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Faculty of Engineering Technology
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Designing a sustainable and energy-neutral business park

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Preface

This report is written as part of the 3 months during internship of John Boon at Alliander in Duiven. The internship was under the supervision of Patrick son and Siebo Horenberg. During this internship research was carried out in association with the Groene Allianties. The goal of this research is to find a way to develop an sustainable and energy neutral business park in Duiven before 2025. The internship is part of the Masters program of Thermal Engineering at the University of Twente, Enschede.

I want to thank Patrick Son and Siebo Horenberg for their guidance, assistance, support and their critical way of looking at the progress. Furthermore I want to thank Lammert van Wijk and the Heat and Cold Processes group for the opportunity of doing this internship at this group within Liandon. Finally I want to thank Alliander and the University of Twente for the opportunity they gave me to do this internship.

Abstract

The goal of this research is to find a way to develop a sustainable and energy neutral business park in Duiven before 2025 with the intention to increase the economic gains, improving environmental quality and make the business park future proof. First the current energy landscape of the business park is analyzed. An adapted Trias Energetica is used to find ways to save energy, exchange energy and generate energy in a sustainable way. Finally, different scenarios of the future energy landscape were developed and the most likely scenarios were analyzed to determine if it is possible to develop a sustainable an energy neutral business park before 2025 and what steps need to be taken.

After the analyzation of the current situation it was concluded that the business park is already energy neutral at this moment. The waste processing plant produces a lot of heat and electricity of which just a small part is used on the business park. From the analyzation of the fulfilled future energy scenarios the conclusion was made that it is possible to generate all the energy which is used on a yearly basis on the business park and in a sustainable way.

When the Groene Allianties actually wants to develop this sustainable business park it is important to do address this goal collectively with a lot of dedication of all the companies which are active on the park. The high investments and short realization time makes it a big challenge. Besides this it is important to determine if the adduced solutions contribute to environmental quality the economic gains of the region because it is also possible that it comes at the expense of the surrounding area. Although there are still some complications and challenges at this moment, it is possible to realize a sustainable and energy neutral business park before 2025.

Contents

List of acronyms

ATES	Aquifer Seasonal Energy Storage
BP	Business Park.
COP	Coefficient of Performance
EIP	Eco Business Park
kWp	Kilo Watt Piek
PV-cell	Photovoltaic Cell

1. Introduction

Eco-Business parks (EIP) represent a promising strategy to promote sustainable industrial development and implement industrial ecology concepts. Within an eco-business park businesses cooperate with each other and the local community in an attempt to reduce waste and pollution, efficiently share resources (such as information, materials, water, energy, infrastructure, and natural resources) to achieve sustainable development. The intention of this is to increase the economic gains, improving environmental quality and make the business park future proof[19].

Stichting Groene Allianties is a foundation which is established by an initiative of Alliander with the aim to implement ideas of an EIP into the business park in Duiven. They have set the goal to realize in collaboration with entrepreneurs, businesses, governments, educational and research institutions and local residents a sustainable and future-proof business park. The economical and sustainable benefits that come with them are beneficial for a business park, the businesses in it and the region around the business park. Together with some companies located on the business park in Duiven the organization have set five ambitions:

- To generate all of the used energy in a sustainable way on site of the business park.
- Make a clean, silent and energy efficient business park.
- Make the business park greener and more attractive.
- Recycle the materials used on the business park as much as possible.
- Share facilities, knowledge, experiences and success stories.

This report focusses on the way this business park can be provided with locally generated sustainable energy. In the first part of this report an introduction of Alliander is given, the problem is discussed and a work plan is made to solve this problem. In the second part the problem will be examined and the results are analysed. The report is concluded with a conclusion and some recommendations.

2. Description of the employer

Alliander is a utility company which is responsible for the regional distribution of energy such as electricity, (bio-)gas and heat. Their expertise is to develop, sustain and manage the energy transport networks with the highest reliability. Besides this they provide insight into the energy streams on these networks such that the suppliers and consumers can easily find each other. In the beginning of 2016 they had 7240 employees and maintained 5.7 million client connections. The internal structure of Alliander is shown in figure 2.1.

Figure 2.1: Organogram Alliander

Network operation
The primary task of the network operator Liander is to distribute gas and electricity to nearly six million consumers, businesses and institutions. Liander NV is the largest utility company in the Netherlands, managing the energy network in the provinces of Gelderland and Noord-Holland entirely, and in large parts of Flevoland, Friesland and Zuid-Holland. Within these licensed areas they have the natural monopoly status but strict regulations come along with this status. They can only transport energy but they are absolutely not allowed to supply and trade energy to consumers[4].

Infrastructure and services
The infrastructure and services group is not bounded by these regulations. Kenter offers innovative solutions for energy metering and energy management and Allego provides charging infrastructure and services for electric mobility[3].

Liandon is concerned with developing sustainable technologies and intelligent energy infrastructures and is the innovation engine and knowledge center within the energy market for the network operator. They offer consultancy, advice, design, implementation and maintenance. Within Energy Consulting about 150 professionals are active in five areas of expertise:

- Gas, heat and sustainability
- Strategic environment management
- Electrical engineering
- Telecom and IT
- Heat and Cold Processes

Alliander aims to play a leading role in the energy transition to a more sustainable future. They are alert to new technologies and trends in the evolving energy landscape. Alongside the work as a network manager, they are also making targeted investments in for example electrically-driven transport, sustainable spatial planning and sustainable living. As part of these innovation projects they started an initiative called the Stichting Groene Allianties. The aim of this foundations is to develop, together with entrepreneurs, businesses, governments, educational and research institutions and local residents, a sustainable and future proof business park in Duiven, on which the head office of Alliander is located.

The research which is discussed in this paper is carried out in the Heat and Cold Prosecces department of Liandon and comissioned by the Stichting Groene Allianties.

3. Defeniton of the problem

Stichting Groene Allianties has set the goal to realize a sustainable and future-proof business park, which is also known as an Eco-Business park(EIP). The economical and sustainable benefits are beneficial for the business park, the business in it and the region around it. An EIP attracts companies who want to establish at the business park. Business derives cost savings and new revenues by shared services, reducing regulatory burden and increasing the competitiveness with other business parks. Finally this the community enjoys a cleaner and healthier environment.

This report is focused on the future of local energy: energy which is produced locally on a sustainable way of which the demand and respond is balanced. By realizing this goal the business park will be less dependent on external factors and the environmental impact of the park will decrease. Stichting Groene Allianties has set the goal to realize this energy self-supplying business park before 2025 but without prescribed realization plan. The current situation of the energy landscape is unknown which makes it impossible to determine the changes which have to be made before 2025. Therefore both current and future demand and way of production of heat, cold and electricity needs to be determined. from this follows the general research question: Is it possible to collectively realize a sustainable and energy neutral business park before 2025?

4. Work Plan

Before the problem of generating all the energy locally can be solved it is important to first provide insight in what the current energy demand is and how this demand is fulfilled. Therefore the current heat, cold and electricity demand needs to be known and the way this energy is produced. Provided literature needs to be studied and information from the energy suppliers needs to be retrieved. Combining this information will give an overview of the current situation.

The next step is to use the adapted Trias Energetica which is developed as a three-step strategy to design the most sustainable possible energy supply. The first step is to find solution to lower the energy demand, the next step is to exchange energy between companies and the last step is to find ways to produce sustainable energy locally. Only when the energy demand is minimized the focus should shift to renewable energy solutions.

- **Trias Energetica - 1. Lower consumption**
  First ways to lower the energy consumption needs to be searched for. The possible reduction in energy demand is checked from which the impact the solution on the energy landscape follows. Besides this the advantages, disadvantages, the price of implementation and the chance of succeeding are checked. Combining this gives the accessibility of implementation. The impact and the accessibility are plotted against each other in a matrix from which the solutions with the highest impact and accessibility follow. To come to a successful result the focus will be on the most important solutions.
- **Trias Energetica - 2. Energy exchange**
  The second step is to find ways to exchange energy which also lowers the amount of energy which needs to be produced. A lower demand on generated energy makes it easier to succeed in the goal to generate all the energy locally and in a sustainable way. Possible methods to exchange energy are searched for and the impact of implementation and the accessibility of implementation are determined. The focus will be again on the most important methods.
- **Trias Energetica - 3. Efficient use of sustainable resources**
  In the final part of the Trias Energetica methods and strategies to produce the remaining energy demand locally on the business pare are determined. In the same way the most important methods, with the highest impact and the highest accessibility of implementation are determined.

To be able to come to a successful answer on the research question first the demand in 2025 needs to be determined. This energy demand will be based on the current energy demand. Scenarios which can influence the energy landscape in the period till 2025 are determined. Again the impact on the energy landscape is determined together with the possibility of occurrence. The two factors are plotted in a similar matrix from which the three most important scenarios follow. These scenarios are used to determine the three different energy demand profiles.

Finally the results of the Trias Energetica are used to find ways to fulfill in the energy demand of the different scenarios. A fourth scenario is also taken into account in which the energy demand is unchanged compared to the current energy demand. From this a conclusion can be made on what the way forward should be to a sustainable self-supplying business park.

5. The business park

The business park in Duiven consists of four different sub-parks located around the highway A12 near Arnhem, as shown in the figure 5.1. Most of the companies on a sub-park are active in the same field of work. This is shown in the table below. In 2010 the business park ensured about 14.000 workplaces[13]. The data of the sub-parks is shown in table 5.1.

Table 5.1: Overview of the business park

	Area (hectare)	*Category*
Centerpoort-Nieuwgraaf	83	Production, wholesale and retail
InnoFase Synergiepark	90	Heavy industry
Centerpoort-Noord	51	Logistics
Centerpoort-Zuid	15	mixed companies
Total	239	

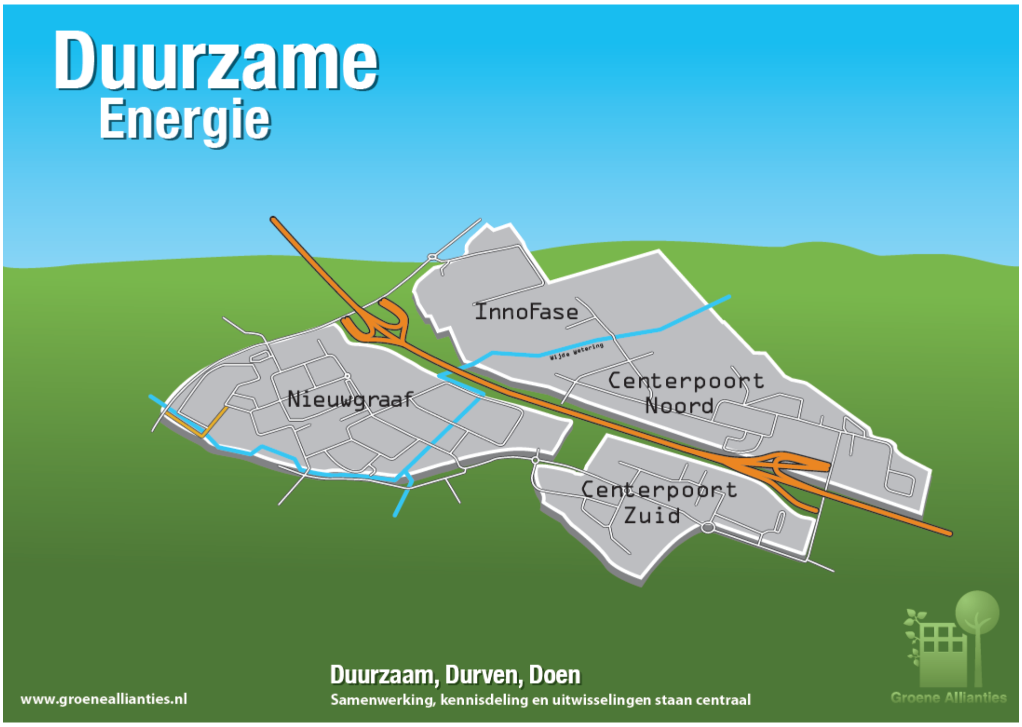

Figure 5.1: Schematic overview of the business park

6. The current energy demand

The three primarily used energy forms used on the business park are heat, cold and electricity. Most of the heat is generated in the AVR from the incineration of waste. Besides this heat is generated from the burning of natural gas and heat is stored in Aquifer Seasonal Energy Storage (ATES). A distribution grid transports the heat from the AVR to the businesses located on the park. The used cold energy is generated from electricity or stored in ATES. Electricity is produced in the AVR, RWZI with solar panels and with windmills. All these electricity producers however are connected to the national electricity grid, and therefore not solely provide electricity to the business park.

6.1 AVR

AVR is waste processing company which is located on InnoFase sub-park in Duiven. The waste material processed consists of just about everything, from fruit, vegetable and garden waste, plastic, waste wood and paper pulp. Some part of the waste is recycled but the remaining part is converted into heat by incineration. A moving grate furnace is used to incinerate the waste. The remaining ashes are collected and used in products like cement or in road construction or disposed on landfill sites. The flue gasses are run through a boiler where steam is generated and after some cleaning steps the gasses are emitted via a chimney to the outer atmosphere.

The steam from the boiler is run through a steam turbine to generate electricity. The outgoing flue gasses are used to heat up water in a district heating network. The district heating network is run in summer on $80°C$ and in winter it is reached to $120°C$ to transport more energy through the network. To heat the temperature of the network to this high temperature level steam team at lower pressure is extracted from the steam turbine. This results in a lower electrical efficiency of the steam turbine. Incinerators have electric efficiencies of 14-28%. The total efficiencies of co-generation incinerators are typically higher than 80%. The facility is connected to a district heating network which transport heat to households and industries in Arnhem, Duiven and Westervoort[5]. The renewable percentage of the generated energy is assumed to be 53% as of the burned waste consists of 53% of renewable sources. An overview of the process is shown in figure 6.1.

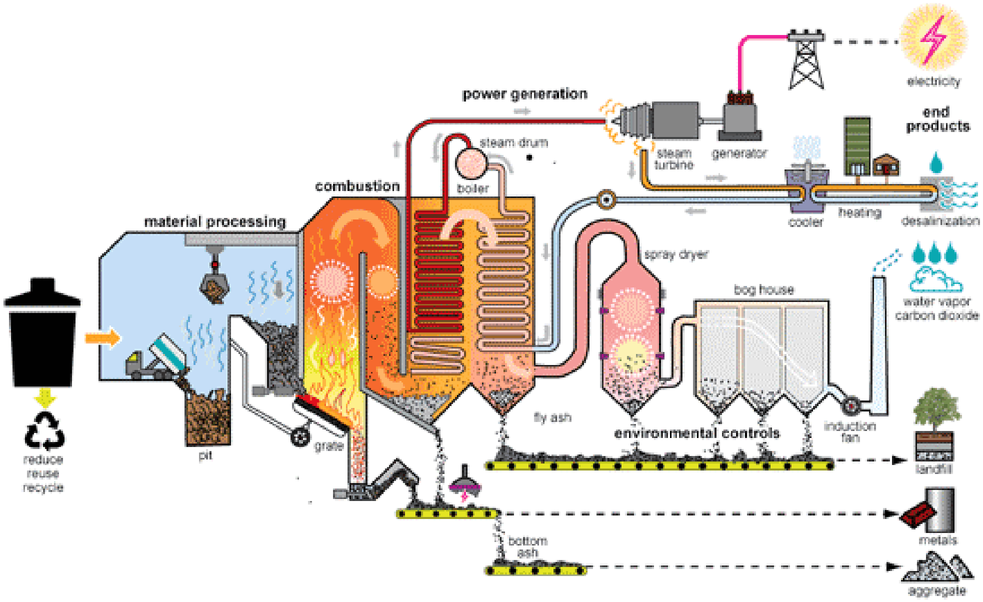

Figure 6.1: Waste to energy plant

The AVR expected in 2015 to deliver 239.44 GWh of heat to the district heating network and produce 93 GWh of electricity. The data of 2014 and earlier is also known but in 2014 the district heating network is extended and so the expected produced heat in 2015 is the most realistic data of the current situation[5].

