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FEASIBILITY STUDY OF A PROPOSED AGROBUSINESS SOLUTION FOR THE VEENKOLONIËN AREA

Integration of a water supply system with solar energy and algae production systems

Feasibility Study of a Proposed Argobusiness Solution for the Veenkoloniën Area

Project Report

By

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Executive Summary

The Veenkoloniën area is situated in the North-eastern part of the Netherlands and covers a part of the province of Groningen; an area with intense agriculture. At the moment the main source of water needed to irrigate the crops in the summer comes from Lake IJssel. It is expected that in the future, the water demand will increase due to intensifying irrigation, while the supply of water from Lake IJssel will decrease due to climate change. The goal of this research was to study the technical feasibility of integrating water storage and retention with the production of energy using solar panels and algae production systems, to create an additional source of income for local farmers.

We start in chapter two with a literature and background study on the three individual sub-problems: hydrometeorology, solar energy and algae production. The hydrometeorological background covers the general physical characteristics of the region and climate. In both the background on solar energy and algae production, the state-of-the-art of both systems is outlined. In chapter three the output of the agribusiness solution is presented: designs and calculations for the water basin, electricity production from solar energy and possible applications for algae cultivation in the Veenkoloniën area. To conclude, a scenario is designed to integrate the different systems into a unified agribusiness solution.

Our main findings are that (1) it is technically feasible to supply a sufficient amount of water from the basins to bridge the gap between the expected water demand and water supply, (2) it is technically and economically feasible to create an additional source of income by means of small scale solar energy production for farmers and (3) algae production may only be economically feasible if the production and processing costs can be reduced and if algae biomass is exploited completely.

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Acknowledgements

1. Introduction

The Veenkoloniën area, situated in the North-eastern part of the Netherlands, is facing numerous problems, partially due to climatic changes. In the current climate scenarios for the Netherlands, summers are expected to be both drier and dominated by more extreme precipitation events (KNMI, 2006; Klein Tank & Lenderink, 2009). This requires an adaptation of the hydrological system to ensure a sufficient supply of water for irrigation and to enable the (temporary) storage of water during precipitation peaks. Even today the area has a negative precipitation excess during growth seasons from April to September (i.e. more evapotranspiration than precipitation), requiring an input of water from Lake Ijsselmeer (**Error! Reference source not found.**) to prevent the sensitive sandy soils from drying out (Rothengatter, 2011). As a result, the water demand is expected to increase whereas the water supply from Lake IJsselmeer may either decrease or remain stable depending on the discharge of the river Rhine. Hence, the creation of extra water storage is required to bridge the gap

Figure 1 Water systems within the jurisdictional area of Hunze en Aa's

between the expected demand and supply of water for agricultural purposes (Querner *et al*. 2011). However, the area needed for storage will have to be partially built at the expense of current arable agricultural plots, and finding suitable locations based on geo-and hydrological properties is a challenge.

In 2003, 823 arable farms were present in the Veenkoloniën with an average area of 59 ha (Rothengatter, 2011). Although arable farming covers by far the largest part of the Veenkoloniën, other farming types are present in the area as well including 221 dairy farms, 29 pig farms, 29 chicken farms, and 192 horticultural farms. In recent years, arable and dairy farms grew to sizes of more than 100 ha each, so that, in 2007 they covered more than 37% of the entire Veenkoloniën area.

As an area of intense agriculture, the Veenkoloniën face structural problems in addition to experiencing water shortage. In search for higher education and employment, especially young people leave the Veenkoloniën. Consequently, the number of lower educated inhabitants is overrepresented and unemployment is above the national and provincial average (Rothengatter, 2011). Hence, the province of Groningen wishes to stimulate the local economy by providing an increase in the agricultural scale (Province of Groningen, 2009), which will further pronounce the irrigation problems within the area.

To address the expected water shortage during the cropping season and present-day socio-economic problems, Tauw consultancy aims at implementing a feasible agrobusiness solution integrating a water supply system for crop production with additional sources of income for local farmers in the Veenkoloniën. The solution should ensure both a reliable supply of water, and encourage sustainable economic activity and social cohesion as well as strengthen the attractiveness of the Veenkoloniën area.

Here we present the results of the technical feasibility study designed to provide insight into possibilities for the development of a sustainable agrobusiness solution. We investigated the state-of-the-art of three separate concepts including water supply, solar energy and algae cultivation systems. In order to develop an economically feasible solution, we analyzed several options for the integration of these systems that would allow the construction of sufficiently large water storages without causing a financial loss to the farmer due to the conversion of plots of arable land. It was envisioned that, by covering the energy requirements of a water storage and retention network using electricity generated by solar panels, the loss of profit following the land conversion could be compensated. The production of algae biomass would, therefore, represent an additional source of income as it can be sold and used for the generation of biofuels and other high-quality products.

1.1 Problem Description

The core problem of this project is the **expected shortage of water for irrigation during the cropping season in the Veenkoloniën area**. The background to this problem is considered to be twofold: First, due to expected changes in the future climate, the supply of water from Lake Ijssel during the growth seasons is expected to decrease or in the best scenario remain stable. Secondly, intensifying irrigation of the cultivated crops increases the areas water demand. In combination with the expected increase in evapotranspiration (Querner *et al.*, 2011), the area is confronted with a shortage of water for irrigation purposes in those future scenarios. This directly affects the farmers as, during a dry summer like 2003, the decrease in crop yield can be as large as 30% (Rothengatter, 2011). In addition, the ongoing rural migration aggravates the economic situation of the area.

1.2 Approach and Methodology

1.2.1 Purpose
The overall, long-term goal of this project is the implementation of a feasible agrobusiness solution for a water supply system enabling efficient crop production. The integration with additional sources of income for local farmers to increase the attractiveness and to encourage sustainable economic activity and social cohesion in the Veenkoloniën was considered. Our purpose was to develop a solution for the expected future water shortage during growth seasons in the Veenkoloniën area. We carried out a technical feasibility study for an integrated water supply system including solar energy and algae production on the scale of a single arable farm with an average area of 100 ha.

Based on this objective the following research question was formulated:

Is it technically feasible to integrate water storage (and water retention) with the production of energy using solar panels and the production of algae to ensure sufficient water supply in the future, and to create an additional source of income for local farmers in the Veenkoloniën?

Accordingly, several sub-questions can be expressed concerning various aspects of the feasibility study:

- **What is the current and expected future water demand and water supply of the area (water balance)?**
- **What should be the capacity of the storage basins?**
- **What type of solar energy facility is best suited for the Veenkoloniën?**
- **Is the use of solar energy economically feasible for the Veenkoloniën?**
- **What is the state-of-the-art of algae production systems?**
- **How can the water storage, solar energy and algae production systems be integrated to generate an optimal sustainable and (economically) feasible solution?**
- **What are the criteria for the installation of such an integrated system in the Veenkoloniën? Based on those criteria, can we determine possible sites for the installation?**

1.2.2 Output
We will present five products that contain several smaller components to achieve the purpose of this project:

1. The **design of a water storage basin**
2. Selection of a **suitable solar system** for the Veenkoloniën
3. **Cost-benefit analysis** for differently sized solar panel installations
4. Selection of a **suitable microalgae strain and cultivation system**
5. Options for an **integrated model design (systematic drawing)**

1.2.3 Activities
A **technical feasibility study** will be carried out to determine if an integration of the water storage, solar energy and algae production systems is possible. A combination of literature study and calculations will eventually lead to a model design, geographical criteria for implementation of this model, and a general overview of design costs. The research question and its sub-questions will be approached in different ways:

In total 288 hours were spent on a **literature study**, whereas 200 hours were spent on **calculations**. The literature study helped us:
- to gain insight into soil and hydrological characteristics of the Veenkoloniën area and to identify the climate conditions within that region
- to get the data needed to calculate the regional water balance and electricity demands

- to review the technical feasibility of water storage systems
- to determine the most recent developments and economic feasibility of solar energy systems
- to specify the applicability of algae growth systems and their implication for efficient energy production (other applications were be considered)

In addition, a **field trip** of one day was arranged to
- provide us with valuable information on the site and its properties
- enable us to meet with the water board as one of the most important stakeholders

Based on the different criteria for the water storage, solar energy and algae production systems an attempt was made to integrate all three systems into a **model design**. To visualize the model design a **systematic drawing** was constructed.

2. Hydrometeorological Background

2.1 Introduction

Different aspects have to be taken into account when possibilities for water storage on a local scale are investigated. First of all, the general physical characteristics of the area have to be identified. In the following sections the soil type (Section 2.2), the ground- and surface water levels (Section 2.3) and the climate variables (precipitation, evaporation and temperature in Section 2.4) will be discussed. A more detailed description of the physical characteristics of the area and the technical aspects of the design will be given in Chapter 5.

2.2 Soil Type

Originally, the Veenkoloniën were a peat area but, nowadays, undisturbed peat layers are left only in small parts of the area. In the remaining parts the upper peat layer was partly or totally removed, and mixed with sand and manure (Rothengatter, 2011). This mixed upper soil layer is typical for the Veenkoloniën area and can be up to two meters thick (Witteveen en Bos, 2011). Below the mixed layer a layer of cover sand is present. However, in areas where the mixed layer is absent the upper soil layer consists of very fine cover sand only. Both the peaty and sandy areas are very prone to drought. A soil map is included in Appendix A (Figure A 1).

