O., Hartog, N., . . . Wennekes, R. (2012). Meer met Bodemenergie. Gouda: SKB Duurzame Ontwikkeling Ondergrond.

TNO. (2016). Energieconcepten woningen Oosterwold. Delft, Netherlands: Gebiedsteam Oosterwold.

Miara, M., Gunther, D., T, K., Oltersdorf, T., & Wapler, J. (2010). Heat pump efficiency. Freiburg: Frauenhofer.

NSG. (2019, January 1). Geluidsaspecten van Warmtepompen. Opgehaald van Kennis en Advies over Geluidshinder: https://nsg.nl/nl/geluidsaspecten__van__warmtepompen

NIBE. (2020, January 1). Onderhoud en onderhoudskosten van een warmtepomp. Opgehaald van Nibe: https://aardgasvrij.nibenl.eu/kosten-en-subsidie/onderhoud-en-onderhoudskosten-van-een-warmtepomp

Klooster, E. v. (2018, April 9). Warmtepompen lekken gemiddeld 6% koudemiddel. Fabel of feit? Opgehaald van Warmtepompplein: https://warmtepompplein.nl/warmtepompen-lekken-koudemiddel/

Stichting Nederlandse Haarden- en Kachelbranche. (2017). Pellethaarden en -kachels, de uitmonding van rookgasafvoeren. Ede: NHK.