The water temperature in the district heating network is higher than its surroundings. As a result heat is conducted through the wall and isolation. This effect is amplified by the long length and density of the network. This conduction of heat is enhanced by the fact that a part of the network already was constructed in the 1980′s. This will increase the chance of broken and wet isolation of the pipes. From knowledge within Heat and Cold Process engineering group within Liandon the heat loss can be estimated on about 20% . This will result in an estimated heat delivery to the consumer of 191.55 GWh.

To determine the amount of energy used on the business park the delevired heat via the district heating network needs to be determined. Nuon stated that in 2015 14,261 household equivalents of heat where used in Duiven and Westervoort together of which 7,013 (49%) household equivalents where used by the industries[26][28]. A household equivalent is the average capacity of the district heating connection of a household. Another source of Nuon states that 127.45 GWh of thermal energy was transported to Duiven and Westervoort. Assuming that the ratio between the household equivalents is the same ratio as the yearly heat use it is estimated that about 62.68 GWh of heat is used on a yearly basis by the industry[28].

The industry in Duiven and Westervoort is not entirely accommodated on the business park but there is not another large business park. The assumption is made that 95% of all the thermal energy used by the industry is used on the business park. From this it is estimated that 59.55 GWh of heat is used on the business park and 132.01 GWh is used in Duiven, Westervoort and Arnhem by households and industries.

6.2 Natural gas

Most of the heat is used to heat up offices and factory halls. Still a lot of natural gas is consumed which is primarily used in processes which require a high temperature. The temperature of the water delivered by the district heating network is in summer 80 degrees Celsius and in winter 120 degrees Celsius which is too low to use in most of the processes. The total used natural gas in 2010 was 2,089,000 Nm3[27]. With a caloric heating value of 0.03165 GJ/Nm3 and a boiler efficiency of 95% about 17.45 GWh of thermal energy is used by burning natural gas[9].

6.3 Electricity

As discussed before the AVR expected to produce 93.00 GWh of electricity in 2015. Besides the AVR there is also electricity produced with PV-cells and windmills. In 2014 four large windmills where installed which produce 18.0 GWh of electricity on a yearly basis[14]. There are some solar power initiatives which produce electricity. At the new Alliander office the parking lot is covered with PV panels with a total power of 1.5 MW which produce 1.48 GWh of electricity every year[15]. The AVR have installed some PV panels which produce 0.17 GWh there are some insignificant PV-panels and small scale windmills installed. This results in a total electricity generation of 112.65 GWh on a yearly basis. The total used of electricity on the business park is 53.28 GWh which means that 59.37 GWh electricity is exported and used externally.

6.4 Aquifer Thermal Energy Storage

On the business park three ATES systems are used by three companies: Alliander, Makro and Ikea. The total amount of cold and heat which can be stored in these system is unknown but with the assumption that all the cold energy which is used by these companies is delivered by the ATES systems an estimation is made.

The floor area is of these three companies is known from the BAG-register and the cold demand per unit area and operating hours per year from BRSIA[23]. This info is shown in the next table. Combining this info gives that the current ATES system provide about 2.61 GWh of cold energy per year. An overview of the data of the different systems is shown in table 6.1.

The electrical cooling COP of the ATES system is 30 while the electrical heating COP is 3.5 . There is a large difference between these COP′s because the cold energy can be used directly to heat up the building and only a few pumps are needed which use electricity. In winter a high electricity consuming heatpump is used to increase the temperature of the hot water for heating purposes. From this follows that 0.09 GWh/year electricity is needed to provide the cooling and 0.75 GWh/year electricity is needed to provide the heating to the buildings on a yearly basis.

Table 6.1: ATES systems Duiven

	Alliander	Makro	Ikea
Floor area (m2)	25.528	21.200	38.372
Cold demand (W/m2)	50	25	25
Yearly operating hours (hours)	800	1067	1067
Cold demand (GWh)	1.021	0.565	1.023

6.5 Cold energy

The total cold demand is calculated in two different ways: once based on the electrical demand and once using surface area combined with the company function.

Every year the RVO, the national office of enterprising Netherlands, gathers information about the average electricity use for cooling based on the primary electricity use. The average use of electricity for cooling in case of industry, production, logistics is about 12.5%. The total energy use is 53.29 GWh from which the electricity used for cooling purposes can be calculated and is 6.482 GWh. The average COP of the installed cooling installations is 3.5 from which follows that the cold demand is 22.69 GWh/year[25].

The other way to calculate the cold demand based on the function and surface area of all the companies on the business park. This data is gathered using the BAG register. The cold demand and operating hours are shown in table 6.2 and are based on info from RVO[25]. This results in a total cold demand of 18.88 GWh/year.

Table 6.2: Cold demand and operating hours of different functional buildings

Function	Cold demand [W/m2]	Operating hours [hour]
Meeting function	50	300
Healthcare	50	800
Industrial	20	1000
Offices	50	800
Education	20	300
Other	20	500
Sporting facilities	50	500
Shopping	20	800

The biggest difference between those two calculations is that the second way uses just two general number while the last way calculates the cooling capacity of every building separately. This makes that the last way seems more realistic and so from now on a cold demand of 18.88 GWh is taken.

A part of this energy demand is fulfilled with ETES (2.61 GWh) and the other part is fulfilled with electrical compression cooling systems (16.28 GWh). When using an average electrical cooling installation with a COP of 3.54, 4.60 GWh of electricity is needed[25].

6.6 RWZI

A sewage treatment installation called RWZI-Nieuwgraaf is located on InnoFase. Sewage treatment is the process of removing contaminants from wastewater, primarily from household sewage. It includes physical, chemical, and biological processes to remove these contaminants and produce environmentally safe treated wastewater (or treated effluent). A by-product of sewage treatment is usually a semi-solid waste or slurry, called sewage sludge. The sewage sludge can be used in an anaerobic digestion process to produce biogas. After digestion the sludge is dried and burned. In conventional secondary treatment processes, most of the electricity is used for aeration, pumping systems and equipment for the dewatering and drying of sewage sludge. The anaerobic digestion can produce enough energy to meet most of the energy needs of the sewage treatment plant itself[38].

The RWZI is designed to treat the water of 330.000 people equivalent per year[14]. It is unknown what the internal energy production and demand is but biogas is produced and used within the plant and heat from the outgoing effluent is reused.

6.7 Overview of the current situation

With all the gathered and calculated information an overview of the current situation can be made. The overview is shown in figure 6.2. The left part shows the generation of energy while the right side is the consumption. The right part of figure 6.3 shows the total generation of energy on the business park. What strikes is that there is already an excess of heat and electricity and with this energy enough cold energy can be produced. The business park is self-sufficient in heat, cold en electricity but the natural gas cannot be fulfilled locally.

In the right part of figure 6.3 an overview of the consumed energy and the sustainability of it is shown. The sustainability of the heat is about 55% and the gas use isn't sustainable at all. The used electricity has a sustainability of about 75% because a about 19.5 GWh is generated by the sustainable PV-panels and windturbines while the other part is generated with 53% sustainability at the AVR. The cold is produced with a part of the electricity but also with ambient energy and energy stored energy in the WKO system.

In Appendix C an expended overview of the current situation is given. The goal from now on is to increase the sustainability of the used energy and to make a self-sufficient business park.

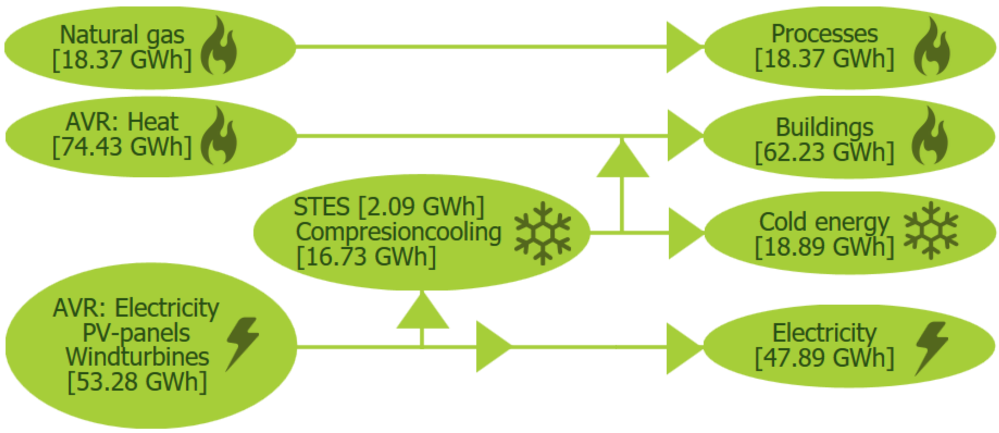

Figure 6.2: Overview of the current energy landscape on de business park

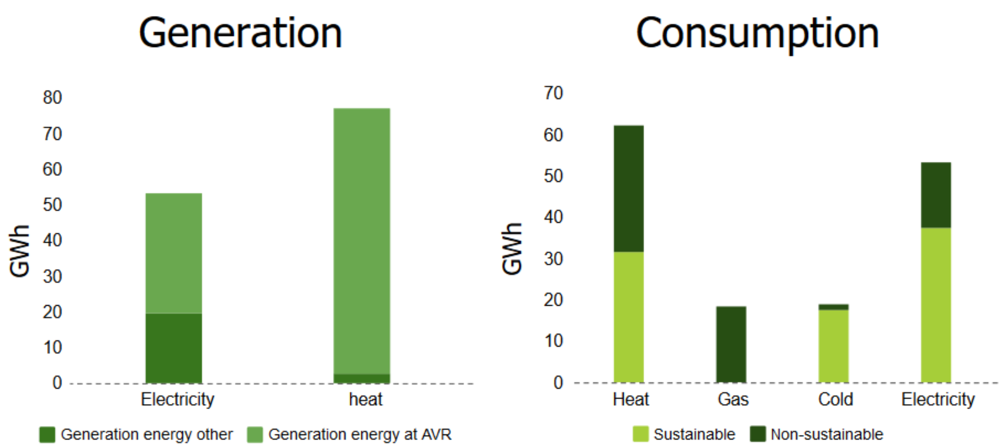

Figure 6.3: Generation and consumption of energy on de business park

7. Adapted Trias Energetica

The Trias Energetica strategy is developed by Kees Duijvenstein from the TU Delft and is primarily used in the design of sustainable buildings. It consists out of three steps: Reduce the energy consumption, maximize the use of sustainable energy and use fossil fuels in the most efficient way. As the aim of this research is to exclude the use of fossil fuel and the strategy is used on a business park instead of on building, an adapted Trias Energetica is used. The adapted Trias Energetica consists out of the next three steps: find solution to lower the energy demand, to exchange energy (waste-)streams and maximize the use of sustainable energy. In this chapter these three steps are analysed and discussed to find the best possible solutions for the business park. The impact of a solution on the energy landscape is checked in combination with the accessibility of implementation which follows from the advantages, disadvantages, the price of implementation and the chance of succeeding.

7.1 Energy savings

The first step on a path to local and sustainable energy generation is to lower the energy demand. When the energy losses are minimized it automatically lowers the amount of energy which should be generated. Only when the energy losses are minimized the focus should shift to renewable energy solutions because this makes it easier to succeed in the final goal. Extensive literature research is performed to make a list with all kinds of techniques which can be used to lower the energy demand. The list is shown in table 7.1.

Table 7.1: Techniques to save energy

Method	**Details**
Energy scan	Thermal heat scan of the in- and out-side of the building
	Measuring electricity consumption installations
LED-lights	Replace street light
	Replace interior lightning
Sustainable building	Build new buildings according to a strict sustainability protocol
Sustainable rebuilding	Rebuild a buildings according to a strict sustainability protocol
Intelligent process control	Lower energy demand by automatically control processes in an energy efficient way
Automatization	Automatization of heating, ventilation and lighting in combination with smart climate control
Isolation	Isolation of installations and buildings
Low temperature heating	Heating of buildings with low temperature climate systems
Green roofs	Use plants on a flat roof to isolate the building and increase the air quality
Separated sewage for greywater	Reducing the amount of treated wastewater
Collective transport	Combining cargo
	Shared cars
	Carpooling
	Shared bicycles
Increase of sunlight	Use a Solabtube or roof windows to increase the incoming sunlight in buildings and decrease the artificial lightning
Solar protection	Solar protection for buildings decreases the cooling demand during the summer
Night cooling	Cool buildings down during the night to lower the cold demand during the day
Smart streetlights	switch the lightning of during the night or decrease the amount of lightning

These different solutions can be used to lower the energy demand. The reduction of each technology on the energy demand, when they are implemented on a large scale, is analysed. From this follows the impact of the technologies on the energy landscape. On the other hand the accessibility of implementation is analysed which is based on the advantages, disadvantages, the price of implementation and the chance of succeeding.

7.2 Exchange of energy

The second part of the adapted Trias Energetica consists of technologies to exchange energy. Exchanging of wast streams of energy will reduce the final energy demand which makes it easier to succeed in the goal to generate all the energy locally. Besides this it is important that the locally produced energy can be transported to the different locations of the costumers. Other important factors which are taken into account are the storing of energy and transformation of energy to other forms. This can be really important when a surplus of a certain energy form is produced.

Transportation of energy
The transportation of energy can be realized in different ways. One way to transport heat is through a district heating network. There is already a district heating network constructed on the industrial park in which heat is transported from the AVR to the companies and the surrounding areas. The temperature of the network is between $80^\circ C$ and $120^\circ C$. Industrial processes often need heat or steam on a higher temperature. A separate heating network could be installed to transport heat of for example $150^\circ C$. The AVR makes it possible to deliver steam at 190 degrees and 12 bar to companies on InnoFase but there are no companies who make use of it yet[37].

The effluent of the wastewater from the RWZI contains a lot of energy but the temperature difference with the surroundings is only $7^\circ C$. This makes it difficult to compete with the large heat producing AVR. A separate heating network on a temperature with a temperature of about $50^\circ C$ could be installed to make use of this lower temperature. Besides this there is a lot of heat available at companies in retail and logistics with a large freezing capacity. This could also be inserted into this lower temperature district heating network.

Another option to transport energy is in a cold district cooling network. Water or other fluids can be cooled down till below the ambient temperature at a central locations. The cooled fluid can be transported through a network of pipes to the consumers which can use it to cool down their buildings and processes. The small scale air-conditioning systems will no longer be necessary and it can result in lower energy and cost efficient way for cooling puroposes.

Other energy forms like liquids and gases can be transported through a transport network or using gas tanks, oil drums, etc. Most of the companies are connected to a gas network. This network could for example be used to transport bio-gas to the companies.

Electricity is exchanged through a large scale electrical grid. Electricity is produced by the AVR, with solar panels and wind turbines which are located on the business park. Other national and international producers are however also connected to the same electricity grid. To exchange energy locally it is also possible to install a microgrid. A microgrid is a local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously.

An overview of the different methods is given in table 7.2.

Table 7.2: Exchanging energy methods

Method	**Details**
District heating network	Transporting and exchanging heat ($80^\circ C$ >T>$120^\circ C$)
	Transporting and exchanging heat (T>$150^\circ C$)
	Transporting and exchanging heat ($50^\circ C$ >T>$80^\circ C$)
	Transporting and exchanging cold (T<$15^\circ C$)
Exchange of bio-energy	Using a transport network
	Using gastanks, oildrums, etc
Microgrid	Local energy grid to exchange electricity

Storing of energy

Energy produced at one point in time can be used at a later point in time by making use of energy storage. An excess of produced energy can for example be stored to use at another moment when it is useful again. When changing to sustainable energy generation using solar and wind power this becomes more and more important.