2.3 Ground Water Regime and Surface Water Levels

In general, three groundwater level classes (Grondwatertrap) are present in the Veenkoloniën area (derived from maps of Stiboka, 1977 see Figure A 1), namely Glc-III*, Glc-V and Glc-VI (see Table 1). A more detailed description of the groundwater regimes and the corresponding fluctuation of groundwater levels throughout the year will be given in Section 5.2 describing the water basin design.

Table 1 Ground water level regimes (from www.natuurkennis.nl, 2012)

Groundwater level	Groundwater level classes						
(cm below soil surface)	I	II[1]	III	IV[1]	V[1]	VI	VII[2]
Mean highest groundwater level	<20	<40	<40	>40	<40	40-80	>80
Mean lowest groundwater level	<50	50-80	80-120	80-120	>120	>120	>160

[1] behind those Glc-codes means a ´dryer part´, i.e. a mean highest groundwater level between 25 and 40 cm below soil level. [2] behind those Glc-codes means ´very dry part´, i.e. a mean highest groundwater level deeper than 140 cm below soil level.

Currently, the typical surface water levels for a representative part of the Veenkoloniën close to Stadskanaal are 1.40 m below soil surface levels in winter and 1.00 m below soil surface levels during summer (Droogers and Besten, 2006). In general, the surface water levels are kept between 0.80 m- 1.00 m and 1.00 m – 1.20 m below the soil surface during summer in the northern and southern parts of the Veenkoloniën, respectively (Rothengatter, 2011). The change between winter and summer levels takes place in April and the change between summer and

winter levels in October. The exact date depends on the actual hydrological situation and groundwater levels (Bakel *et al.*, 2012). The difference between the surface water level in summer and winter is normally about 0.50 m and can be as high as 0.70 m (Bakel *et al.*, 2012).

2.4 Climatological Analysis

Climatological data (1965-2011) from the KNMI measurement station at the airfield of Eelde was used to estimate the amount of precipitation and evaporation (KNMI, 2012). Using the measurement data, the amount of open water evaporation was calculated using a modified version of the Penman equation (de Bruin, 1979). To stay in line with the method used by the KNMI, the reference evapotranspiration was calculated using the Makkink equation (e.g. de Bruin, 1987). In view of the expected climatic changes, the observations were corrected for the expected change in temperature and precipitation in the KNMI W+ scenario (van den Hurk *et al.* 2006), as shown in Table 2. The values for summer (June, July, August) and winter (December, January, February) months were retrieved from the KNMI W+ scenario, the months in between were linearly interpolated. Throughout the text, *Eelde W+* will be used to refer to the corrected dataset.

Table 2 Imposed climate change in the KNMI W+ scenario on the 1965-2011 historical data of Eelde. The values for JFM and JJa are retrieved from the KNMI scenarios, the months in between were linearly interpolated. ΔT denotes the absolute change in temperature; ΔP the relative change in precipitation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ΔT [°C]	+2.3	+2.3	+2.43	+2.55	+2.68	+2.8	+2.8	+2.8	+2.68	+2.55	+2.43	+2.3
ΔP [%]	+14.2	+14.2	+5.9	-2.4	-10.7	-19.0	-19.0	-19.0	-10.7	-2.4	+5.9	+14.2

The results of this analysis are shown in Table 3 (period 1 April - 31 August) and Table 4 (period 1 April - 30 September). The minimum in precipitation and maximum in evaporation and evapotranspiration correspond to the record year of 1976. As the predicted change in precipitation is negative for all months from April to October, all statistics show a decrease in precipitation. In addition, with the expected increase in temperature, the moisture holding capacity of the atmosphere increases, resulting in an increase in evaporation and evapotranspiration. It should, however, be noted that this increase in evaporation is merely a first guess. In the W+ scenario, changes in large-scale synoptic circulations are expected to decrease the summertime relative humidity. This could further enhance the evaporation rate, a factor that is not taken into account here.

Table 3 Climatological statistics for Eelde over the period of 1 April - 31 August. Evaporation denotes the open water evaporation according to the Penman equation. Evapotranspiration represents the reference evaporation according to Makkink (Bruin, 1987).

	Precipitation		Evaporation		Evapotranspiration	
	1965-2011	Eelde W+	1965-2011	Eelde W+	1965-2011	Future
Mean	324.3	275.1	498.3	528.1	398.4	421.5
Min	150.9	126.7	425.9	453.0	343.9	365.2
Max	508.0	432.6	571.6	604.6	459.2	485.0
5 driest	206.5	173.1	559.9	591.7	445.0	469.8
10 driest	228.1	191.6	547.3	579.0	436.4	460.8

Table 4 Climatological statistics for Eelde over the period of 1 April - 30 September. Evaporation denotes the open water evaporation according to the Penman equation. Evapotranspiration represents the reference evaporation according to Makkink (Bruin, 1987).

	Precipitation		Evaporation		Evapotranspiration	
	1965-2011	Eelde W+	1965-2011	Eelde W+	1965-2011	Future
Mean	399.0	341.8	560.0	593.7	447.3	473.3
Min	199.9	170.4	475.1	505.3	383.5	407.2
Max	622.7	538.3	637.6	674.5	510.6	539.2
5 driest	262.8	222.3	626.7	662.5	497.7	525.1
10 driest	290.4	247.5	613.4	649.0	488.1	515.5

With an increase in evaporation and a decrease in precipitation, the precipitation shortage over the growth season will increase. The average cumulative shortage from 1 April onwards for the past and W+ climate is shown in Figure 2. The grey band indicates the spread between the driest (1976) and wettest (1965) year. The left figure shows the shortage with respect to potential evapotranspiration, whereas the right figure denotes the shortage with respect to open water evaporation. Over the period 1965-2011, the average precipitation shortage in reference to potential evapotranspiration was 50 mm over the period 1 April - 31 September (not shown) and 75 mm over 1 April - 31 August (Figure 2). By approximation, these shortages will increase with 100 mm in the W+ climate.

2.5 Water System Veenkoloniën

The water system in the Veenkoloniën is, for the largest part, controlled by Waterschap Hunze en Aa's. During the summer months, water from Lake IJsselmeer is supplied to the area *via* the northwest (Friesland) and southwest (Drenthe) (Hunze en Aa's, 2009). The input of water is required both for irrigation and maintenance of the ground water levels. The current water

demand for the area is 100,000 million m³ and is expected to increase to 175,000 million m³ due to climate change (Section 2.4) and due to intensifying irrigation (personal communication, Johan de Putter). With a constant or decreasing supply from Lake IJsselmeer, alternative measures are needed to bridge the gap between the demand and supply.
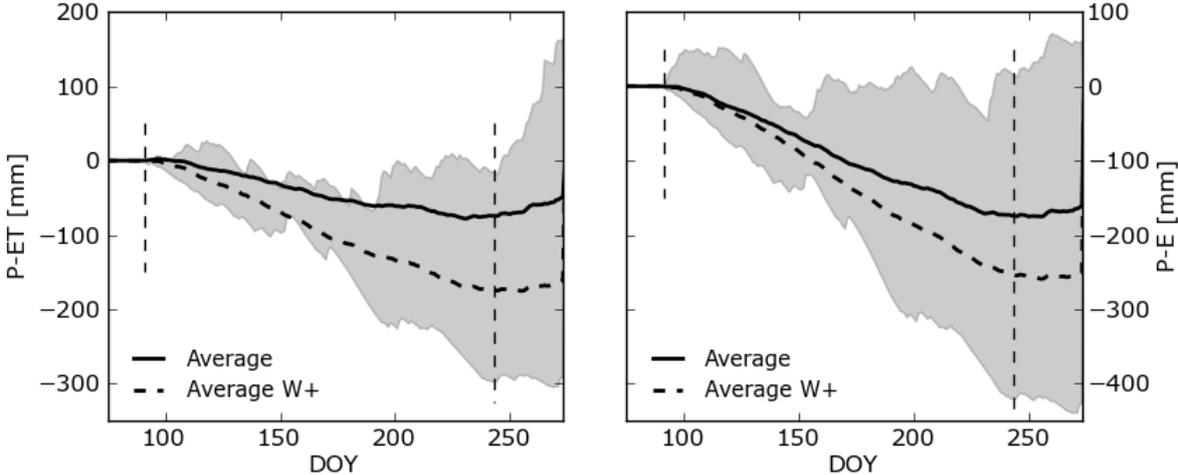
Figure 2 Precipitation shortage with respect to evapotranspiration (left) and open water evaporation (right). DOY depicts the day of the year with 1 April and 31 August indicated with dashed lines. The x-axis ends at 30 September.

3. Solar Energy Background

3.1 Introduction

By 2020, renewable energy should account for 20% of the EU's total energy consumption (8.5% in 2005). To meet this common target, each member state needs to increase its production and use of renewable energy in electricity, heating, cooling and transport (van Rooijen and van Wees, 2006). The Netherlands is, therefore, obliged to comply with the commitment. Hence, the development of solar energy facilities in the Veenkoloniën area is most likely to be welcomed by the Dutch government. However, it has also been stated that costs for generating energy with photovoltaic (PV) panels were so high that any market introduction would have been prohibitively expensive for the Netherlands (Agnolucci, 2007). Currently PV installations cannot compete with fossil energy.