Seasonal thermal energy storage (or STES) is the storage of heat or cold for periods of up to several months. The thermal energy can be collected whenever it is available and be used whenever needed, such as in the opposing season. This storage can for example be done in the ground or in an open water reservoir. There are two different ground systems: the open and closed systems. Open systems pump directly hot and cold water into aquifers in the ground while the closed systems make use of closed pipes in which a liquid runs to exchange energy with the surrounding ground.

An excess of electricity can be stored in batteries. This stored energy can be used for peak shaving purposes to supply the peaks of a highly variable load. It is possible to make use of a battery pack which are installed on the business park but another option is to use batteries of electric cars. At this moment it is still really expensive to store large amounts of energy in batteries. The current price is above 300 US dollars per kWh and the lowest price in 2020 is estimated on 230 Euro per kWh[24][6].

Pumped-storage hydroelectricity is a method which stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines to produce electric power. Large height differences make the system more efficient but the differences are not that high near the business park which makes it difficult to make use of this technique.

Liquid or gasses can be installed in tanks, oil drums, in other materials or on other ways. The stored energy be used on a moment when the energy demand is higher than the production at that moment.

Table 7.3: Storing energy methods

Method	**Details**
Seasonal Thermal Energy Storage	Closed system
	Open system
	Water reservoir
Battery	Batteries from electrical cars
	Local battery system
Pumped-storage hydroelectricity	Storing electricity by pumping up water to a higher level
Gas and liquid storage	Using gastank, oildrums, etc

Transformation of energy

Transformation of the form of energy can be useful when there is an excess of one energy form while there is a lack of another. Another reason to choose to transform an energy form is when another form is easier to store.

One technique to transform heat into cold energy is by making use of sorption cooling. The AVR produces a lot of heat in summer while the demand for it is really small and the cold demand is high. This would make it an good option to make use of.

It is easy to transform electricity into other forms of energy. Electricity can be used to produce heat in an electric boiler. Power to hydrogen is a method which uses electricity to split water into hydrogen and oxygen by means of electrolysis. The hydrogen can be stored and produce electricity using a fuel cell. Other ways to use this hydrogen is to produce methane or Ammoniac. Methane can be used in the natural gas network and be burned for heat and electricity. Ammoniac can also be burned or used in a fuel cell. Both methane and ammoniac are easier to store compared to hydrogen.

A heatpump is a useful way to increase the temperature to a higher level. It is possible to use this kind of transformation to lift the energy level of district heating so it can be used for industrial purposes.

Table 7.4: Upgrading energy methods

Method	Details
Sorption cooling	Transforming heat to cold energy
Power to gas	Transform electrical energy into hydrogen
	Transform electrical energy into Ammonia
Power to heat	Transform electrical energy into heat
Heatpump	Upgrading the temperature

7.3 Energy generation

The previous parts of the Trias Energetica is used to find ways to lower the energy demand and exchange energy. The final step is used to find sustainable ways to generate the remaining energy demand. An overview of the results is shown in table 7.5.

Table 7.5: Energy generation methods

Energy generation technique	output
Solar power	Electricity
Wind energy	Electricity
Hydropower	Electricity
Solar water heating	Heat
Geothermal energy plant	Heat
Miscanthus cultivation	Biomass
Vegetable, fruit and green waste	Biomass
Industrial waste	Biomass
Sewer sludge	Biomass
Animal waste	Biomass
Algae cultivation	Biomass

Solar panels convert light into electricity using semiconducting materials that exhibit the photovoltaic effect. At this moment about 1.7 GWh is generated on a yearly basis: 1.48 GWh at Alliander, 0.17 GWh at the AVR and besides this some spread solar panels around the business park. Besides this de Groene Allianties is in association with Energie Van Hollandse Bodem to double the amount of solar panels by installing an extra 1.5 hectare of panels with a yearly generation of 1.92 GWh in 2017[20]. The panels at Alliander are installed as a roof of a parking lot while the planned 1.5 hectare of solar panels are going to be installed on the ground. Roofs of building are however also very suitable to install solar panels because this area can not be used for a lot of other purposes and it increases the insulation of the roof.

Wind turbines can be used to generate electricity on the business park. In 2014 four wind turbines where installed with a height of 150 meters and a production of about 18 GWh per year. It possible to extent this wind park by installing more of those wind turbines or by installing smaller wind turbines.

Hydro power is a way to derive power from the energy of falling water or fast running water. The river de IJssel streams along the business park but the height differences are relatively small which makes it difficult to extract energy from it. It is however possible to install small hydropower installations which produce energy from streaming water but the efficiencies are low and the investment is high[41].

Solar water heating is a technique to convert sunlight into thermal energy. Thermal collector can be used to produce heat and can for example be installed on a roof area. Another way to produce heat from sunlight is by installing collectors in asphalt.

Geothermal energy is thermal energy stored in the earth. The hot water can be pumped up from water holding earth layers. These layers can be on a depth up to 10000 meters but in general water holding layers up to 3000 meters are used. The temperature just below ground level is $10°C$ and increases with about $31°C$/km. In 2014 a total of 13 deep wells where installed in the Netherlands with a total of about 100 MWth and an annual production of 416 GWh[39].

Bioenergy is renewable energy made available from materials derived from biological sources. One of the advantages of biomass fuel is that it is often a by-product, residue or waste-product of other processes. There are however also agricultural products specifically grown for biofuel production like corn, soybeans willow, Miscanthus and palm oil. Different by-products are available on and near the business park such as vegetable, fruit and green waste and other industrial biological waste from the companies. Besides this the RWZI produces a lot of sewer sludge and animal waste can be collected from the area around the business park. Agricultural land is also available to grow agricultural products used for biofuel. There is already a farmer near the business park who produces on a small scale Miscanthus and he wants to expand his production. Another way to cultivate biomass is by producing algae′s which consist out of a large portion of oil. Algae′s can efficiently be cultivated in the water of the RWZI which also clean the water as a side effect[11].

7.4 Analysis of the results

The impact of all the different solution of saving, exchanging and generating the energy is checked together with the accessibility of implementation which follows from the advantages, disadvantages, the price of implementation and the chance of succeeding. The impact and the accessibility are then plotted in a table which results in a scenario-analyses. The solutions with the highest impact and accessibility are the most important factors which have to be taken into account in the next steps of the research to come to a successful solution.

The matrix is shown in Appendix A. The two most important solutions are the ones in red at the right upper corner and are listed below:

- Wind power
- Solar power

With these two methods it is still impossible to realize a self-sustaining business park. This is why the solutions in the brown part of the table are also taken into account. These are:

- Heat and cold storage
- Sewer sludge
- Geothermal energy
- Miscanthus cultivation
- Sorption cooling
- Heatpumps
- Vegetable, fruit and green waste
- Industrial waste
- Exchanging network

What strikes is that the most important solutions are almost all ways of production of energy and not ways of saving or exchanging it. This does not mean that they are not important. Some of them are simple ways to start with and are a good way to make everybody aware of the problem and raise a collective feeling.

Potential of the most important energy transition methods

The most important solutions, with the highest probability of occurrence and the highest impact on the energy landscape, which are listed above are further developed in this chapter. From this the maximal potential of these energy transition methods can be calculated and how these solutions can support in finding a solution on the research question. An overview of the data is listed in Appendix G.

Solar panels

The area of a standard solar panel is 1.65m2 and the average power of a panel is 150 Wp/m2 panel and 130 kWh/m2 panel per year[40][33][16]. The price of a PV-panels depends on a lot of factors. ECN calculated a price between 0.95 and 6.69 Euro per kWh with an average price of 1.84 Euro per kWh. When these panels are installed at the ideal angle of 35 degrees the distance between the beginning of the first panel and the beginning of the second panel should be 5.3 meters (distance z in figure 7.1)[34]. A minimal distance from the roof edge of 1.60 meters is required[42].

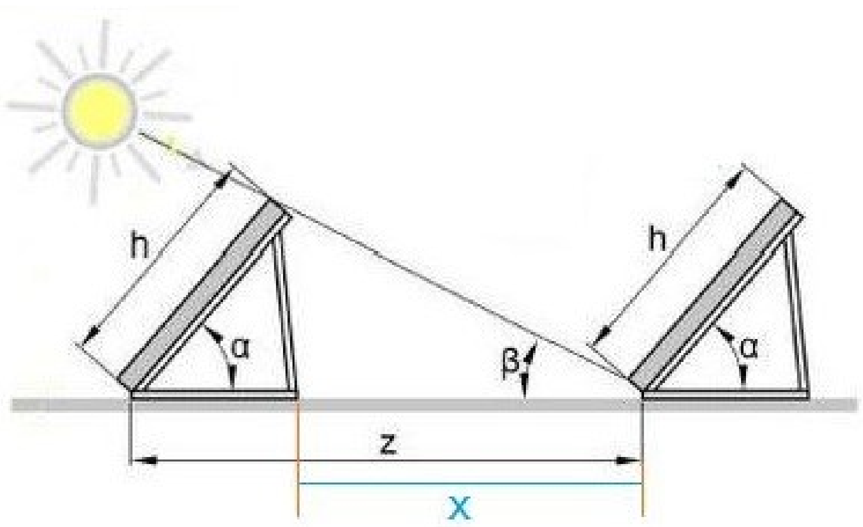

Figure 7.1: Orientation of solar panels[16]

To calculate the total potential of solar power on the business park the potential of solar power on the roof area is calculated. First the potential of the 20 biggest buildings are calculated by measuring the roof area using Google Maps. Combining the roof area with the roof area required for one panel gives that the total surface of the panels which can be installed is about 29% of the roof area. This results in a potential power of 8952 kWp and 7.758 GWh/year.

Now the scope is extended from the 20 biggest buildings to the whole business park. From the BAG register the floor space of the 20 buildings is taken and From this follows that the ratio between the roof area and the floor area was 72%. When looking at the whole business park this percentage will however be lower because the smaller companies have more unsuitable roof area like a sloped area or even greenhouses. The ratio taken for the whole business park is 50%. Besides this the average of 29% of the roof area is suitable for solar panels will be lower because smaller roofs in ratio a longer roof edge. This percentage is taken to be 25%. The surface area of all the companies on the business park together is 780.000 m2. Combining this gives a total solar panel area of 17 hectares with a potential of 12.6 GWh/year.

Sorption cooling

The cooling demand on the business park is quite high. Compression coolers are the most commonly used cooling machines. An overview of the process is shown in figure 7.2. The electric COP of modern compression cooling machine can be up to 5.

Sorption cooling is a technology that uses heat instead of electricity to produce cold energy. The overproduction of heat of processes can be used for cooling purposes. Especially in summer an excess of heat is available, for example at the AVR, while the cooling demand is the largest at this moment. Two kind of sorption cooling machines are available on the market: ADsorption and ABsorption. Adsorption chillers are purely hot water driven, whereas absorption chillers are driven by hot water, steam, or combustion. Both adsorption and absorption types of chillers are connected through a network to chilled ceilings or fan coils in room installations. The typical cooling capacity of an adsorption chiller ranges from 5.5 to 500 KW, whereas the cooling capacity of an absorption chiller ranges from 4.5 KW to 5 MW[43].

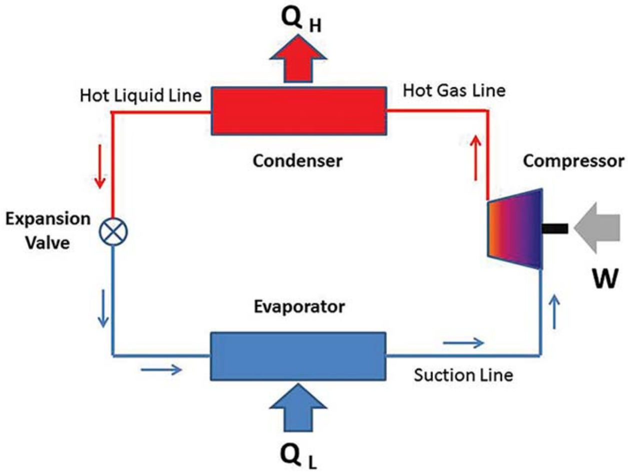

Figure 7.2: working principle of compression cooling

Commercial absorption chillers have been used for a long time, typically as part of a district heating and cooling plant or on refrigeration trucks and RV′s. Some systems use water as a refrigerant and a hygroscopic salt as the absorbent while other systems use ammonia as the refrigerant and water as the absorbent. An overview of the process is show in figure 7.3 [10].

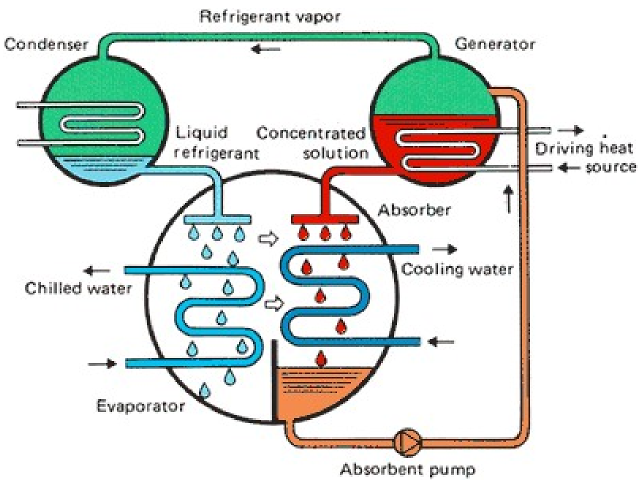

Figure 7.3: working principle of absorption cooling

Commercially available adsorption chillers typically use water as the refrigerant and a desiccant like silica gel or zeolite as the adsorbent. There are no possibilities of crystallization, corrosion, hazardous leaks, and the electricity consumption is minimal compared to compression coolers. The expected life span is because of this 30 years while the life span of Absorption is 15 years and compression cooling is 10 years. The working principle is shown in figure 7.4.

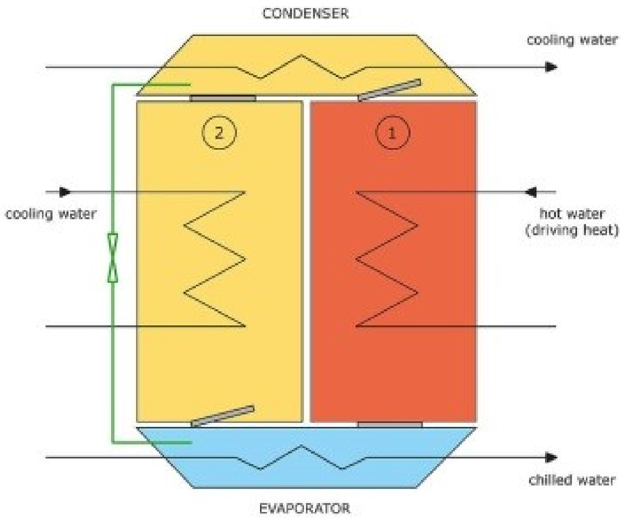

Figure 7.4: working principle of adsorption cooling

In table 7.6 a summary of the price of the different cooling machines are given for different power ranges. The numbers are based on a large amount of data. The price of conventional cooling is substantially lower compared to sorption cooling machines. The electrical COP is on the other hand about 5 while the electrical COP for sorption cooling can be up to 40. Besides this is the life span of an adsorption cooling machine 3 times higher. The difference between absorption and adsorption is quite low for a low power demand while for higher power demand absorption is substantially lower.

Table 7.6: Price range of different cooling mechanisms

kW Min	kW Max	Price conventional [€/kW]	Price absorption[€/kW]	Price adsorption[€/kW]
0	20	604	1797	2000
20	50	210	1708	2000
50	100	144	698	888
100	300	131	531	1219
300	9999999	113	200	1000

An overview of the differences between the cooling machines is given in figure 7.7.

Table 7.7: Overview of the different cooling mechanisms

Factors	**Compression cooling**	**Absorption cooling**	**Adsorption cooling**
High temp. input	-	$>80\ ^{\circ}C$	$>55^{\circ}C$
Low temp. output	$<0^{\circ}C$	$>1^{\circ}C$	$>1^{\circ}C$
Medium temp. output	-	$\sim 35^{\circ}C$	$\sim 35^{\circ}C$
Cooling medium	Divers	Water with LiBr/NH3	Water with silicagel/zeolitegel
Cooling power range	2-30000 kW	5-10000 kW	5-1000 kW
COP (thermal)		0.6-0.8	0.5-0.65
COP (electrical)	>3.5	<40	<40
lifespan (years)	10	15	30+
Complexity	Complex	Medium Complex	Simple, no moving parts
Operational cost	High	Low	Low
Investment	Low	Medium	High
Benefit	Widely used system	Large powers	No vibrations

The cold demand, calculated in chapter 6, is now used to calculate and compare the total cost of implementation of absorption cooling and compression cooling. The total cold demand is set on 80.000 GJ/year and the cold capacity is taken to be 22.000 kW. The heat price is set on 7 euro/GJ en the electricity price on 0.14 euro/KWh. An overview of the calculation is given in table 7.8.

Table 7.8: Calculation of the costs between compression cooling and absorption cooling

	Compression cooling	Absorption cooling: net on 120°C	Absorption cooling: net on 80°C
Net-temperature[°C]	-	120	80
COP Qcold/Qheat	-	0,9	0,66
Total heat demand [GJ]	0	88.889	121.212
Total Electra demand [GJ]	20.000	2.000	2.000
COP Qcold/Qelectra	4	40	40
Depreciation period [Jaar]	15	15	15
Total investment [€]	3.176.048	11.828.624	11.828.624
Operating cost heat [€/year]	-	622.222	1.818.182
Operating cost electricity [€/year]	800.000	80.000	80.000
Total operating cost [€/year]	1.011.737	1.490.797	1.817.727

From this follows that cost of absorption cooling is substantially higher compared to the other methods. Even when the temperature of the district heating network is increased in summer from 80°C to 120°C the price is much higher for the investors. The increasing temperatures will bring higher heat losses with it and the exploiter of the net will not like it.

Power to gas

Power to gas (P2G) is a technology that converts electrical power to a gas fuel; all use electricity to split water into hydrogen and oxygen by means of electrolysis.

$$2H_2O \rightarrow 2H_2 + O_2 \tag{7.1}$$

The different methods of using hydrogen are shown shown in table 7.9. The resulting hydrogen can be used to generate electricity using a fuel cell. These cells can also be installed and used in the transport sector. The second method is to combine the hydrogen with carbon dioxide and convert the two gases to methane (see natural gas) using a methanation reaction such as the Sabatier reaction, or biological methanation. The methane may then be fed into the natural gas grid. The third way is to combine the hydrogen with nitrogen to produce ammonia. Ammonia but also hydrogen are used in large quantities in the chemical industry. The hydrogen can also in small quantities be injected into the natural gas grid.

Table 7.9: Different ways of hydrogen usage

	Input	Input	Output	Output
Fuel cell	H2	O2	H2O	Electricity
Methane production	H2	CO2	H2O	CH4
Ammonia production	H2	N2	NH3	
Chemical industry	H2			

Algae cultivation

Algae are plants which grow in the water and can range from microscopic microalgae to larger seeweeds. Microalgae are the fastest growing photosynthesizing unicellular organisms and can complete an entire growing cycle every few days. Yields from algae are much higher than those from other oil crops and there is a huge potential to increase this high yield even further. At this point about 20.000 litres of oil can be produced per hectare and a lot of research is going on to increase this amount. This is already 3 times more than palm oil (6000[$l \cdot ha^{-1} \cdot year^{-1}$]) and 100 times more than corn (172 $l \cdot ha^{-1} \cdot year^{-1}$). Autotrophic microalgae are cultivated on land in large ponds, or in enclosed so-called photobioreactors, using enriched CO2, water and nutrients to grow.

Algae fuel or algal biofuel is an alternative to liquid fossil fuels that uses algae as its source of energy-rich oils. Also, algae fuels are an alternative to common known biofuel sources, such as corn and sugarcane. Several companies and government agencies are funding efforts to reduce capital and operating costs and make algae fuel production commercially viable[30].

A possible nutrient source is waste water from the RWZI. It is an interesting step for wastewater treatment because it is a way to clean the water on a biological way coupled with the production of valuable biomass. The microalgae is able to use inorganic nitrogen and phosphorus for their growth and is capable of removing heavy metals and toxic organic compounds[31].

Algae cultivation seems like an ideal way to produce bio-oil at this location because waste water is available in combination with CO2 from the waste burner. Two general types of production systems are available: The open pond system and the closed pond system. Open pond systems are the most common system of algae cultivation, already used commercially in the United States to produce nutritional products and treat wastewater. They often use paddle wheels or other water moving devices to keep the algae circulating. In the closed system the algae is enclosed into a transparent vessel which can be in many shapes, sizes and orientations. One of main advantages of the closed pond is that they can better match the ideal conditions and growth requirements of particular types of algae not easily grown in open ponds. They can also prevent, or at least reduce, invasion by weed algae, zooplankton grazers and other organisms that could affect the cultures. Besides this they can be installed on the top or the side of buildings. The disadvantage is that it is more expensive than the open pond[2].

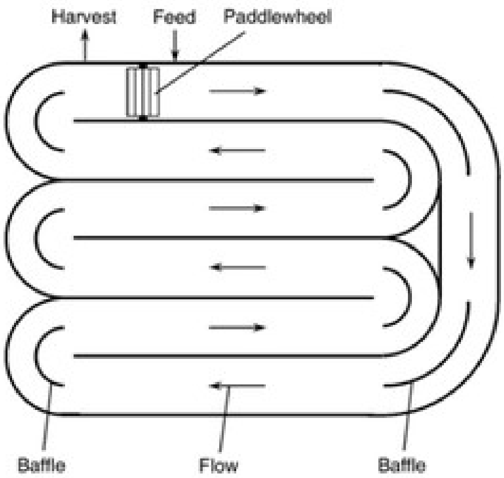

Figure 7.5: Working principle of an open pond Algae cultivation

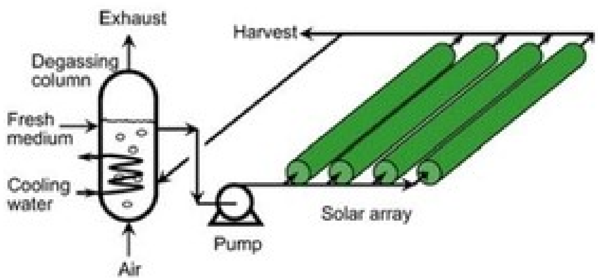

Figure 7.6: Working principle of an closed pipe Algae cultivation

The most suitable choice at this location is the open pond. Enough space is available to install these open ponds, the techniques are in a further stage of development and it is already commercially used. Besides this the energy input is most of the times higher the the energy content of the outgoing biomass. The company Ingrepo produced 35 tons of dry algae per hectare in the Netherlands in an open pond. The oil content of the dry algae is about 40% and the density of the oil is 0.875 kg per litre of oil. From this follows that 16000 litres of oil can be produced per hectare every year. The heating value of the oil is 41 MJ/kg[11]. When 20 hectares will be used to cultivate Algae, 74.2 million litres of oil can be produced which contain of 3.18 GWh. When this oil is burned in a boiler with an efficiency of 95%, 3.03 GWh of useful heat can be produced on a yearly basis.

Cultivation of Miscanthus

An energy crop is a plant grown as a low-cost and low-maintenance harvest used to make biofuels, such as bioethanol, or combusted for its energy content to generate electricity or heat. Energy crops are generally categorized as woody or herbaceous plants; many of the latter are grasses.

Miscanthus, which is also known as elephant grass, is an grass which is used as an energy crop. It is currently used in the European Union as a commercial energy crop, as a source of heat and electricity, or converted into biofuel products such as ethanol[17]. Miscanthus is grown in Europe mainly for cofiring in coal power generating facilities[12]. Miscanthus Giganteus exhibits greater photosynthetic efficiency and lower water use requirements than other kinds of plants. It has very low nutritional requirements: it has high nitrogen use efficiency and therefore is capable of growing well on barren land without the aid of heavy fertilization[1]. There are some concerns about using food crops to produce ethanol, as we are creating fuel from a product that could be used to feed people or livestock. When market forces change the demand for these, prices can fluctuate wildly, deeply affecting the ability of many to purchase food.

Miscanthus Giganthus is already produced near the business park and the producer wants to expand his market. A few calculations are made to determine the opportunities of the cultivation of this grass and use it to produce heat or a biofuel. An overview of these calculations is given in Appendix H.

Different direct combustion principles can be used to burn the Miscnathus. The principles can be arranged into three groups: Fixed bed, Fluidized bed and dust combustion. In general fluidized bed and dust combustion are for larger scale combustion from 5 MW and higher. Due to the good mixing achieved, fuel flexibility is high, although attention must be paid to particle size and impurities contained in the fuel. Besides this the cost are much higher compared to fixed bed systems. It is most probable that the designed combuster is smaller than 5 MW so we will do more research on Fixed bed combustion[35].

Fixed-bed combustion systems include grate furnaces and underfeed stokers. Primary air passes through a fixed bed, where drying, gasification, and charcoal combustion take place in consecutive stages. They have the distinct advantage over underfeed stokers in that they can accommodate fuels with high moisture and ash content as well as with varying fuel sizes. Generally only suitable for small-scale systems, underfeed stokers are a relatively cheap and safe option for biomass combustion. Underfeed stokers are limited in terms of fuel type to low ash content fuels such as wood chips. Due to ash removal problems it is not feasible to burn ash rich biomass as this can affect the air flow into the chamber and cause combustion conditions to become unstable[29].

There are several different types of grate firing, with both fixed and moving grates commonplace. They have the distinct advantage over underfeed stokers in that they can accommodate fuels with high moisture and ash content as well as with varying fuel sizes. It is very important that fuel is spread evenly over the grate surface in order to ensure that air is distributed uniformly throughout the fuel and thus combustion is kept homogeneous and stable. There is however poor mixing which makes is difficult to co-fire different fuels and the moving elements can give problems when rocks and metal enters the combustion chamber[18]. An advantage is that all wood fuels can be used so it is possible to change to other crops after a few years. A higher deposit build up have been determined (4-20 times higher than those for wood chips and bark combustion in the same plant) which makes that an efficient boiler cleaning system is needed. The moving grate furnace seems the best option in this case of which the working principle is shown in figure 7.7.

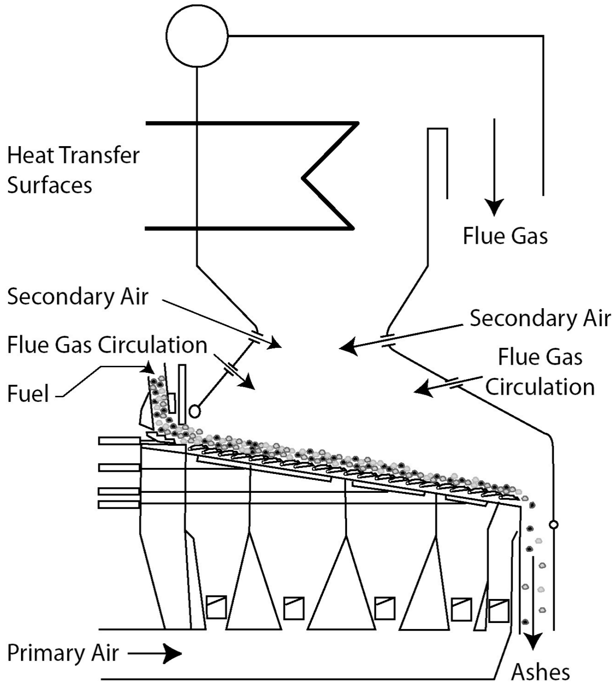

Figure 7.7: Moving grate furnace; working principle

Primary air passes through a fixed bed, where drying, gasification, and charcoal combustion take place in consecutive stages. Secondary air can be inserted for the secondary combustion. By flue gas recirculation the combustion temperatures should be kept lower than 950 in order to avoid slagging problems[8].

Miscanthus can also be used to produce bio-oil using the pyrolysis process. The bio-oil can for example be used in the transport sector and is easier to store. The pyrolysis process produces also char and non-condensable gases. In most cases the char and non-condensable gases are combusted to produce energy which is needed in the process. The process is shown in figure 7.8. The Miscanthus can be cultivated near the business park and there is enough space to store the particles. This makes it unnecessary to convert Miscanthus into bio-oil with the additional losses which come along with them.

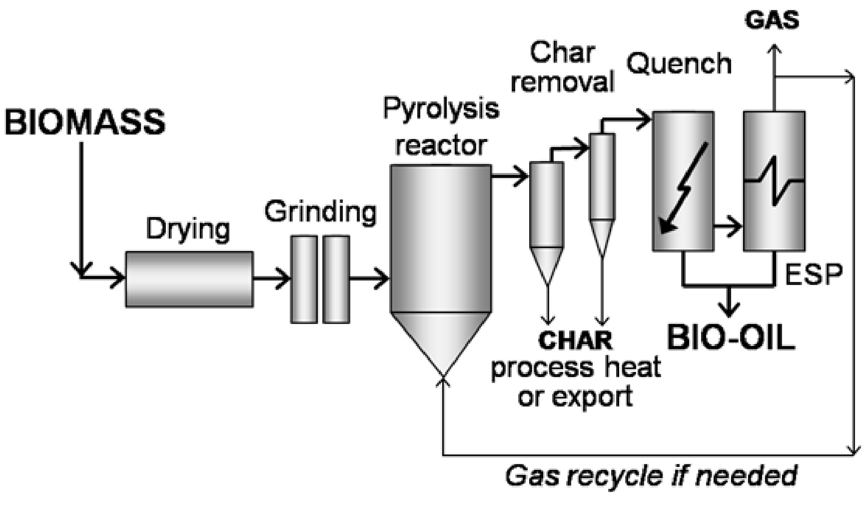

Figure 7.8: Conversion of biomass into Bio-oil; working principle

Sewer sludge conversion

The RWZI on the business park produces a lot of heat and from sewer sludge which can be converted into useful energy sources. The temperature of the incoming influent is above the ambient temperature and the sludge contains a lot of chemical energy in it. This sludge can be dried and burned but it is more energy efficient to use the wet sludge to produce biogas by anaerobic digestion. The water cleaning process uses however a lot of energy. The outgoing effluent also contains a lot of thermal energy but this is on a low temperature level which makes it inefficient to upgrade the temperature to a useful temperature. Besides this the AVR produces an excess of heat on a high temperature level which makes it difficult to compete with.

Thermal hydrolysis is a process used to treat sewage sludge which combines high-pressure boiling of sludge followed by rapid decompression. This combined action sterilizes the sludge and makes it more biodegradable, which improves digestion performance. The treatment adjusts the rheology to such an extent that loading rates to sludge anaerobic digester's can be doubled, and also dewater-ability of the sludge is significantly improved. Besides this the sterilization results in an exceeding of the requirements of using it for agricultural purposes.