According to the world solar energy map (www.gstriatum.com/solar-power/articles/15-world-solar-energy-map), the Netherlands (including the Veenkoloniën area) receives an annual solar energy of more than 100 W m^{-2} on average. The solar radiation strikes the land surfaces at an angle smaller than 90° for most of the year. Nonetheless, it is possible to harvest tremendous amounts of energy during the entire year assuming an efficiency of 8% from the sun (Solangi *et al.*, 2011).

Nowadays, there are various technologies for energy conversion and storage available. One of these technologies may be utilized to convert solar energy into heat, which can then be used for generating electricity using turbines and/or storing in insulated tanks for domestic heating. For electricity generation applications, however, low temperature thermal conversion devices suffer from low efficiency because of the inherent limitations of the Carnot cycle[1] and temperature drops across heat exchanger walls. The Carnot Cycle can be thought of as the most efficient heat engine cycle the physical laws can allow. Not all the heat supplied to a heat engine can be converted into useful work (energy). The maximum efficiency (Carnot efficiency, η_{max}) is given by equation 1.

$$\eta_{max} = 1 - \frac{T_{out}}{T_{in}} \tag{1}$$

Where: T_{in}　　=　　Temperature (K) of steam going in to the heat engine/ turbine
　　　　T_{out}　=　　Temperature (K) of the sink (steam leaving the turbine)

Generally solar energy could be harvested in two major ways: as thermal energy using solar thermal collectors for heating purposes or electricity (if high temperatures can be attained) and as direct electricity using PV cells.

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[1] The Carnot cycle shows that the power output of a heat engine/ turbine is increased when there is a wide difference between heat source (e.g. steam) and the ambient (heat sink).

3.2 Solar Energy Harvesting Mechanisms

3.2.1 Solar Thermal Collectors

There are different types of solar thermal collectors which differ in simplicity of construction and efficiency. They range from the simple flat plate (Figure 4) and evacuated tube (Figure 3) collectors commonly used for small scale domestic heating, to the more complex parabolic collectors (Figure 6) used for generating electricity. They all have an absorber element as the principal component. This ensures a high degree of absorption of short wave lights. The absorber, which is usually black, is heated up to a temperature far greater than the ambient temperature and releases the energy as long wave radiators. Its efficiency is indicated by the degree of absorbed heat to the emitted heat. Therefore, in order to reduce energy loss through heat emission, efficient absorbers have a selective surface coating. This coating enables the conversion of a high proportion of the solar radiation into heat, simultaneously reducing the emission of heat. The usual coatings provide a degree of absorption of over 90% (Boyle, 2004). Galvanically-applied selective coatings include black chrome, black nickel, and aluminium oxide with nickel. The parabolic solar collector which is commonly used for electricity production is discussed here to evaluate whether it is an option for the Veenkoloniën area.
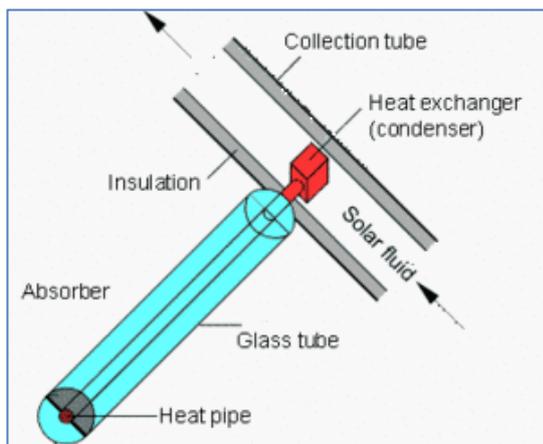
Figure 3 Evacuated tube solar collector. A heat pipe collector incorporates a special fluid which begins to vaporize even at low temperatures. The steam rises in the individual heat pipes and warms up the carrier fluid in the main pipe by means of a heat exchanger. The condensed liquid then flows back into the base of the heat pipe (from: www.solarserver.com/know ledge/basic-knowledge/solar-collectors).
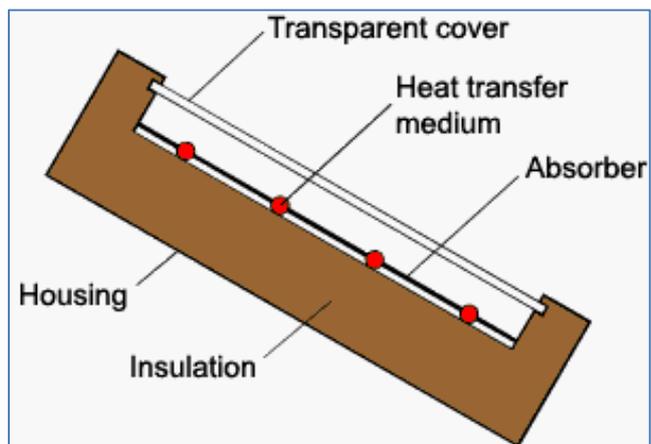
Figure 4 Flat plate solar collector (www.solarserver.com/ knowledge/basic-knowledge/solar-collectors.html).

3.2.2 Parabolic Solar Thermal Collectors and Electricity Generation

Parabolic solar collectors, also called line focus collectors, are the most common solar collectors for generating electricity. They consist of a large, modular array of single-axis-tracking parabolic trough solar collectors (Figure 6). Many parallel rows of these solar collectors span across the solar field, usually aligned on a north-south horizontal axis. Each solar collector assembly is an independently tracking, parabolic trough solar collector composed of the following key subsystems (Figure 4):

- Concentrator structure
- Mirrors or reflectors
- Linear receiver or heat collection element or absorbers
- Collector balance of system

Figure 6 Parabolic trough type solar collector (from www.solar server.com/knowledge/basicknow ledge/solar-collectors).
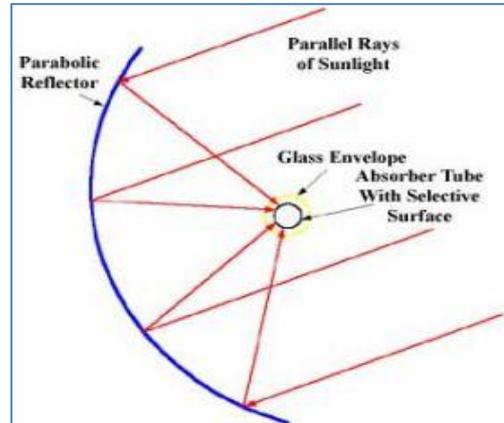
Figure 5 Schematic cross-section of single row of parabolic solar collector (www.alternative energyprimer.com/Linear-Solar-Concentrators.html).

Benefits

1. Free sun energy
2. Lifetime of more than 20 years

Limitations

1. High initial costs, longer payback period
2. Low energy density[2]
3. Solar collectors are usually difficult to reach for maintenance and repair.
4. The need for big tanks with excellent insulation
5. Heat loss particularly with long transportation
6. Unable to convert diffused radiation in to thermal energy

If the mirrors are used to concentrate sun rays continuously as in Figure 5, sufficiently high temperatures can be used to drive steam engines. These can be used for mechanical work for water pumping or steam generation. All rays of light that enter parallel to the axis of a mirror formed in this particular shape will be reflected to one point, the focus where the medium is located (Figure 5). However, if the rays enter slightly off-axis, they will not pass through the focus. It is, therefore, essential that a good tracking facility be made to enable the mirrors track the sun throughout the day. With a south-facing solar collector, only upward and downward adjustment is required. Normally, electric motors and gear trains commanded by controllers and radiation sensors are provided to continuously adjust the orientation of the solar collector relative to the sun for maximum output. For a point focus (solar parabolic dish) on the other hand, the axis needs to point at the sun. Therefore it needs to track the sun both in elevation and

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[2] Energy density is the amount of energy stored per unit volume or mass. For example the amount of energy (KWh/kg of heated water)

in azimuth (side to side). A line focus parabolic trough may achieve a concentration ratio of only 50 (Boyle, 2004). However, this is adequate for most power plant systems. The ratio required depends on the desired target temperature. A line focus parabolic trough collector can produce a temperature of 200 to 400^{0}C (Boyle, 2004).

Typical examples of the parabolic thermal collectors have recently been installed in Egypt and the USA. Five parabolic trough collectors, each 80 m long and 4 m wide, in Egypt produce 55 horse powers[3]. The payback period was only 5 years for Egypt (Boyle, 2004). A parabolic trough concentrator in California heats up synthetic oil to a temperature of 390 ^{0}C (Boyle, 2004). This installation was found to be competitive with energy from PV cells and fossil fuels. The author also suggests that the system has to be combined with fossil power generation or some kind of heat storage tank to function also during the night to improve the capital investment of the steam turbine.

Generally, electricity generation by solar thermal collectors together with heat engines or turbines is technically not feasible for the Veenkoloniën. This is because of the low intensity of solar radiation in the area. Taking the low ambient temperature of the area into account, a high heat loss would occur across the pipes even with excellent insulation. The handling and management of a precise tracking mechanism may be difficult for a farmer. Furthermore, such an installation will not be profitable in areas with too much cloud cover like the Veenkoloniën.

3.2.3 Electricity from Photovoltaic Cells

3.2.3.1 General Information
Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current flow is generated. In order to produce electricity, photovoltaic cells require a pn[4]-junction across a semiconductor. The majority of the PV panels in the market are made up of crystalline silicon or thin film panels, which utilize silicon as a semiconductor, making silicon the major source for semiconductors in this industry. A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module (Figure 7). Current crystalline PV are for example designed with 36 or 72 series – connected PV cells. The system helps to ensure the supply of electricity at a fixed voltage, such as the common 12 volts system. The DC current produced by such a module depends on the amount of light striking the cells. Today most of the PV devices use a single junction or interface to create an electric field with in the semiconductors. The limitation with these types of panels is however that they can make use of specific energy of the sun – photons with energy greater than the electron gap of the junctions only. The electricity of PV panels can be used in two ways: connected to grid and stand-alone (off grid). When the solar electricity is to be connected to the grid, the DC[5] current is first converted into AC[6] by an inverter. Figure 8 shows a schematic drawing of a PV (FPV) system connected to an inverter. In case of an off-grid, batteries are used to store the DC electricity.

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[3] 1 horse power = 746 Watts
[4] Pn stands for positive negative junction
[5] DC = Direct Current
[6] AC = Alternating current

With a PV module, the semiconductor is doped (p-type or n-type) to allow free electrons to become available for electricity conduction. The main doping elements used are boron/gallium (p-type) or phosphorus (n-type).

PV cells require contacts or junctions, widely referred to as electrodes, through which electricity can be conducted. An electrode is made up of a metal element, frequently aluminum (Al), copper (Cu), zinc (Zn), tin (Ti) or lead (Pt).
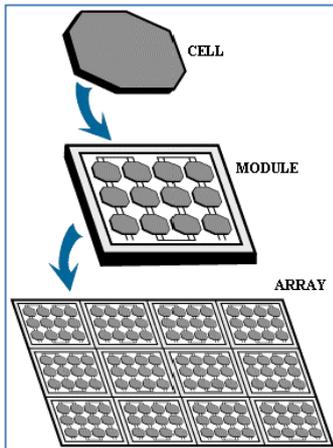
Figure 7 Single components of PV modules
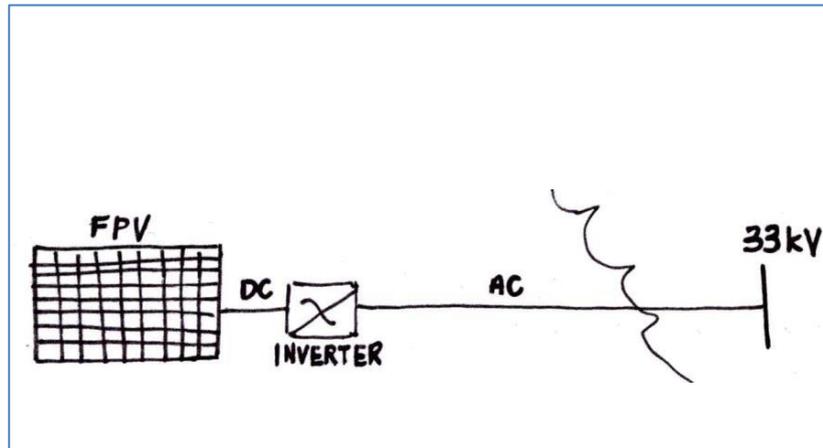
Figure 8 Schematic drawing of a grid-connected PV system (Trapani, 2011)

3.2.3.2 Efficiency of PV Panels

In Figure 9 (left) I_{SC} and V_{OC} are the short circuit current and open circuit voltage of a cell. The product of those two is the maximum power of the cell. The Veenkoloniën receive solar radiation of more than 100 W m^{-2} on a yearly basis. Hence, referring to Figure 9 (right), the maximum power generated by a single cell would be 1 x 0.5 W = 0.5 W on average. Overheating decreases the performance of PV cells by 0.4-0.5% for every 1^{0}C above the optimum temperature (usually 25^{0}C). Thus, cooling of PV panels is important. Sometimes the temperature of the PV module may reach up to 50^{0}C, reducing the power output by 25% (Krauter and Hanitsch, 1996). The heat energy removed from a PV module in this way is 3x that of the energy converted to electricity (Figure 10). Hence, without cooling a system the PV panels work at efficiencies lower than the rated values (12–16 %).

About 80% of the solar energy striking the PV is converted to heat (Dubey et al., 2009). Consequently, the temperature of the PV panel rises to about 50°C, further reducing the power output. This is why PV panels come with normal efficiency rating and performance rating. It has been reported that under working conditions the performance may be reduced to 75% (Zahedi, 2009). A PV panel with an efficiency of 15% would perform at 11% in the field. By creating a cooling mechanism the output of the PV panels in Veenkoloniën can be enhanced.
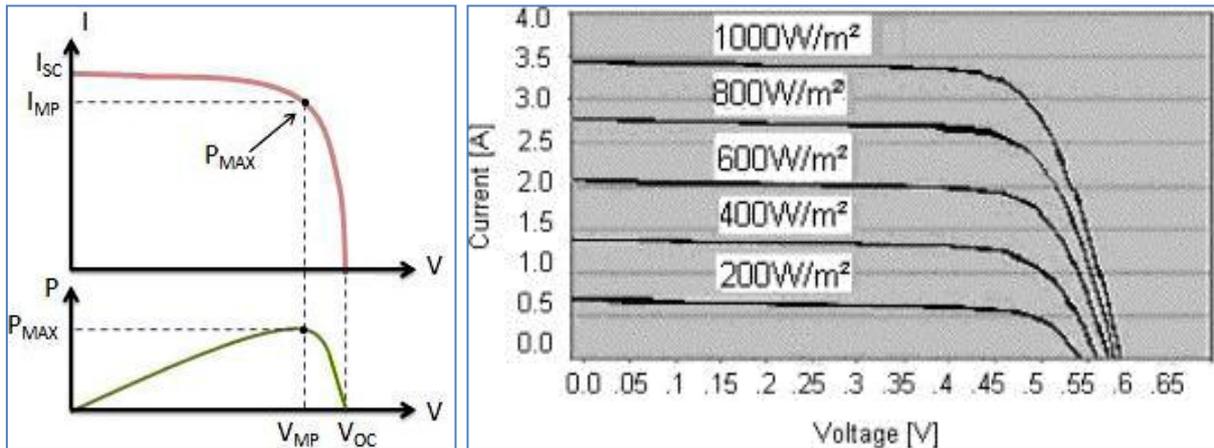
Figure 9 Maximum power from a single cell for different insolations (Trapani, 2011)
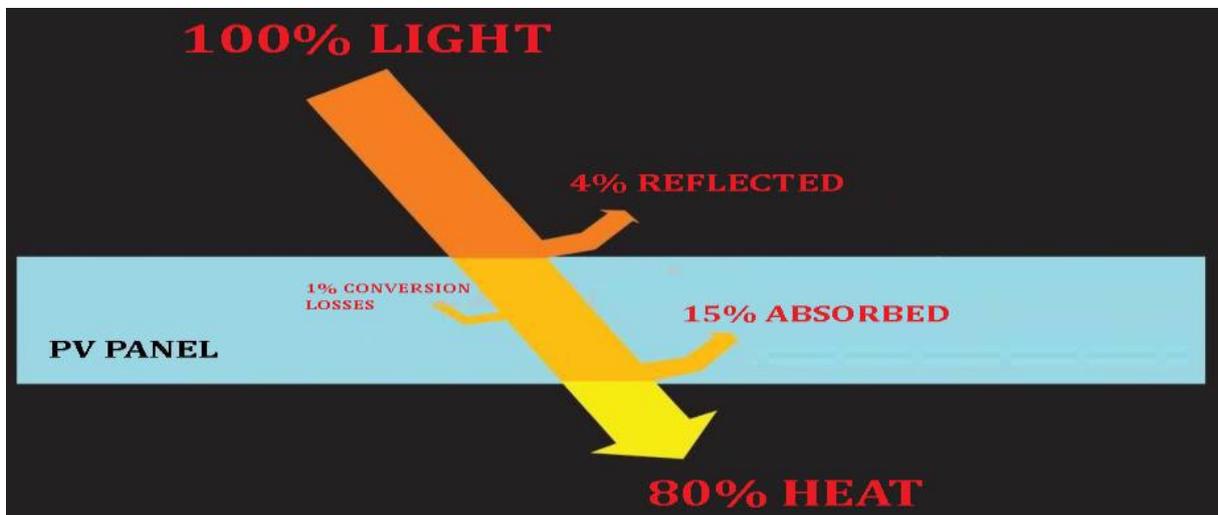
Figure 10 the proportion of solar energy converted to electricity (15%) and heat (80%) (Trapani, 2011).

A good thermal contact is to be maintained between the water (coolant) and the cells. The thermal energy may be used for heating purposes as well. Thermal heat collected, providing energy supply in winter and cooling energy in summer, can be combined with seasonal storage of excess solar energy.