The RWZI Nieuwgraaf is designed to handle a load of 330.000 persons[32]. With and estimated general load of 85% and a load of 0.087 kg of dry matter per person every day, the total yearly load of this location is 8.9 million kg of dry matter[7]. The energy content of one ton of dry matter of sewer sludge is 18 GJ, which makes the potential of 44.5 GWh. The combined efficiency of thermal hydrolysis and a thermal boiler is 30% which results in a total production of 13.36 GWh of heat[22].

Geothermal energy

Deep geothermal energy can be used directly for heating purposes. The depth of the drillings are between 1000 and 3500 meters and the temperature is between $40°C$ and $100°C$. It is important to have a geothermal water reservoir with a good thickness and permeable ground layer. An overview of the potential of geothermal energy is shown in figure 7.9. The values are in GJ per hectare per year and is between 5-300 GJ/ha.year[21]. When taking an average of 50 GJ/ha.year and an area of 100 hectare, the total heat production can be 1.39 GWh.

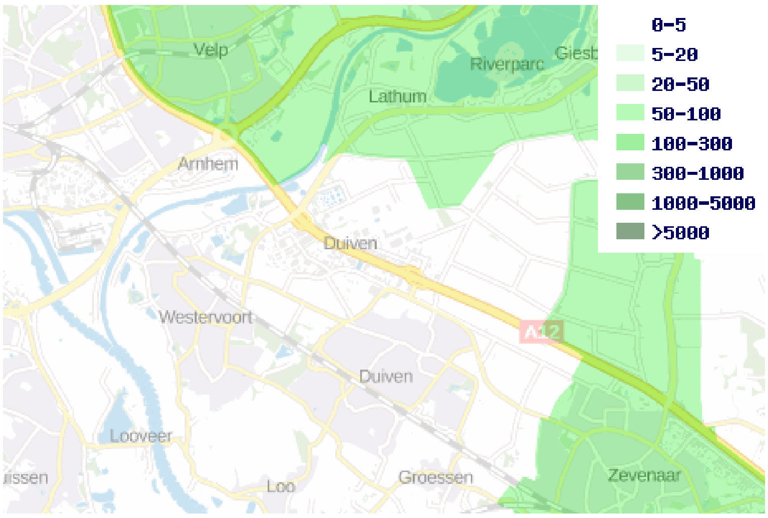

Figure 7.9: Geothermal potential in Duiven between 1000 and 3500 meters [21]

Seasonal Thermal Energy Storage

Heat and cold can be stored using ATES systems. There are already three ATES systems installed on the business park with a total estimated cold and heat storage capacity of 2.610 GWh per year. One at Ikea, one at the MAKRO and on at ALliander. The cold energy can directly be used to cool buildings which results in a COP of 30. The heating COP is 3.5 and much higher because a heatpump is required before the energy can be used for heating purposes. The potential of ATES systems is quite big. An expansion of a factor 10 of the current ATES systems seems to be possible.

Windpower

In 2014 four large Vestas 2.0 MW V90 wind turbines with a height of 150 meters where installed. These four wind turbines produce 18.0 GWh of electricity on a yearly basis. This wind park can be expended with more wind turbines. The residential people living around the park have made some complaints about the park. When expending the farm they would probably counteract it which will give some complications. Smaller turbines are easier to install because the investment is lower, the authorization from the government is easier to get and the residential people around the park give less complaints. The energy yield and efficiency is however also much lower. A WES50 50 kW turbine with a height of 50 meters can for example produce about 0.2155 GWh in a year[36].

8. Future energy scenarios

Now the energy scenarios which could have an impact on the energy landscape in 2025 need to be determined. These scenarios result in an increase or reduction of the heat, cold, electricity or gas demand or supply. All these different scenarios are analysed by determining the impact on the energy landscape and the probability of the scenario to occur. These two factors are used in a risk analysis matrix which is shown in appandix B. From this follows the most important scenarios with the highest impact and the biggest chance of occurrence. The two most important scenarios are:

- Expansion of the business park which would result in an increase of the heat, cold and electricity demand.
- Decrease of the amount of non-biological waste which is burned at the AVR which would result in a smaller supply of heat and electricity from.

The third scenario which is taken into account is that the energy landscape wouldn't be changed in 2025. These three scenarios are used and developed in the next chapter to see if it is possible to realize a sustainable and energy neutral business park before 2025.

9. Fulfilling the future energy scenarios

The different options discussed in chapter 7 are now used to fulfil the three future energy scenarios discussed in chapter 8. The goal is to fulfil the energy demand in a sustainable way. First the situation in which the energy supply and demand in the future stay constant will be discussed followed by the other two scenarios. An overview of the elaboration of the different scenarios is given in the Appendix D, E and F. The chosen options seems to be the most realistic way to generate all the energy in a sustainable way. It is however not the only way to realize the goal. Ratios can for example change: more wind turbines can for example be used instead of solar power. Besides this the rapid development of some techniques can change the view on this subject over the years.

Scenario 1: The energy demand and supply stays constant

- PV-panels on the 20 biggest roofs.
  The generated energy with solar energy should be extended with 9 hectares of PV-panels. The current area of the panels is about 1.5 hectares of which the majority is installed at Alliander. The installation results in a yearly generation of 11.6 GWh.

- 5 Wind turbines.
  The wind park should be extended from 4 to 9 wind turbines of the same hight. The wind turbines generate 4.5 GWh per year which results in an extra generation of 22.5 GWh.

- Enlargement of the number of ATES systems with a factor of 6.
  As stated before it is possible to extend the ATES systems. The 3 systems deliver about 2.2 GWh cold energy and 2.7 GWh of heat. It is possible to extend this with a factor 6 resulting in a combined system which can deliver 12.9 GWh of cold and 16.1 GWh of heat. It is important to install these systems in the right way such that the sources do not interfere with each other.

- Digestion of sewer sludge.
  At this moment most of the sewer sludge at the RWZI is already digested and it is used to generate heat and electricity for the processes. To come to a total sustainable business park it is however important to replace the natural gas. The biogas should be upgraded and inserted to the gas network. The gas can be used at the other companies which still use natural gas for their processes which cannot be replaced by heat from the district heating network. About 8.5 GWh of biogas can be produced from the sewer sludge on a yearly basis.

- Digestion of the available organic waste at the AVR.
  The Organic waste can be used available at the AVR can be used in a anaerobic process. The process is difficult and more expensive compared to anearobic digestion of sewer sludge but the efficiency can be the same. About 53 kton is available for digestion which using this process results in 14.2 GWh of biogas.

- Burning of the available organic waste on the business park.
  about 15.3 kton of organic waste is available on the business park. This waste can be burned and converted into 28.4 GWh of usable heat. The heat can be inserted into the district heating network.

- Cultivation of Miscanthus on 160 hectare.
  About 160 hectares of miscanthus need to be cultivated which results in 3.7 kton wet biomass. At this moment only a few hectares is cultivated at a small firm near the business park. There are large plots of agricultural land around the business park which could be used for this purpose. 15.7 GWh of heat can be produced by burning the miscanthus.

Appendix D shown an overview of the fulfilled scenario. The table 9.1 shows the increase in sustainability and the resulting sustainability percentage of the 100% in all the cases.

Table 9.1: Sustainability of the new situation

	Sustainability percentage	Increase
Electricity	100%	+29,4%
Heat	100%	+49,3%
Gas	100%	+100.0%
Cold	100%	+7,5%

Scenario 2: Expansion of the business park

The expansion of the business park will result in an increase of the energy demand with 20%. The differences with scenario 1 will be discussed below. The overview of this scenario is shown in Appendix E.

- Enlargement of the number of ATES systems with a factor of 10.
  To fulfil the cold and heat demand the ATES systems should be increased with a factor of 10. This will result in a total yearly heat delivery of 26.8 GWh and a cold delivery of 21.6 GWh.
- PV-panels on the 20 biggest roofs.
  To fulfil the increase of electricity with 20%, PV-panels should be placed on all the roofs of the buildings on the business park. This will increase the total PV-panals area to 17 hectare which will produce 22.1 GWh of electricity on a yearly basis.
- Cultivation of Miscanthus on 200 hectare.
  The cultivation of Miscanthus should increase to 200 hectares.
- Cultivation of algae on 10 hectare. To fulfil the total heat demand algae should be cultivated in the wastewater of the RWZI. With 10 hectares of open ponds, oil can be produced which can generate about 1.57 GWh heat per year.

The sustainability of this scenario will be the same as in scenario 0 and so table 9.1 shows the total sustainability.

Scenario 3: Decrease of burning of non-biological waste at AVR

In this scenario the non-biological part which is burned at the AVR will decrease. In scenario 1 this part was already excluded such that the sustainability would go to 100%. The electricity production and demand will stay as a result constant compared to scenario 0 and also the production of biogas will stay the same. Scenario 3 is as a result equal to scenario 1.

10. Conclusion

The general research question of this paper is: Is it possible to collectively realize a sustainable and energy neutral business park before 2025? In chapter 5.2 it was already clear that the business park is already energy neutral. Using the Adapted Trias Energetica in chapter 5.3 and the different scenarios in chapter 5.4 it is was possible to fulfil the different energy scenarios in chapter 5.5. From this it can be concluded that it is possible to realize a sustainable and energy neutral business park before 2025.

The electricity will be produced by wind turbines and solar power. Most of the cold energy will be delivered by ATES systems and a small part by electric compression cooling machines. A large part of the heat will also be delivered by the ATES system but in combination with the thermal energy from biomass. Some of the biomass is at this moment already available at the AVR while an other part should be cultivated around the business park. In some energy scenarios it is also necessary to produce algae. The natural gas is replaced by biogas which is produced by anaerobic digestion of sewer sludge and biomass streams of the AVR.

11. Recommendation

The most important part of the new sustainable way of producing energy will still be the treatment of waste, both burning and digesting. It is important that the AVR will lay the focus on the sustainable generation of energy. The RWZI should focus on the upgrading the biogas and deliver it to the companies on the business park. It will be a large investment to realize all the goals so it is important to tackle this problem collectively. All the companies should be dedicated to realize the different goals by for example providing their roofs for solar power and share their own energy sources. Besides this the companies should be willing to invest and pay a higher price compared to conventional technologies but on the long term these investments will pay back. It will not directly lead to lower energy prices but rather to an improved environmental quality, an future proof business park, economic gains and an improved cooperation between companies. This will indirectly will lead to higher profits and a better working environment. Only when the energy transition is tackled together it will be possible to realize a sustainable and energy neutral business park before 2025 with the enormous benefits which come along with them.

Some points of concern are listed below:

- Investment.
  The total investment is really high compared to the current used technologies. This will make it really difficult to convince the companies to invest in these technologies.
- Realization time.
  The realization time of this project is relatively short. In about 8 years energy transition should be realized. The high investment in such a short time will make it difficult for most of the companies.
- Exchanging of energy.
  Most of the technologies are based on the exchanging of energy. When for example the 20 biggest roofs are used for solar power it will be important to exchange the energy with the other companies. The law makes it difficult and expensive to do this as it is mandatory that an third party like Nuon will exchange the energy. The same applies to the exchange of heat, gas and cold. A micro grid would be a good solution but still laws will make it difficult to realize it at this moment.
- Cultivation area Miscanthus.
  The area needed for the cultivation of Miscanthus is enormously. 160 hectares is about the same as 2/3 of the area of the business park. These plantations will compete with area available for agricultural purposes which is not sustainable. There are many concerns about the impact of biomass production on food production, the stability of food and feed prices and the availability of food for the poor. Besides this there are concerns about adverse effects on nature and biodiversity and there are questions about the net energy savings and CO2 emission reductions that can be realised with bio-energy compared to conventional, fossil energy. More attention must be paid to this matter before realizing this on such a large scale.
- Sustainability of the area.
  The sustainability of the AVR is at this moment about 53% because it consists out of about 53% of the biological material. In the future scenario the biological part is used to generate sustainable energy which will be used on the business park. The AVR will however still use burn the 47% of non-biological material to generate heat and electricity with a much lower percentage of sustainable energy and transport it to households. The sustainability of the business park will go up but the total sustainability will stay the same. The question is whether this is a positive development.
- Sustainability of the entire chain.
  The major advantage sustainable energy is that no net pollution is created in the process of generating energy. The energy is renewable (unlike gas, oil and coal) and sustainable. Yet materials, manufacturing, installing and other processes can have environmental downsides. Although this is not taken into account in this report, it will be important to get a good overview of the sustainability of this project.

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A. Risk analysis: Trias Energetica

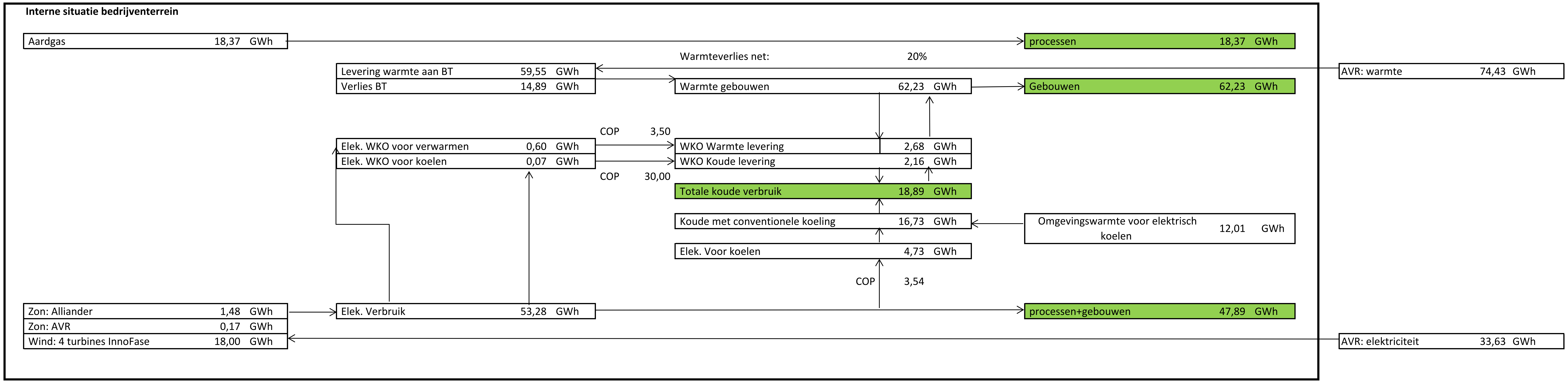
Very High				Wind power	District heating network
High	Power to gas	Algae cultivation Power to heat	Geothermal energy Miscanthus cultivation Sorption cooling Heatpumps	Heat and cold storage Isolation	Solar power
Average	Hydroelectric energy storage	High temperature district heating network Batteries Sustainable building	Low temperature network Energy scan Low temperature heating	Vegetable, fruit and green waste Industrial waste Exchanging network	Sewer sludge
Low		Hydropower Separated sewage for greywater Collective transport Animal waste	Solar water heating	Bio-energy exchanging	
Very Low		Green roofs Solar protection smart streetlights Sustainable rebuilding	Intelligent process control Increase of sunlight Night cooling	LED-lights Automatization	
Impact on the energy landscape / Probability of occurrence	Very Unlikely	Unlikely	Possible	Likely	Very Likely