3.2.4 Concentrating Photovoltaics

Concentrated photovoltaic (CPV) technology uses optics such as lenses to concentrate a large amount of sunlight onto a small area of solar photovoltaic materials to generate electricity. In practices, it is a relatively new technology even though research in the field was initiated in the 1980's. An example of this technology is the practice of focusing the direct radiation with Fresnel lenses and intercepting this by PV modules (Sonneveld *et al.*, 2010). Fresnel lenses are optical devices that can be used for concentration of solar radiation by the refraction principle. These lenses are thinner, have a lower weight and a shorter focal length than the thicker standard lenses. In some studies with greenhouses, the lenses were used to concentrate the direct solar

radiation for energy generation. The diffused light was kept for plant growth (Sonneveld *et al.*, 2010).

Fresnel lenses can also be connected to a solar thermal collector, PV panels, or a hybrid technique (PV and solar thermal collector), where the concentrated energy is released in the form of hot water, electric energy or a combination of both. With a hybrid CPV (concentrating PV and heat of the cooling water) up to 69% of the solar energy can be harvested (Joe, 2005).

Nowadays, there are Fresnel films that can be painted onto a glass surface (http://multimedia.3m.com/mws). These are cheaper than normal Fresnel lenses. Unlike the traditional PV, CPV systems are often much less expensive to produce, because the concentration allows for the production of a much smaller area of solar cells. According to the principle of photoelectric effect solar cells produce electrical energy in proportion to the amount of light energy that strikes them. By applying 10 times the amount of light to a solar panel it is possible to generate 10 times the amount of electricity. As a disadvantage, the single cell efficiency decreases with rising temperatures. This means that to increase the output, it is necessary to keep the temperatures low. Another problem is that the cost of the concentrator and tracking system can defeat the cost reduction resulting from the use a lower number of solar panels. Moreover, the local concentration of the solar radiation may create hot spots decreasing the overall output (Ryu *et al.*, 2006). Last but not least, solar radiation that is scattered by clouds or aerosols (diffuse radiation) cannot be used to produce electricity with this type of design (Sonneveld *et al.*, 2010). Generally speaking, however, CPV is profitable because the solar collector is less expensive than an equivalent area of solar cells. The overall CPV hardware is less expensive than a conventional PV of the same output (Ryu *et al.*, 2006).
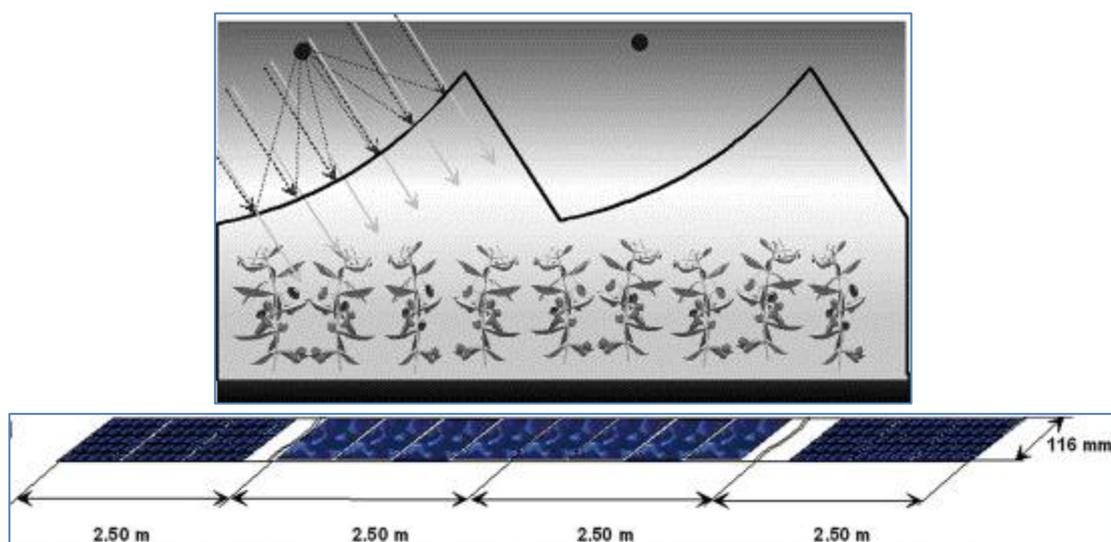
Figure 11 Concentrating PV; specially designed greenhouse roof concentrating solar radiation to a narrow PV (Sonneveld et al., *2010). The parabolic shape of the greenhouse roof concentrates the solar radiation on the black spots where the PV panes are situated. Note the PV panel should face the bottom. A tracking mechanism (not shown) keeps the PV at an optimal orientation for maximum solar energy harvesting.*

According to an experiment carried out at Wageningen University (Figure 11), a yearly total electrical and thermal energy of 20 KWh m^{-2} and 160 KWh m^{-2}, respectively, could be obtained from a CPV integrated with a special roofing of a greenhouse with a selective coating. The coating ensured about 50% of the incoming solar energy (which is non-photosynthetic active

radiation (non-PAR)) to be trapped. The trapped part was mostly near infrared (NIR) and was reflected to a point where the PV cells were located. To avoid overheating water was circulated around the PV cells. The hot water was then stored for heating the greenhouses during the cold season (Sonneveld *et al.*, 2010). The advantage was cheap cooling, and an energy saving of about 35% compared to heating with a boiler. The disadvantage was that the excess solar energy was converted to low grade thermal energy which was stored at a temperature level of about 30ºC. This could only be exploited for heating in winter with a heat pump, driven by high grade energy like electricity (Sonneveld *et al.*, 2010).

While this model could be a good option for the Veenkoloniën area, the sophisticated tracking mechanism makes it less suited for a farmer. Movements of the system due to wind, imperfectly manufactured optics, imperfectly assembled components, finite stiffness of the supporting structure or its deformation due to aging, among other factors, may require frequent maintenance and expertise.

3.3 Conclusive Remarks

A literature study was conducted investigating two solar energy harvesting mechanisms (solar thermal collectors and photovoltaic panels) as options for the Veenkoloniën area. The option of harvesting solar energy as heat was discarded because of the cheap price for heat compared to electricity. Technical details if more sophisticated solar thermal collectors (parabolic trough or line axis and parabolic dish or point axis) were briefly reviewed. With these types of solar energy harvesting mechanisms, it is possible to attain high temperatures to produce electricity with the help of heat engines or turbines. However, the requirements of a tracking mechanism, and of high-efficiency heat engines, as well as the heat loss occurring across exchange walls, and regular cloud covers make it less suited for the area. Thus, the state-of-the-art of PV systems was reviewed. A flat panel PVs was compared with a concentrating PV system. While it is possible to minimize the cost by reducing the amount of semiconductor material per unit of energy produced, the need for accurate tracking of the sun and specially treated concentrator lenses makes the manageability complex. Hence, it is suggested to use flat photovoltaic panels for the Veenkoloniën area.

4. Algae Systems – Green Microscopic Factories

4.1 General Information

4.1.1 Introduction

Climate change and the depletion of world reserves of fossil fuel energy resources pose a threat to the environment and to human life. Therefore, it is essential to investigate novel clean and renewable energy sources rendering energy production more sustainable. The production of biofuels is regarded as one of the most promising alternatives (Mata *et al.*, 2010). Biofuels are expected to provide opportunities for additional sources of income promoting employment in rural areas, and to replace fossil fuels in the long term. In recent years, the cultivation of microalgae has increasingly been used as a basis for the production of biofuels. According to Brennan and Owende (2010) the application of microalgae has several advantages:

- Algae can be cultured throughout the whole year (Schenk *et al.*, 2008)
- Algae grow in aqueous media but need less water than terrestrial crops (Dismukes *et al.*, 2008)
- Algae can be cultivated in brackish water on non-arable land (Searchinger *et al.*, 2008)
- Algae grow rapidly and contain oil of as much as 20-50% of the dry weight of biomass (Chisti, 2007; Metting, 1996; Spolaore *et al.*, 2006)
- Algae are capable of fixing waste CO_2 (1 kg dry algal biomass utilize about 1.83 kg of CO_2) contributing to an improvement in air quality (Chisti, 2007)
- Nutrients (nitrogen (N) and phosphorus (P)) can be obtained from waste water (Cantrell *et al.*, 2008)
- Algae cultivation in photobioreactors (PBR) does not require the application of potentially harmful pesticides (Rodolfi *et al.*, 2008)
- Algae produce highly valuable by-products (e.g. biopharmaceuticals, proteins, and starch) (Hirano *et al.*, 1997; Spolaore *et al.*, 2006)
- Growth conditions can be adjusted as to modulate the composition of the algal biomass (Qin, 2005)
- Algae are capable of producing 'biohydrogen' for electricity generation (Ghirardi *et al.*, 2000)

There are several methods that are currently employed to grow microalgae on larger scales. To solve technical difficulties, on-going research is trying to integrate novel findings from microbiological and engineering backgrounds with systems used so far. Commercial viability can be achieved by addressing the several challenges that obstructed the development of algal technology so far. These include (1) the selection and cultivation of algal strains with a high lipid content; (2) the maintenance of outdoor cultures and growth systems; (3) the existence of only few example of operation in commercial environments; (4) the limited availability of data on large-scale algal culture systems; (5) the large amounts of energy required to sustain microalgae cultures and the downstream processing events of algal biomass (Rodolfi *et al.*, 2008).