B. Risk analysis: Future energy scenarios

	Scenario	Scenario	Scenario	Scenario	Scenario
Very High	AVR cease to exist		Wasteburning at AVR is regarded as non-sustainable	Decrease of burned waste at AVR	
High		Wind farm cease to exist	Cancellation of the current heat connections		Expansion of the industrial park
Average		RWZI stops producing biogas Company with a large gas demand moves from BT RWZI ceases to exist Increase of cooled buildings	Fashing out the gas connections Company with high gas demand moves to BT Company with high heat demand moves from BT Company with high electricity demand moves from BT Increase of waste processing at AVR	Company with high heat demand moves to BT Company with high electricity demand moves to BT	
Low		Decrease of the load on the RWZI	Increase of heat supply from AVR Change of activities of companies Increase of load on the RWZI	Increase of district heating network connections Replacement of old buildings Increase of efficiency anaerobic digestion at RWZI	Increase of efficiency machines, cooling, heating Increase in use of electronic devices and machines
Very Low				Company with small gas demand moves to BT Company with small gas demand moves from BT	Company with small heat demand moves to BT Company with small heat demand moves from BT Company with small electricity demand moves to BT Company with small electricity demand moves from BT Increase of temperature by climate change
Impact on the energy landscape / Probability of occurrnece .	Very Unlikely	Unlikely	Possible	Likely	Very Likely

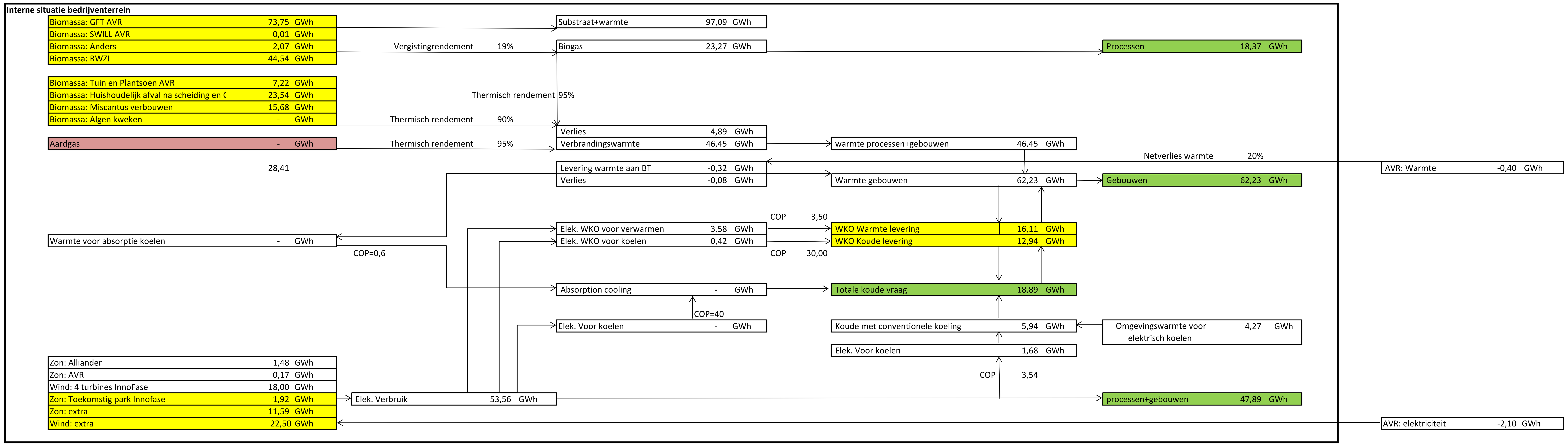
C. Current situation of the energy landscape on the business park

Huidige situatie



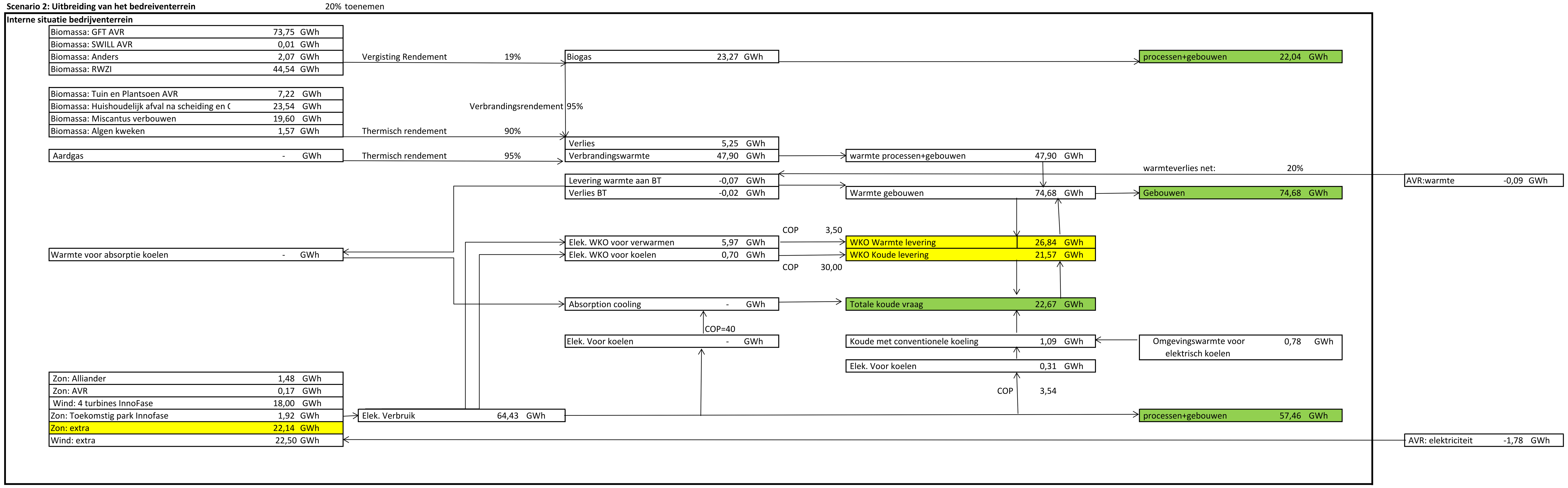
D. Energy landscape of future energy scenario 1: no change

Scenario 0


Interne situatie bedrijventerrein
Biomassa: GFT AVR 73,75 GWh
Biomassa: SWILL AVR 0,01 GWh
Biomassa: Anders 2,07 GWh
Biomassa: RWZI 44,54 GWh
Biomassa: Tuin en Plantsoen AVR 7,22 GWh
Biomassa: Huishoudelijk afval na scheiding en (23,54 GWh
Biomassa: Miscantus verbouwen 15,68 GWh
Biomassa: Algen kweken - GWh
Aardgas - GWh
28,41
Vergistingrendement 19%
Thermisch rendement 95%
Thermisch rendement 90%
Thermisch rendement 95%
Substraat+warmte 97,09 GWh
Biogas 23,27 GWh
Verlies 4,89 GWh
Verbrandingswarmte 46,45 GWh
Levering warmte aan BT -0,32 GWh
Verlies -0,08 GWh
Processen 18,37 GWh
warmte processen+gebouwen 46,45 GWh
Netverlies warmte 20%
AVR: Warmte -0,40 GWh
Warmte gebouwen 62,23 GWh
Gebouwen 62,23 GWh
Warmte voor absorptie koelen - GWh
COP=0,6
Elek. WKO voor verwarmen 3,58 GWh
Elek. WKO voor koelen 0,42 GWh
COP 3,50
COP 30,00
WKO Warmte levering 16,11 GWh
WKO Koude levering 12,94 GWh
Absorption cooling - GWh
Totale koude vraag 18,89 GWh
COP=40
Elek. Voor koelen - GWh
Koude met conventionele koeling 5,94 GWh
Omgevingswarmte voor elektrisch koelen 4,27 GWh
Elek. Voor koelen 1,68 GWh
COP 3,54
Zon: Alliander 1,48 GWh
Zon: AVR 0,17 GWh
Wind: 4 turbines InnoFase 18,00 GWh
Zon: Toekomstig park Innofase 1,92 GWh
Zon: extra 11,59 GWh
Wind: extra 22,50 GWh
Elek. Verbruik 53,56 GWh
processen+gebouwen 47,89 GWh
AVR: elektriciteit -2,10 GWh

E. Energy landscape of future energy scenario 2: Expansion of the business park

Scenario 2: Uitbreiding van het bedreiventerrein 20% toenemen



F. Data and its bibliography of the current energy landscape

huidige situatie				Jaartal	Auteur	Titel artikel	Extra info	Link
Aardgas	Totaal gas verbruik BT	2089046	Nm3	2010	Onbekend	Energieverbruik Duiven	Totale afname van gas	Energieverbruik Duiven.pdf
	Calorische onderwaarde van aardgas	0,03165	GJ/Nm3	-	Energielevernaciers	Calorische waarde, bovenwaarde en onderwaarde		http://www.energieleveranciers.nl/energie/begrippen/calorische-waarde
	Totaal energie inhoud gas	18,37	GWh	-	-	-	Berekend	-
	Procentueel verbruik van gas voor warmte	100%		-	-	-	Aanname	-
	Rendement CV-ketel	95%		2009	Unica bv	Energiebesparenden maatregelen en		http://adbioresources.org/wp-content/uploads/2013/06/59-
	Nuttige verbrandingswarmte	17,45	GWh	-	-	-	Berekend	-
	Percentage van deze warmte wordt gebruikt voor processen+gebouwen	100%		-	-	-	Aanname	-
	totaal verbruik warmte uit gas	17,45	GWh	-	-	-	Berekend	-
AVR: warmte	Rendement AVR	90%		2014	Greenspread	De warmtepotentiekaart van de gemeente		http://www.greenspread.nl/wp-content/uploads/2014/10/De-
	Totaal levering van warmte van AVR aan het warmtenet	239,44	GWh	2014	AVR	Our location: AVR Duiven	Verwachte hoeveelheid 2015	http://en.avr.nl/our-locations/avr-duiven/
	Verlies warmtenet:	20%					Aanname	
	Levering warmte aan consumenten gehele warmtenet	191,55	GWh	-	-	-	Berekend	-
	percentage van opwekking AVR duurzaam	54%		2013	Nuon	Stadswarmte in Arnhem, Duiven en Westervoort:		https://www.nuon.com/globalassets/nederland/newsroom/doc
	Percentage van energielevering van NUON duurzaam	53%		2013	Nuon	Stadswarmte in Arnhem, Duiven en Westervoort: CO2-prestatieverslag 2015	Opvangen van piekvraag wordt gedaan met fosiele brandstoffen	https://www.nuon.com/globalassets/nederland/newsroom/documenten/co2-prestatieverslag-arnhem-duiven-en-westervoort-2013.pdf

	Duiven+Westervoort	Arnhem	Totaal	Eenheid	Jaartal	Auteur	Titel artikel
aantal grootverbruikers(2013)	201	78	279	-	2013	Nuon	Stadswarmte in Arnhem, Duiven en Westervoort: CO2-
Woningequivalenten grootverbruikers	7013	2722	9735	-	2015	Nuon	Resultaat, Nieuw transportnet Arnhem-Duiven verzilverd
Wooningequivalent totaal	14261	8610	22871	-	2013	Nuon	Stadswarmte in Arnhem, Duiven en Westervoort: CO2-
% woningequivalent grootverbruikers ten opzichte van totaal	49%	32%	43%	-	-	-	-
Warmtelevering	458830	279367	738197	GJ	2013	Nuon	Stadswarmte in Arnhem, Duiven en Westervoort: CO2-
warmtelevering aan grootverbruikers	225647	88308	314212	GJ	-	-	-
warmtelevering aan grootverbruikers	62,68	24,53	87,28	GWh	-	-	-

				Jaartal	Auteur	Titel artikel	Extra info	Link
	Percentage van grootverbruikers in Duiven+Westervoort zit op het	95%	-	2016	Google maps		Aaname met behulp van google maps	googlemaps.com
	Warmtelevering warmtenet op het bedrijventerrein	214.365	GJ	-	-	-	Berekend	-
	Warmtelevering warmtenet op het bedrijventerrein	59,55	GWh	-	-	-	Berekend	-
	Extern verbruik	132,01	GWh	-	-	-	Berekend	-
Elektriciteit	AVR: Elektriciteit levering aan het net	93,00	GWh	2014	AVR	Our location: AVR Duiven	verwachte producie in 2015	http://en.avr.nl/our-locations/avr-duiven/
	RWZI	0	GWh					
	Zon: Alliander	1,48	GWh	2015	Innax gebouw en omgeving	Energielijst Alliander	Verwachte productie	Energielijst Alliander 20150521 tbv meerwerken Data structureren bedrijven.xlsx
	Zon: Alliander	1,14	hectare					
	Zon: AVR	800,00	panelen	-	De groene hub	Zonnepanlen op de ARN		http://degroenehub.nl/project/zonnepanelen-op-het-dak-van-arn/
	Zon: AVR	0,13	hectare					
	Zon: AVR	0,17	GWh	-			130 kwh/m2, 1,65m2 per paneel, bron: 20160803 Koudevraag en BC_toevoeging PV	
	Wind: 4 turbines InnoFase	18,00	GWh	2014	Winkpark Duiven	Duurzaam investeren	Verwachte productie	https://www.duurzaaminvesteren.nl/Projecten/Open-projecten/
	Som van alle opwek Elektriciteit	112,65	GWh	-	-	-	Berekend	-
	Totaal verbruik Elektriciteit op BT	53,28	GWh	2010	Onbekend	Energieverbruik Duiven	Totale afname van gas	Energieverbruik Duiven.pdf
	Extern verbruik	59,37	GWh	-	-	-	Berekend	-
WKO systemen	Aantal WKO systemen BT	3		2016			Alliander, Makro, Ikea	
	Alliander							
	Bedrijfsoppervlak	25528	m2	2016	BAG Register			https://bagviewer.kadaster.nl/lvbag/bag-viewer/index.html#?geometry.x=196636.37989991&geometry.y=442151.72949953&zoomlevel=11&objectId=0226100000014826&detailsObjectId=0226010000018344
	koelvraag	50	W/m2				Kantoorfunctie	20160803 Koudevraag en BC
	vollastdraaiuur	800	uur				Kantoorfunctie	20160803 Koudevraag en BC
	Totale jaarlijkse koudevraag	1,021	GWh/jaar					
	Makro							
	bedrijfsoppervlak	21200	m2	2016	BAG Register			https://bagviewer.kadaster.nl/lvbag/bag-viewer/index.html#?geometry.x=196636.37989991&geometry.y=442151.72949953&zoomlevel=11&objectId=0226100000014826&detailsObjectId=0226010000018344
	koelvraag	25	W/m2				Kantoorfunctie	20160803 Koudevraag en BC
	vollastdraaiuur	1.067	uur				Berekend	Bedrijfsuren overdag zijn vergelijkbaar maar Ikea en Makro is zaterdag de hele dag open en zondag 2/3 dag open
	Totale jaarlijkse koudevraag	0,565	GWh/jaar					
	Ikea							
	bedrijfsoppervlak	38372	m2	2016	BAG Register			https://bagviewer.kadaster.nl/lvbag/bag-viewer/index.html#?geometry.x=196636.37989991&geometry.y=442151.72949953&zoomlevel=11&objectId=0226100000014826&detailsObjectId=0226010000018344
	koelvraag	25	W/m2				Kantoorfunctie	20160803 Koudevraag en BC

	vollastdraaiuur	1.067	uur	-		-	-	Berekend	Bedrijfsuren overdag zijn vergelijkbaar maar Ikea en Makro is zaterdag de hele dag open en zondag 2/3 dag open
	Totale jaarlijkse koudevraag	1,023	GWh/jaar	-		-	-	Som van Ikea, Makro en Alliander	-
	Totale jaarlijkse koudevraag 3 bedrijven	2,610							
	Percentage koudevraag kan geleverd worden met WKO	80%				Aaname			
	Totale Koude levering WKO systemen	2,088	GWh/jaar	-		-	-	-	-
	Totale Warmte levering WKO systemen	2,088	GWh/jaar	-		-	-	Identiek aan totale koude levering	-
	COP Elektrisch voor koeling	30,00	-		2013	Bram Bot en Marette Zwamborn	Nederlandse Vereniging voor Ondergrondse Energieopslag	tussen 20 en 40	https://www.nhv.nu/uploads/fileservice/stromingen/attachment/2013-3_open%20wko%20systemen_a%20inleiding.pdf
	COP Elektrisch voor verwarming	3,50	-		2013	Bram Bot en Marette Zwamborn	Nederlandse Vereniging voor Ondergrondse Energieopslag	tussen 3 en 3.8	https://www.nhv.nu/uploads/fileservice/stromingen/attachment/2013-3_open%20wko%20systemen_a%20inleiding.pdf
	Elektriciteit voor koeling	0,07	GWh/jaar	-		-	-	Berekend	-
	Elektriciteit voor verwarming	0,60	GWh/jaar	-		-	-	Berekend	-
	Percentage warmte verlies WKO	0%							
	Percentage koude verlies WKO	0%							
Koude	Totale koude vraag	18,89	GWh		2016	20160803 Koudevraag en BC	3) Koelvraag obv kentallen	gebasseerd op bedrijfsoppervlak, bedrijfsfunctie en kengetallen die hieraan zijn toegekend	20160803 Koudevraag en BC.xlsx
	Conventionele koeling								
	Totale koude opwek conventionele koeling	16,80	GWh	-		-	-	Berekend	-
	COP Elektrisch koelen	3,54			2011	KWA advisuers	Het elektrisch energieverbruik van koelinstallaties in Nederland en de aanwezige hoeveelheid koudemiddelen per sector	gemiddelde berekende COP koelinstallaties, verschil tussen verschillende branches meegenomen	https://www.rvo.nl/sites/default/files/Het_elektrisch_energiever
	Elektriciteit nodig voor koelen	4,75	GWh	-		-	-	Berekend	-
	omgevingswarmte nodig voor koelen	12,06	GWh	-		-	-	Berekend	-

G. Data and its bibliography of the future energy landscape

Toekomstige situatie				**Eenheid**	**Jaartal**	**Extra info**	**Link**
Bedrijventerrein		Oppervlak	100	ha			
Warmte koude opslag	Open systeem in grond	Potentie	1000	GJ/ha*jaar			http://nationaalgeoregister.nl/geonetwork/srv/dut/search?#
		Potentie BT	27,78	GWh	Berekend		
		COP warmte	3,5				https://www.nhv.nu/uploads/fileservice/stromingen/attachment/2013-3_open%20wko%20systemen_a%20inleiding.pdf
		COP Koude	30				https://www.nhv.nu/uploads/fileservice/stromingen/attachment/2013-3_open%20wko%20systemen_a%20inleiding.pdf
Accu's		Kosten	231	Euro/kWh	2020		http://www.duurzaambedrijfsleven.nl/energie/893/kosten-energieopslag-tegen-2020-gehalveerd
PV		Opwek	130	kWh/m2			https://www.bespaarbazaar.nl/kenniscentrum/financieel/zonnepanelen-opbrengst/
	Grootste 20 bedrijven	Dakoppervlak	204163	m2	Berekend		20160803 Koudevraag en BC_toevoeging PV
		Dakoppervlak beschikbaar voor pv	44%		Berekend		20160803 Koudevraag en BC_toevoeging PV
		Totaal opppervlak panelen	89149	m2	Berekend		20160803 Koudevraag en BC_toevoeging PV
			9	hectare			
		Totale potentie PV	11,59	GWh	Berekend		20160803 Koudevraag en BC_toevoeging PV
	Gehele bedrijventerrein	Dakoppervlak	390000	m2	Berekend		20160803 Koudevraag en BC_toevoeging PV
		Dakoppervlak beschikbaar voor pv	44%		Berekend		20160803 Koudevraag en BC_toevoeging PV
		Totaal opppervlak panelen	170296	m2	Berekend		20160803 Koudevraag en BC_toevoeging PV
			17				
		Totale potentie PV	22,14	GWh	Berekend		20160803 Koudevraag en BC_toevoeging PV
Windmolens	Kleine windmolens (50 meter)	Opwek per turbine	0,2155	Gwh/jaar			http://windenergysolutions.nl/portfolio-item/wes-50/
	Grote windmolens (150 meter)	Opwek per turbine	4,50	Gwh/jaar			gebasseerd op huidige windmolenpark
Waterkracht	Oryon watermill	Opwek	1,182	Gwh/jaar			http://www.oryonwatermill.com/energy/rekenvoorbeeld
		aanschaf	€ 775.000,00	Euro			http://www.oryonwatermill.com/energy/rekenvoorbeeld
		onderhoudskosten	€ 22.000,00	Euro/jaar			http://www.oryonwatermill.com/energy/rekenvoorbeeld
asfaltcollector		Opwek	0,5	GJ/jaar/m2			https://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjYr8zH-bvOAhWrIMAKHSzeCVgQFggjMAA&url=https%3A%2F%2Fwww.rvo.nl%2Fsites%2Fdefault%2Ffiles%2Fbijlagen%2FConcept%2520B6%2520asfalt warmte.pdf&usg=AFQjCNG0ygbEwZ4xEK8I9y8E6raaGMWXoA&cad=rja
		COP	4				https://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjYr8zH-bvOAhWrIMAKHSzeCVgQFggjMAA&url=https%3A%2F%2Fwww.rvo.nl%2Fsites%2Fdefault%2Ffiles%2Fbijlagen%2FConcept%2520B6%2520asfalt warmte.pdf&usg=AFQjCNG0ygbEwZ4xEK8I9y8E6raaGMWXoA&cad=rja
		Investering	30	Euro/m2		Tusse 20 en 40 eu	https://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjYr8zH-bvOAhWrIMAKHSzeCVgQFggjMAA&url=https%3A%2F%2Fwww.rvo.nl%2Fsites%2Fdefault%2Ffiles%2Fbijlagen%2FConcept%2520B6%2520asfalt warmte.pdf&usg=AFQjCNG0ygbEwZ4xEK8I9y8E6raaGMWXoA&cad=rja
Zonneboilers		Opwek	361,11	kWh/m2 dakoppervlak*jaar			http://nieuws.eneco.nl/download/17298/enecoonderzoekdecentraleduurzameenergiepotentie202014112012pdf.pdf?10000.
Geothermie		Gemiddelde Potentie BT	50	GJ/ha		1500/4000 meter	http://www.nationaalgeoregister.nl/geonetwork/srv/dut/search#|649b3ff1-ae66-4275-bc0f-f8cd59ba3874
		Oppervlak	100	ha			
		Potentie BT	1,39	GWh			
Absorptiekoeling		Nettemperatuur	80	°C	2016		Technische specificaties 2016 Adsorptie koelmachines.pdf
		COP Qkoude/Qwarmte	0,6		2016		Technische specificaties 2016 Adsorptie koelmachines.pdf
		COP Qkoude/Qelektra	40		2016		Technische specificaties 2016 Adsorptie koelmachines.pdf
		Totale koudevraag	2,00	GWh	Berekend		
		Totale warmtevraag	3,33	GWh	Berekend		
		Totale elektravraag	0,05	GWh	Berekend		
Biomassa		Meerkosten vergisting tov compostering	15	euro/ton		10 tot 16 euro/to	http://www.rvo.nl/sites/default/files/RVO-Publ-Grasvergisting-webdoc-mei15_1_def.pdf
		Omvorming van DS biomassa in biogas	80%				http://ecp-biomass.eu/sites/ecp-biomass.eu/files/books/HP_review_natte%20vergisting_BB.pdf
		rendement Vergassing+WKK	15%			15-30 %	http://ecp-biomass.eu/sites/ecp-biomass.eu/files/books/HP_review_natte%20vergisting_BB.pdf
Conversietechnieken	Conventionele koeling	COP	3,540		2005		Bron: Koudevraag gebasseerd op elek. verbruik
	Biogas->heat+elek.	Elek. Rendement	32%		2005		ECN
		Therm. Rendement	46%		2005		ECN
		kosten (Euro/kWe)	800		2005		http://docplayer.nl/863260-De-wereld-van-aardgas.html
	Biogas->heat	Rendement	95%		2005		http://industry.gov.au/Energy/EnergyEfficiency/Non-residentialBuildings/HVAC/FactSheets/Documents/HVACFSBoilerEfficiency.pdf
	HR CV ketel	Rendement	80%		2005		http://www.inoxcon.nl/faq/ik-wil-mijn-cv-ketel-op-gas-vervangen-voor-een-elektrische-cv-ketel-waar-moet-ik-rekening-mee-houden
	CV ketel	Rendement	85%				http://adbioresources.org/wp-content/uploads/2013/06/59-80_chapter5_v41.pdf
	prijs CV ketel Collectief	euro/kW	100				WKO-tool
	Prijs warmtepomp collectief	euro/kW	250				WKO-tool
	prijs koelmachine	euro/kW	225				WKO-tool
	SLIB en mest vergisting	Rendement: Vergisting + boiler	30%				
	Co-vergisting niet vloeibaar	Rendement: Vergisting + boiler	20%				
	Verbranding biomassa	rendement: biomassa-->heat	90%		bron		
Biomassa potentie	RWZI Nieuwpoort	Ontwerpcapaciteit belasting	330000	[i.e.]	16		http://www.neerslag-magazine.nl/magazine/artikel/68/
		belasting percentage	85%		schatting		
		Belasting	280500	[i.e.]	-		
		Droge stof(DS) gehalte	0,087	kg DS/(IE*dag)	17		http://document.environnement.brussels/opac_css/elecfile/Afval%2054%202002
		hoeveelheid	8907278	kg DS/jaar	-		
		energie inhoud per ton	4	GJ/ton NS	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		energie inhoud per ton	18	GJ/ton DS	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Potentie	160331	GJ	-		

		conversietechniek	ting voor groen gas+boiler		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Rendement: Vergisting + boiler	30%	%	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Potentie	48099	GJ	-		
		Potentie Elektrisch	13	GWh	-		
	Berm- en Slootmaaisel	snelweg Berm breedte	10	m	6		Royal Haskoning DHV, Rendabele bermgras inzamelstructuur Utrecht, https://www.cumela.nl/sites/default/files/2013-11-28%20Rapportage%20Inzamelstructuur%20bermgras.pdf
		Snelweg lengte	2500	m	Berekend		
		andere wegen berm breedte	3	m	6		Royal Haskoning DHV, Rendabele bermgras inzamelstructuur Utrecht, https://www.cumela.nl/sites/default/files/2013-11-28%20Rapportage%20Inzamelstructuur%20bermgras.pdf
		Andere wegen lengte	17500	m	Berekend		
		Waterkant berm breedte	3		6		Royal Haskoning DHV, Rendabele bermgras inzamelstructuur Utrecht, https://www.cumela.nl/sites/default/files/2013-11-28%20Rapportage%20Inzamelstructuur%20bermgras.pdf
		Waterkant lengte	8000		Berekend		
		Totaal oppervlakte berm	101500	m2	-		
		productie per hactare	11	ton nat/ha	6		Royal Haskoning DHV, Rendabele bermgras inzamelstructuur Utrecht, https://www.cumela.nl/sites/default/files/2013-11-28%20Rapportage%20Inzamelstructuur%20bermgras.pdf
		Totale productie	111,65	Ton	-		
		energie inhoud per ton	6,3	GJ/ton	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Potentie biomassa	703,395	GJ	-		
		biogas productie per ton	70	Nm3/ton	6		Royal Haskoning DHV, Rendabele bermgras inzamelstructuur Utrecht, https://www.cumela.nl/sites/default/files/2013-11-28%20Rapportage%20Inzamelstructuur%20bermgras.pdf
		biogas productie	7815,5	Nm3	-		
		verbrandingswaarde	23,3	MJ/nm3	10		http://www.rvo.nl/sites/default/files/bijlagen/Bio-energie%20-%20Input%20-%20Groente-,%20fruit-%20en%20tuinafval%20(gft).pdf
		Potentie gas	182	GJ	-		
		potentie Elektrisch met WKK	0	GJ	-		
		Potentie Thermisch met WKK	0	GJ	-		
		conversietechniek	vergisting of vergassing voor groen gas/WKK		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Rendement: Vergisting of vergassing + boiler	20%	%	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		opbrengst	141	GJ	-		
			0,04	GWh	-		
	Snoeiafval hout	opbrengst	8	m3/ha/jr	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		huidige oppervlak bos BT	15	ha	Maps		
		opbrengst	120	m3/jaar	-		
		dichtheid eik	710	kg/m3	18		https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#oak
			85,2	ton/jaar			
		calorische waarde eik	5,36	kWh/kg	18		https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#oak
		Potentie	0,456672	GWh	-		
		Potentie	1644	GJ	-		
		Conversietechniek	verbranding		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		rendement	90%		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		opbrengst	1479,62	GJ	-		
			0,4110048	GWh			
	SWILL-Afval	verspilling restaurants	20%		Aanname		
		aantal bezoekers restaurant (mc donalds+Ikea	5000	per dag	Aanname		
		Aantal arbeidsplaatsen bedrijventerrein	14000		19		bestemmingsplan bedrijventerrein duiven
		verspilling werknemers	5%		Aanname		
		verbruik	0,4	kg/dag/persoon	Aanname		
		totale productie afval	248200	kg/jaar	-		
		Stookwaarde keukenafval	1,36	MJ/kg	10		http://www.rvo.nl/sites/default/files/bijlagen/Bio-energie%20-%20Input%20-%20Groente-,%20fruit-%20en%20tuinafval%20(gft).pdf
		potentie	337,55	GJ	-		
		conversietechniek	vergisting of vergassing voor groen gas/WKK		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Rendement	20%	%	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		opbrengst	67,51	GJ	-		
			0,02	GWh			
	Dunne Mest	Dunne mest rundvee duiven	54000	ton	8		CBS, Duiven mest, http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=7311slmi&D1=0-20,23-26,28,31-33,37-38,41-45,48-50,54-92&D2=306&D3=1,6,11,(l-1)-l&VW=T
		Dunne mest anders duiven	10000	ton	8		CBS, Duiven mest, http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=7311slmi&D1=0-20,23-26,28,31-33,37-38,41-45,48-50,54-92&D2=306&D3=1,6,11,(l-1)-l&VW=T
		beschikbaarheid	25%		7		BTG, innovatienetwerken, Biomassa Binnenveld eindrapport, 2012,http://webcache.googleusercontent.com/search?q=cache:sSrr_YL2UL8J:www.innovatieagroennatuur.nl/sitemanager/downloadattachment.php%3Fid%3D1mSINCPpEeK9hd-dm-j0K_+&cd=5&hl=nl&ct=clnk&gl=nl
		beschikbaarheid	16000	ton	-		