The exploitation of the imminent potential of microalgae as a biofuel resource and for the production of other valuable raw materials will help to develop more sustainable means of energy generation. Here we provide an overview of the state-of-the-art of the cultivation methods and applications of microalgae. We will outline possibilities of cultivation for the

Veenkoloniën area selecting a suitable algal strain and cultivation system for the integration into different scenarios.

4.1.2 Microalgae Species and Raw Materials

Microalgae are single-celled, plant-like organisms that constitute a larger part of the earth's aquatic biomass. They occur both in fresh and marine systems where they form the basis for the majority of food chains. Depending on the species, the morphology and growth requirements differ considerably. However, most microalgae are photoautotrophs, i.e. they contain chlorophyll that enables them to harvest sunlight to cover their energy requirements. Using carbon dioxide (CO_2) as carbon source they produce biomass and more than 75% of the oxygen (O_2) required for animals and humans on a global scale (Wolkers *et al.*, 2011). So far, only a small fraction of the existing 200,000 to 800,000 species have been identified indicating a promising source of possibilities yet to be exploited.

Despite the fact that microalgae classification is still incomplete, taxonomists generally distinguish between groups of green algae, red algae, diatoms, brown algae, gold algae, yellow-green algae and blue algae or cyanobacteria. This classification mainly derives from genetic analyses and from the pigments that are characteristically produced by the different groups. Green algae constitute one of the largest groups comprising about 7,500 species known to date. As can be deduced from their name, they contain chlorophyll that makes them appear green especially when growing in large quantities. However, the best-studied group is the diatoms of which more than 100,000 species have been identified.

The chemical composition and, thus, the raw materials produced by microalgae differ over a wide range depending both on the species and the conditions of cultivation. Many microalgae have a high inherent lipid content that can be elevated to desired levels by the modification of growth conditions such as nutrient supply (Wolkers *et al.*, 2011). Especially under nutrient-limiting conditions, algae are subject to stress which enhances the production of lipids (preferably triacylglycerides, TAGs, and fatty acids), pigments and starch at the expense of biomass. Oils produced by microalgae are mainly composed of omega-3 and omega-6 fatty acids that can be used for food supplements or for biofuel. In addition, microalgae produce a broad variety of other compounds. In 2007, more than 15,000 novel components of algal biomass have been chemically determined by Cardozo and colleagues (Cardozo *et al.*, 2007). Most importantly, algal cells contain carotenes (yellow/red pigments), antioxidants that have beneficial effects on human health, proteins and carbohydrates stored in the form of starch.

Increasing commercial interests in such bulk products contribute to the development of harvesting techniques and the processing of raw materials for bioplastics, biofuels and protein for feed and food markets.

4.1.3 Culture Conditions

Algae cultivation is based on the allocation of specific environmental conditions. Growth requirements differ between species and include light intensities and wavelengths, optimal temperatures and CO_2 concentrations, nutrient compositions of growth media and aeration (mixing) conditions. Here we summarize the most important aspects for algae cultivation.

4.1.3.1 Light

Light is a key limiting factor to the successful cultivation of phototrophic microalgae. The photosynthetic response of an algal culture can be described by a light curve or a photosynthesis-irradiance (PI) curve (Figure 12). At low light intensities, algal cultures live at the compensation point, i.e. no net growth occurs (Lee, 1997). The rate of photosynthesis at this point depends entirely on the concentration of chlorophyll that characterizes the efficiency of light-dependent reactions. With increasing light intensities, however, photosynthetic rates will rise until a maximum growth rate is achieved. The maximum net growth at a given light intensity is called the light saturation point (Goldman, 1979; Lee, 1999; Richmond, 2000). Saturation is attained by an excess production of energy. Therefore, at high light intensities, algal biomass production is limited by the efficiency of light-independent reactions. An increase in light intensities beyond the point of saturation leads to a reduction in photosynthetic capacity characterized by the light-induced damage of photosystem II (PSII), which is the most light-sensitive component of the photosynthetic machinery.

In nature, microalgae are constantly exposed to low light intensities. Therefore, their light harvesting morphological features are adapted to absorb all light that hits the photosynthetic antennae in the reaction center of microalgae cells. At high cell concentrations, almost all light available is absorbed by the thin layer close to the surface of the culture, shading the algal cells below (mutual shading). However, Pulz (2001) states that most microalgae reach light saturation at about 30% of the total terrestrial solar radiation (1,700 - 2,000 $\mu E\ m^{-2}\ s^{-1}$)). Thus, microalgae cells present in the top layer are likely to confront light saturation whereas the lower layers are light-limited.

Difficulties associated with culture layers and their differences in light exposure can be overcome by increasing the light penetration and adjust cell densities so that mutual shading minimizes the light exposure of each single cell. Continuous mixing by gas inflow facilitates the equal distribution of light exposure throughout the entire culture (Benemann *et al.*, 2002) and prevents cell precipitation. Natural or fluorescent light sources may be used for illumination with an optimal photoperiod of 18/6 (light/dark hours) (FAO, 1996). Fluorescent lamps should ideally emit light in the blue to red ranges since these parts of the white light spectrum most efficiently excite the photosynthetic apparatus of algae cells.
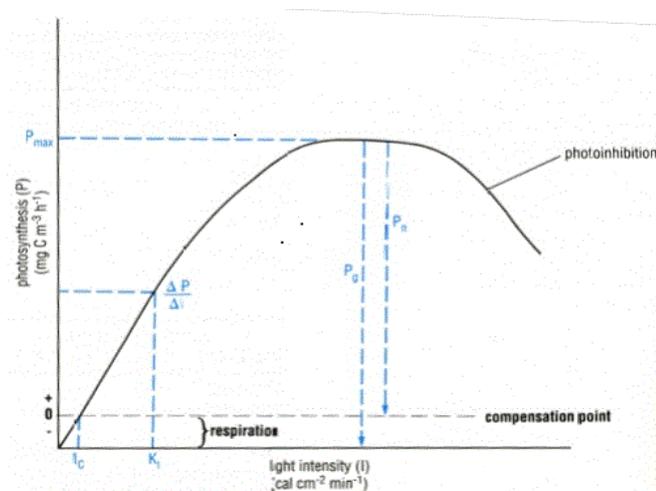
Figure 12 PI Curve
Graphical representation of the relationship between solar irradiance and photosynthesis. The photosynthetic rate (P; mg C $m^{-3}\ h^{-1}$) increases with increasing light intensities (I; cal $cm^{-2}\ min^{-1}$) until it reaches a maximum potential (P_{max}). I_c describes the compensation point: the light intensity at which no net growth occurs. The light intensity at which the photosynthetic rate proceeds at 1/2 P_{max} is called the half-saturation constant. P_{max} and the initial slope of the curve ($\Delta P/\Delta I$) depend on the species and are influenced by the availability of nutrients, the temperature and physiological capabilities of the individual. I is influenced by the latitudinal position and undergoes daily and seasonal fluctuations. At light intensities stronger than required to achieve P_{max} the cultures reaches photoinhibition, thus, a decrease in photosynthetic rate (adapted from http://en.wikipedia. org/ wiki/PI_Curve).

4.1.3.2 Temperature

Generally, net growth occurs with rising temperatures until an optimum is reached. For the majority of microalgae, the optimal temperature range lies between 18°C and 24°C (FAO, 1996). The maintenance of this optimum level is particularly difficult for outdoor cultures, especially in open systems (see below). Temperatures of outdoor cultivation systems are mainly determined by atmospheric temperature, solar irradiance and relative humidity. Diurnal temperature differences of as much as 20°C may occur in response to changes in ambient temperatures (Borowitzka, 2005; Olaizola, 2000; Richmond, 1987). This may affect the productivity of microalgae cultures due to the very high heat capacity of water, i.e. even if ambient temperatures are at optimum levels, culture temperatures may be 10-15°C below their optimum (Borowitzka, 2005). Additionally, the long response time to atmospheric temperatures affects the synchronization of other environmental factors including solar light intensities: optimal culture temperatures are usually not achieved before midday, whereas solar radiation increases rapidly during the morning (Vonshak *et al.*, 2001) influencing photosynthesis. Figure 13 shows examples of the influence of temperature on the algal production for some marine species.
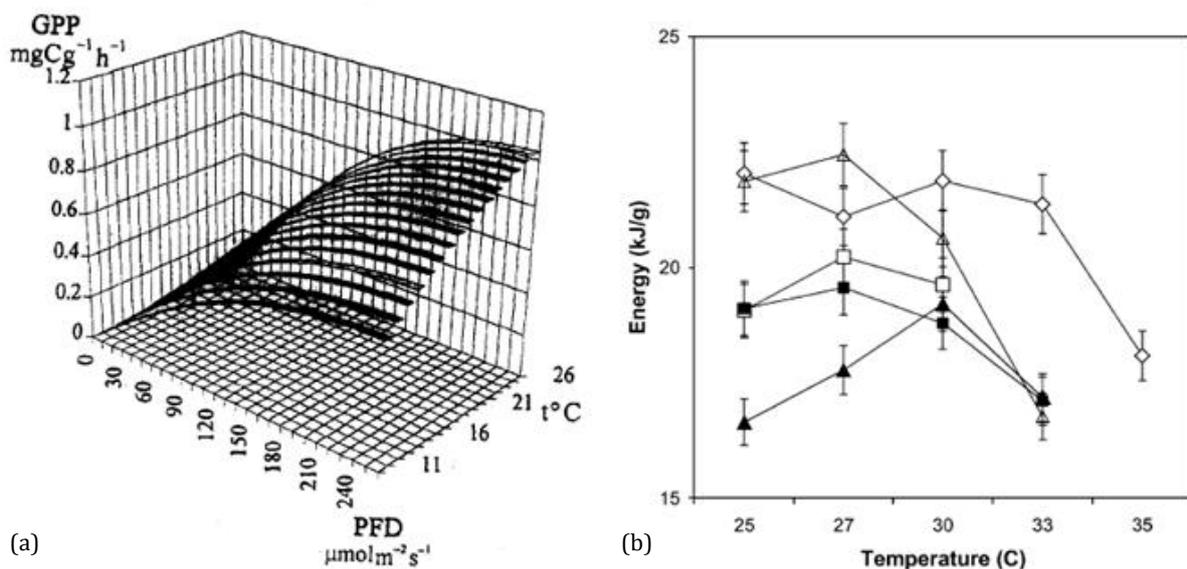
Figure 13 (a) Gross Primary Productivity (GPP) estimates by the model at various combinations of light (PPFD-Photon flux density) and temperature for the marine specie Gelidium sesquipedale (Duarte, 1994). (b) Calculated energy content (in kJ/g, based on the algal carbohydrates, lipid content and proteins for five tropical Australian marine micro algal species) as a function of temperature, the vertical bars represent the standard deviation (Renaud et al., *2001).*