		energie inhoud per ton	0,4	GJ/ton	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Potentie	6400	GJ	-		
		conversietechniek	vergisting voor groen gas+boiler		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Rendement:	30%	%	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		opbrengst	1920	GJ	-		
			0,53	GWh			
	Algen	Oppervlak	10	ha	Aanname		
		Productie	35	ton droge stof/ha/jaar	20		Ingrepo Nederland
		oil content	40%	aanname: droge algens	20		Ingrepo Nederland
		density	0,875	kg/liter olie	20		Ingrepo Nederland
		Productie	16000	liter olie/ha/jaar	20		Ingrepo Nederland
		Totaal productie	1,60E+05	liter olie/jaar	-		
		density	0,864	kg/liter olie	21		Department of Biological Sciences and Biotechnology, Tsinghua University, Beijing , China (2004) http://www.oilgae.com/algae/oil/oil.html
		massa totaal	1,38E+05	kg/jaar	-		
		Heating value	41	MJ/kg	21		Department of Biological Sciences and Biotechnology, Tsinghua University, Beijing , China (2004) http://www.oilgae.com/algae/oil/oil.html
		Potentie	5668	GJ	-		
		conversietechniek	verbranding		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Rendement:	95%		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		opbrengst	5384,448	GJ	-		
			1,49568	GWh			
	Myscanthus verbranding	Beschikbaar Oppervlak	100,00	ha	Aanname		
		Gemiddelde hout productie per hectare	23,31	ton NS/ha			https://dl.sciencesocieties.org/publications/aj/abstracts/93/5/1013?access=0&view=pdf
		Hout productie	2.331,00	ton NS			
		Vollastpercentage	60%		Aanname		
		Vollast uren	5256	uur			
		m_wood	0,12	kg/s			
		HHV	16,81	MJ/kg			https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#miscanthus
		Q_required	2,07	MW			
		Boiler efficientie	0,9				
		Q_water	1,86	MW			
		Jaarlijkse warmte productie	9,80	GWh			
Potentie organisch afval AVR	Totaal huidige verwerking van organisch afval	Totaal verbrand afval (onorganisch)	383093	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Totaal vergunde vergistingscapaciteit	0	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Totaal vergunde composteercapaciteit	65000	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
	Verbranding	Verbrandings Totaal	383093		21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Gemengd stedelijk afval	271286	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		(Grof) Huishoudelijkafval	3218	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Bedrijfsafval (hdo)	2227	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Industrieel afval	5779	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Overig afval	20146	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Residu compostering/vergisting	10351	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Scheidingsresiduen	67676	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Specifiek ziekenhuisafval niet gevaarlijk	2410	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
	Compostering	Compostering Totaal	52065		21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		GFT-huishoudens	36873	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		SWILL	24	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Tuin en plantsoen	3398	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		Huishoudelijk afval na scheiding	8976	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
		overige mengstromen	2794	ton	21		Rijkswaterstaat, Afvalverwerking in Nederland, gegevens 2012, 2013, pdf
	GFT afval	hoeveelheid	36873	Ton	18		http://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&sqi=2&ved=0ahUKEwia9qiw6I7OAhXsDMAKHXVmDMAQFgg0MAQ&url=h
		energie inhoud per ton	7,2	GJ/ton	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Potentie	265486	GJ			
		conversietechniek	Vergisting+boiler		1		
		biogas production	100	m3 biogas/ton	10		http://www.rvo.nl/sites/default/files/bijlagen/Bio-energie%20-%20Input%20-%20Groente-,%20fruit-%20en%20tuinafval%20(gft).pdf
		biogas production	3687300	m3 biogas			
		Calorische onderwaarde van biogas	0,02	GJ/Nm3	20		http://www.seai.ie/Publications/Renewables_Publications_/Bioenergy/Anaerobic_Digestion-Factsheet.pdf
		Potentie afval	73746	GJ			
		biogas-->heat: rendement boiler	95%	0			
		Potentie warmte	70.058,70	GJ	4		StoWA Thermische enrgie op de RWZI, 2013, http://www.energymatters.nl/Portals/0/Publicaties/STOWA%202013%2003_LR.pdf
	SWILL	Hoeveelheid verwerkt SWILL	24	Ton/jaar	18		http://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&sqi=2&ved=0ahUKEwia9qiw6I7OAhXsDMAKHXVmDMAQFgg0MAQ&url=h
		Stookwaarde keukenafval	1,36	GJ/ton	10		http://www.rvo.nl/sites/default/files/bijlagen/Bio-energie%20-%20Input%20-%20Groente-,%20fruit-%20en%20tuinafval%20(gft).pdf
		potentie	32,64	GJ			

		conversietechniek	Vergisting+boiler		1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Rendement	20%	%	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		opbrengst	6,53	GJ			
	Tuin en plantsoen	Hoeveelheid verwerkt Tuin & Plantsoen	3398	Ton/jaar	18		http://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&sqi=2&ved=0ahUKEwia9qiw6I7OAhXsDMAKHXVmDMAQFgg0MAQ&url=h
		Percentage houtachtige stromen	50%		Aanname		
		energie inhoud per ton Houtachtige stromen	9	GJ/ton	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Percentage Berm en slootmaaisel	50%		Aanname		
		energie inhoud per ton Berm en slootmaaisel	6,3	GJ/ton	1		Greenspread, De warmtepotentiekaart van de gemeente Arnhem, Een studie naar de ruimtelijke verdeling van kansen voor de toepassing van warmtetechnieken, 2014
		Gemiddelde energie inhoud tuin en plantsoen	7,65	GJ/ton			
		Potentie	25994,7	GJ/jaar			
		conversietechniek	verbranding		1		
		Rendement	90%		1		
		opbrengst	23395	GJ/jaar			
	Huishoudelijk afval na scheiding en Overige me	Hoeveelheid	11770	Ton/jaar	18		http://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&sqi=2&ved=0ahUKEwia9qiw6I7OAhXsDMAKHXVmDMAQFgg0MAQ&url=h
		Energieinhoud per ton	7,2	GJ/ton			
		Potentie	84744	GJ/jaar			
		Conversietechniek	verbranding		1		
		Rendement	90%		1		
		Opbrengst	76269,6	GJ/jaar			

H. Calculation of the processing of Miscanthus

Appendix H: Calculation of the processing of Miscanthus

Miscanthus is burned in a moving grate furnace with a boiler. The composition of the Miscanthus wood is given in the table. The boiler heats water from 60 to 100 degrees Celsius for the district heating and has an efficiency of 0.85 and an output of 5 MW. The boiler uses ambient air with a relative humidity of 70% at 15 degrees Celsius (x=0.014 kg water/kg air).

Moisture content	14,2	wt-%
Ash content	1,29	wt-%
C	41,53	wt-%
H	5,41	wt-%
N	0,26	wt-%
S	0,09	wt-%
O	37,13	wt-%
HHV_AR	14,43	MJ/kg
LHV_AR	13,07	MJ/kg

$$Q_{water} = 5\ [MW]$$
$$HHV_{ar} = 14.43\ \left[\frac{MJ}{kgK}\right]$$
$$C_p = Cp_{Exhaust\ gasses} = 1.10\ \left[\frac{kJ}{kgK}\right]$$
$$\eta_{\ boiler} = 0.85$$
$$T_0 = 283\ [Kelvin]$$

The required wood can be calculated using:

$$Q_{required} = Q_{water} * \eta_{\ boiler} = 5.88\ [MW]$$
$$\dot{m}_{wood} = \frac{Q_{required}}{\mathrm{HHV_{ar}}} = 0.41\ \left[\frac{kg_{wood}}{s}\right]$$

The air requirement can be calculated with:

$$\left(\frac{\mathrm{A}}{\mathrm{F}}\right)_{\mathrm{st}} = \frac{100}{21} 22{,}4\ \left[\frac{\mathrm{C}}{100}\frac{1}{12} + \frac{\mathrm{H}}{100}\frac{1}{4} - \frac{\mathrm{O}}{100}\frac{1}{32}\right] = 3.90 \left[\frac{m_3}{kg_{fuel}}\right]$$
$$\left(\frac{A}{F}\right) = \lambda * \left(\frac{A}{F}\right)_{st} = 5.07 \left[\frac{m_3}{kg_{fuel}}\right]$$
$$\dot{V}_{air} = (A\backslash F) * \dot{m}_{wood} = 2.07 \left[\frac{m_{air}^3}{s}\right]$$
$$\dot{m}_{air\ stoiciometric} = \rho_{air} * \dot{V}_{air} = 2.45\ \left[\frac{kg_{air}}{s}\right]$$
$$m_{air,total} = \dot{m}_{air} + \dot{m}_{air} * x = 2.48\ \left[\frac{kg_{air}}{s}\right]$$

With this information the total mass flow and the temperature of the exhaust gasses can be calculated

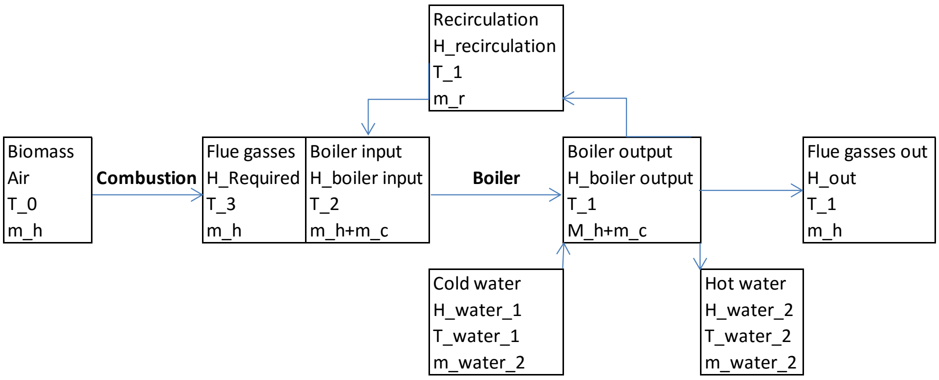
$$\dot{m}_h = m_{air} + m_{wood} = 2.89 \left[\frac{kg_{exhaust\ gasses}}{s}\right]$$

$$T_3 = \frac{HHV_{ar,wood} * \dot{m}_{wood}}{c_{p,exhaust} * \dot{m}_h} + T_0 = 2314\ [Kelvin] = 1861\ [Celcius]$$

The temperature is too high because the ashes will melt at this temperature. To lower the temperature exhaust gases can be recirculated from after the boiler to the combustion chamber. This is shown in the figure below. From literature follows that the maximum temperature is:

$$T_2 = T_{max} = 1223\ [Kelvin] = 950[Celcius]$$

[Source: http://www.ieabcc.nl/workshops/task32_Lyon/full%20page/05%20Brunner.pdf]



To calculate the amount of recirculation and the outlet temperature the following equations are used:

In which m_r is the recycled mass flow.

$$H_{required} + H_{recirculation} = H_{boiler,in}$$
$$H_{req} = c_p \cdot m_h \cdot (T_3 - T_0)$$
$$H_{recirculation} = c_p \cdot m_r \cdot (T_1 - T_0)$$
$$H_{boiler,in} = C_p(m_h + m_r)(T_2 - T_0)$$
$$m_h \cdot (T_3 - T_0) + m_r \cdot (T_1 - T_0) = (m_h + m_r) \cdot (T_2 - T_0)$$
$$m_h \cdot (T_3 - T_0) - m_h \cdot (T_2 - T_0) = m_r \cdot (T_2 - T_0) - m_r \cdot (T_1 - T_0)$$
$$m_r = \frac{m_h \cdot (T_3 - T_0) - m_h \cdot (T_2 - T_0)}{(T_2 - T_0) - (T_1 - T_0)}$$

$$H_{boiler,in} - Q_{water} = H_{boiler,out}$$
$$H_{boiler,out} = c_p \cdot (m_h + m_r)(T_1 - T_0)$$
$$Q_{water} = c_{p\_water} \cdot m_{water} \cdot \left(T_{water_2} - T_0\right) - c_{p_{water}} \cdot m_{water} \cdot \left(T_{water_1} - T_0\right) = 5MW$$
$$C_p(m_h + m_r)(T_2 - T_0) - Q_{water} = C_p(m_h + m_r)(T_1 - T_0)$$
$$C_p(T_2 - T_0) - \frac{Q_{water}}{(m + m_r)} = C_p(T_1 - T_0)$$
$$\frac{Q_{water}}{c_P(m + m_r)} = T_2 - T_1$$

Fill m_r into the equation gives:

$$\frac{Q_{water}}{c_P\left(m + \frac{m_h \cdot (T_3 - T_0) - m_h \cdot (T_2 - T_0)}{(T_2 - T_0) - (T_1 - T_0)}\right)} = T_2 - T_1$$

$$\frac{Q_{water}}{c_P\left(m_h * \frac{(T_2-T_0)-(T_1-T_0)+(T_3-T_0)-(T_2-T_0)}{(T_2-T_0)-(T_1-T_0)}\right)} = T_2 - T_1$$

$$\frac{Q_{water}}{c_P\left(m_h \cdot \frac{(T_3-T_1)}{(T_2-T_1)}\right)} = T_2 - T_1$$

$$Q_{water} = (T_2 - T_1)c_P\left(m_h \cdot \frac{(T_3-T_1)}{(T_2-T_1)}\right)$$

$$Q_{water} = c_P\big(m_h \cdot (T_3 - T_1)\big)$$

$$T_1 = T_3 - \frac{Q_{water}}{m_h\, c_p}$$

$$T_3 - \frac{Q_{water}}{m_h \cdot\ c_p} = T_1 = 560\ [Kelvin] = 287\ [Celcius]$$

Filling T_1 into the recycled mass flow equation m_r gives:

$$m_r = \frac{m \cdot (T_3 - T_0) - m \cdot (T_2 - T_0)}{(T_2 - T_0) - (T_1 - T_0)} = 3.98\ \left[\frac{Kg_{air}}{s}\right]$$

Now the required area which is needed to produce the Miscanthus can be calculated
If the full load percentage is 60%, The full load hours are 5256, which results in a yearly heat production and wood consumption of:

$$Heat\ production = Q_{water} \cdot Full\ load\ hours = 26.28\ GWh = 94{,}608\ GJ$$

$$\dot{m}_{wood,yearly=}\dot{m}_{wood} * Full\ load\ hours * 3600 = 7715\ \left[\frac{ton\ wood}{year}\right]$$

With an average wood production of 20 ton dry wood per hectare and 23.31 ton per hectare per year the total required area can be calculated:

$$A_{wood} = \frac{\dot{m}_{wood,yearly}}{P_{wood}} = \frac{7715}{23.31} = 331\ hectare$$

331 hectare is needed to produce 7715 tons of wood per year and to produce 26.28 GWh of heat.

I. Reflection on functioning within Alliander

One of the goals of this internship for me was to experience what it is like to work as a Mechanical Engineer within a (big) company. I wondered what it would be to work within a large organization with the challenges and opportunities that entails. Besides this I wanted to apply knowledge, which I learned during my courses, in practice and gain some working experience. Furthermore, I wanted to develop weaknesses by practising my presentation skills, work in a well structured way and practice my discussion skills.

During this internship I learned a lot. I developed in my weaknesses and the goals of this internship mentioned above came true. I gained a good impression about the work of an Mechenacal Engineer within Alliander. I participated in the inhouseday of Alliander and a networking event of young professionals active in the energy sector. I not only gained a good impression within my own department within Liandon but also about the whole company and even the energy sector in the Netherlands.

During the intership I ran into some problems which I would approach in an different way when doing it over. I listed these things below.

- I wasted a lot of time on some small matters. These matters seemed interesting but eventually turned out irrelevant. I could have maybe prevented this by holding on to the good project proposal I have written and by discussing it with my supervisor in an earlier stage.
- I didn't have a lot of contact with the client of the research, the supervisor within the Groene Allianties. When I nearly finished my research I discussed my results with him for the first time and he had some other ideas about the research compared to my supervisor. He asked me to change some things with eventually took a lot of time. I could have prevented this by contacting him in an earlier stage of the research. Besides this he could have given me a lot of information which took me a lot of time to find on the internet. It was however really interesting to discuss the project with him because it wasn't an engineer.
- The technical challenges of the project where not of a high level. I knew when I accepted the project that it was not on a high technical and scientific level but I expected that I could turn this into a higher technical level. This was however quite difficult and eventually I missed technical depth during the project.
- I did a large part of the research during the summer period. A lot of colleagues where on holiday which made it difficult to collaborate and get answers to certain questions.
- The goal was to do some research and tests on a test set-up for small heat exchangers. This was eventually difficult because I wasn't allowed to work on my own on this and the people who where allowed where on holiday or busy with other things. Eventually I only did some research on the working principle of it.

This research discussed in this paper is not the only thing I did during this internship. I did for example some internal courses about safety, an excel course and some depth research about the sorption cooling machines which is not mentioned in this report.