Temperatures below the optimal range will not have a negative impact on microalgae biomass (Alabi *et al.*, 2009). However, sustained higher temperatures have been shown to increase biomass losses during dark periods (Weissman and Goebel, 1985). Hence, it is essential that microalgae cultures reach optimal temperatures quickly with increasing light intensities and that temperature rapidly decrease after darkness to maintain high productivities during daytime hours and to reduce biomass loss in the dark.

4.1.3.3 Gas exchange and pH

Atmospheric CO_2 concentrations of 0.03% are too low to provide sufficient amounts of carbon to growing microalgae cultures. Pure CO_2 can be supplied via an aeration system or a gas exchange

vessels. In addition to being a carbon source, the supply of CO_2 also helps to buffer the culture pH. Most cultured algae grow at a pH between 7 and 9 with optimal ranges being 8.2-8.7 (FAO, 1996). It is crucial to maintain suitable pH values since cultures collapse under acidic or alkaline conditions. Similarly, O_2 generated as a photosynthetic product has to be removed. Excess oxygen concentrations cause photo-oxidative damage of the photosynthetic reaction centers leading to cessation of photosynthesis (Molina *et al.*, 2001; Pulz, 2001; Sánchez Mirón *et al.*, 1999; Ugwu *et al.*, 2008).

As a means of decreasing industrial CO_2 emissions, CO_2 flue gas produced in large amounts during thermochemical and anaerobic digestion processes may be used as carbon source for microalgae. Usui and Ikenouchi (1997) report that algae naturally fix CO_2 via photosynthesis ten times more efficiently than plants. At industrial scales, CO_2 sequestration by microalgae from gases originating from a coal-fired electrical power plant has been established by an Australian consortium in collaboration with GreenFuel Technologies (Bullock, 2006). Other reports on utilizing flue gases from anaerobically digested animal waste biogas exist (Doucha *et al.*, 2005).

4.1.3.4 Nutrients

Nutrients that have to be provided for algae growth include macronutrients, vitamins and trace elements (Alabi *et al.*, 2009). The optimal levels of nutrients required vary between species and little work has been carried out to determine nutrient requirements for mass microalgae production (Alabi *et al.*, 2009). However, essential macronutrients include nitrogen (N) and phosphorus (P) at a ratio of 16N:1P (Brzezinski, 1985), and potassium (K). To avoid nutrient limitation, nutrients are normally supplied at excess levels (Acién Fernández *et al.*, 2001; Fuentes and Rebolloso Sánchez, 1999; Sánchez Mirón *et al.*, 1999). Trace metals used in growth media comprise chelated salts of manganese, iron, cobalt, zinc, selenium, and nickel (Alabi *et al.*, 2009).

Similar to CO_2-containing flue gases, wastewater from (un)treated livestock or agro-processing industries contain nutrients required for algae growth. In addition to the removal of N and P macronutrients, microalgae have been reported to clean off heavy metals from wastewater (Romera *et al.*, 2007). Thus, the use of wastewater and flue gas CO_2 for algae cultivation represents a sustainable way of environmental remediation.

4.1.4 Cultivation Systems

Many techniques have been developed and are available for the cultivation of algae on small scales. For scientific purposes, algae growth systems are well-developed and allow for the study of different microalgae species under different growth conditions. However, there are several challenges associated with the production of algae at an industrial scale. To date, photoautotrophic production is the sole technically and economically feasible technique for large-scale algae production (Borowitzka, 1997). In the following section, we highlight the most common growth techniques that are currently employed in commercially-oriented projects.

Open systems - Raceway ponds

Raceway ponds are open pond production systems that generally consist of a concrete or foil lined closed loop, oval-shaped recirculation channel (Figure 14). The average depth is between

Figure 14 Open raceway pond (Wolkers et al., 2011)

0.2 and 0.5 m. Circulation via a paddlewheel stabilizes algae growth and enhances productivity. Nutrients and algae broth are introduced into the system in front of the paddlewheel, whereas the culture is collected at a harvest point behind the wheel. CO_2 can be introduced via an aeration system below the culture surface to meet the algae carbon requirements (Terry and Raymond, 1985). In comparison to other cultivation methods, raceway ponds are cheaper and have lower energy input requirements (Rodolfi *et al.*, 2008). In addition, regular maintenance and cleaning are easier (Ugwu *et al.,* 2008), and open ponds usually display high biomass production rates, despite inconsistencies in reported production rates (Brennan and Owende, 2010).

However, there are several technical difficulties that are generally encountered in raceway pond systems. Due to the prevailing threat of contamination, microalgae need to be grown under highly selective conditions (Pulz and Scheinbenbogan, 1998) such as high salinity or high alkalinity. This requires a careful selection of algal strains for monocultures with only a small fraction of available strains being suitable (Brennan and Owende, 2010). Despite high biomass production rates, raceway ponds are less efficient than close cultivation systems (Chisti, 2007) due to (1) evaporation losses, (2) temperature fluctuations, (3) difficulties to supply sufficient amounts of CO_2, (4) ineffective mixing, and (5) mutual shading (Brennan and Owende, 2010). Light limitation by mutual shading can be overcome by decreasing the layer thickness using thin layer inclined systems (Doucha and Lívanský, 2006).

Closed systems
In contrast to open pond production methods, closed photobioreactors allow for the prolonged cultivation of single species with a reduced risk of contamination (Chisti, 2007). These include tubular, flat plate and column photobioreactors. As a pay-off for the high costs for installation, harvesting costs can significantly be reduced due to higher biomass productivities that can be obtained in closed systems. They usually consist of glass or plastic panels or tubes that can be oriented horizontally (Molina *et al.*, 2001), vertically (Sánchez Mirón *et al.*, 1999), inclined (Ugwu *et al.*, 2002), or as a helix (Watanabe and Saiki, 1997). Mixing occurs through a mechanical pump or through aeration via a so-called airlift system (Eriksen, 2008). Agitation and recirculation are essential for the gas exchange within the reactors.

4.1.4.1 Tubular photobioreactors
Tubular photobioreactors have an upper limit for scale-up possibilities since the length of the tubes is dependent on O_2 accumulation and CO_2 exhaustion, as well as pH variations (Eriksen, 2008). Nonetheless, they are considered to be suitable for outdoor mass cultures due to the large surface areas that are exposed to sunlight (Brennan and Owende, 2010). There are two types of tubular photobioreactors: vertical (Figure 16) and horizontal (Figure 15). The advantages of the vertical PBRs are that they use less space. On the other hand, the horizontal PBRs can receive more light on its surface which prevents light limitation for the algae.

Figure 16 Picture of a vertical tubular PBR (Wolkers et al., 2011)
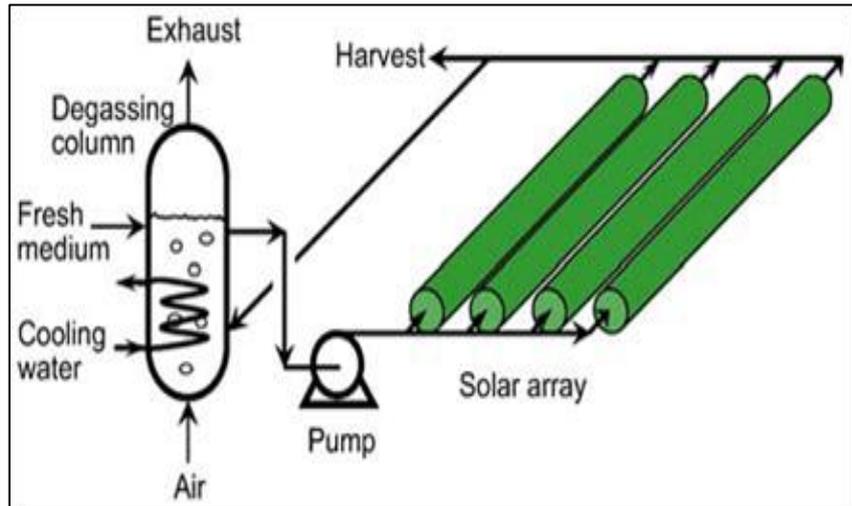
Figure 15 Schematic drawing of a horizontal tubular PBR (http://wiki.uiowa.edu/ display/greenergy/Algae+Biofuels)

4.1.4.2 Flat plate photobioreactors

Advantages of flat plate photobioreactors for algae mass cultivation are the large surfaces (Ugwu *et al.*, 2008) and the high cell densities (>80 g L^{-1}) that can be achieved (Hu *et al.*, 1998). A thin algae layer at the surface captures solar energy (Richmond *et al.*, 2003). The use of flat plate reactors prevents the accumulation of O_2 and reaches high photosynthetic efficiencies in comparison to tubular reactors (Figure 17).

Figure 17 Picture of a flat plate PBR (http://www.cleantick. com/users/franc/pages/developments-in-closed-reactors-for-algae-cultivation/updates/10245)

4.1.4.3 Column photobioreactors

Column photobioreactors are comparably cheap and easy to operate. Aeration is provided from the bottom and efficiently mixes the culture at a high volumetric mass transfer. According to Eriksen (2008) the culture growth conditions are easiest to control in these systems. In terms of productivity, column photobioreactors are similar to tubular reactors.

4.2 Bioprocessing and Algal Products

Algae can produce raw materials for a wide variety of products, the most common to be biofuels. This chapter will mainly describe the general processing setup for biofuel production. The bioprocessing methods are also applicable to produce other end products from algal oils and carbohydrates, for example animal feed. In the last part of the chapter an overview of possible costs related to the production of algae will be given.

4.2.1 Harvesting and Processing Algal Biomass

The generation of algal products requires a multistep process that includes harvesting, extraction and purification, and end product conversion technologies.

4.2.1.1 Harvesting Methods

Harvesting includes the separation of the algal biomass from the suspension and concentrating the slurry. Selecting a harvesting technique is crucial to the algae production and the resulting biofuel production. The choice is dependent on the characteristics of the algae like density and size (Brennan and Owende, 2010).

- Flocculation and ultrasonic aggregation: a prior step to flotation and gravity methods. It's intended to aggregate the algae cells by reducing the negative charge of the cells with multivalent cations or cationic polymers. Negative charge of algae cells prevents them from aggregation and, in this way, makes processing difficult. The ultrasonic aggregation is an acoustic methods that has the advantage of preventing shear stress to the algae which could destroy valuable metabolites
- Flotation: trapping algae cells using dispersed micro-air bubbles (this method is not much used yet)
- Gravity sedimentation and centrifugation: based on Stoke's law. The gravity sedimentation is only used for large microalgae (>70 μm) and large volumes of biomass which have been cultivated with waste water treatment. Centrifugal sedimentation can be used for smaller microalgae. Also it is used for harvesting high value metabolites, but is more expensive because of the high energy costs and also higher maintenance requirements
- Filtration: the conventional filtration process is only used for large algae species (>70 μM). For species smaller than 30uM, membrane microfiltration and ultra-filtration can be used. Membrane filtration is in general more costly than centrifugation

4.2.1.2 Extraction and Purification

The harvested slurry has to be dehydrated or dried in order to protect the biomass from perishing. A certain temperature has to be used to be able to dry efficiently and at the same time have a cost effective drying (Brennan and Owende, 2010). Some methods that can be used are:

- Sun drying, which is the cheapest method but requires large surfaces and long drying times
- Spray drying, is relative expensive and used for extraction of high value products
- Freeze drying, which is also expensive, but makes the extraction of oils easier

After the drying the oils and other metabolites have to be extracted from the cells by methods that disrupt the algae cell walls. Most of these methods use certain solvents to do this.

4.2.1.3 Algal biomass to end product conversion technology

There are two main types of algae biomass conversion: thermochemical and biochemical conversion (Figure 18). The conversion type depends on the type and amount of biomass, type of energy needed from the algae, economical aspects and the desired end products. Thermochemical conversion is used to fuel products from the organic compounds of the algae biomass. This is achieved by thermal decomposition of the biomass through combustion in general, but also through other methods like gasification, pyrolysis. Biochemical conversion includes the chemical processes of biomass conversion into fuels by anaerobic digestion, fermentation processes and photobiological hydrogen production.
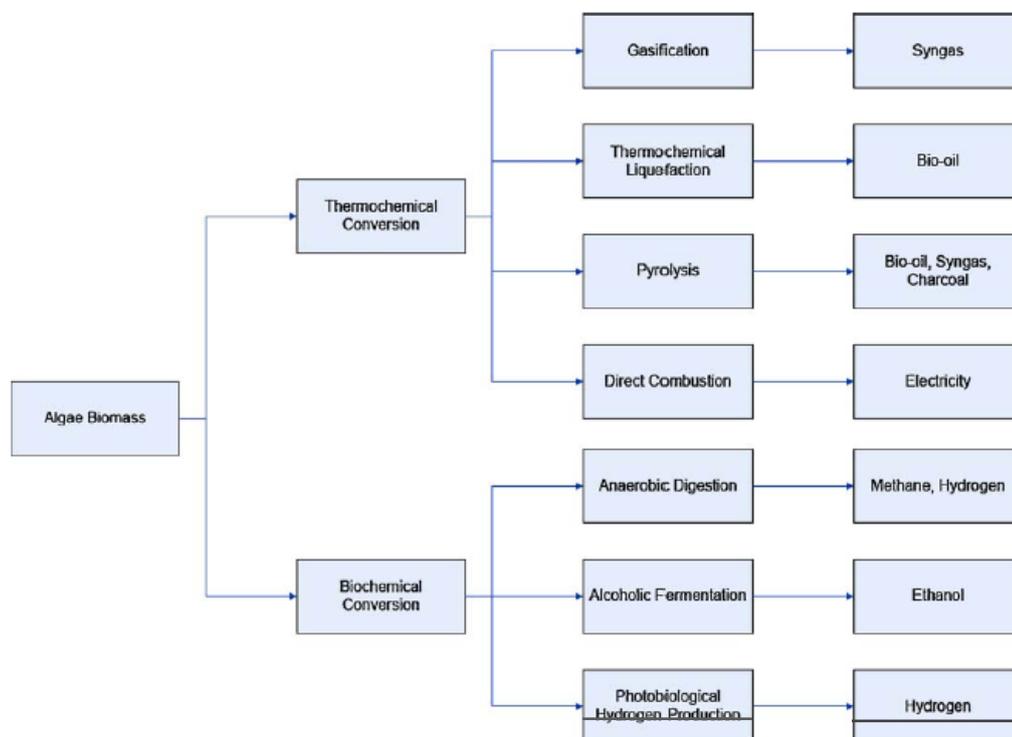
Figure 18 Biorefinery processes (adapted from Brennan and Owende, 2010)

4.2.2 Microalgae Products

Microalgae are among the most productive organisms on earth. Their simple morphology renders them suitable for industrial applications such as the production of food and feed supplements, cosmetics, as well as the generation of biofuels (Figure 19). This section summarizes the most prominent uses of algal biomass.

4.2.2.1 Biofuels

Currently biofuels are becoming more and more important as a sustainable alternative to the use of fossil fuels. But biofuels produced from crops, like maize and sugarcane, place a strain on the world food markets and contribute to water shortages which can worsen with future climate

change (Brennan and Owende, 2010). In addition, the land use change and deforestation related to the production of biofuels may become a problem for our natural resources and ecosystems in the future. Biofuels from algae can address these problems. In general, the cultivation of algae does not require large areas of land, is water efficient (use of waste water) and the crops can be saved for the production of food instead of biofuels. More importantly, there are no greenhouse gas emissions associated with the production of biofuels from algae (Wolkers *et al*., 2011; Brennan and Owende, 2010).

However, there are several challenges related to the use of algae for biofuel production (Brennan and Owende, 2010):

- Certain algae species have to be chosen which are in balance with the requirements for biofuel production and the extraction of desired other co products
- Production systems have to be developed which can enhance the photosynthetic efficiency of algae
- Development of techniques for cultivating only one specie, less evaporation in open ponds systems and CO2 diffusion losses reduction
- Lack of data for large scale algae commercial plants of algae and biofuel production
- Developing techniques for low-cost harvesting, dewatering and extraction of algal biomass (Rodolfi *et al*, 2008).

One of the most important criteria for the selection of a suitable microalgae strain is the inherent lipid content. Many algae strains naturally have a lipid content between 20 and 50% of their dry weight (Brennan and Owende, 2010), which can be described as the lipid accumulation within algae cells. These lipids have to be extracted to produce biofuel. The amount of extracted lipid per kilogram of algal biomass depends both on the lipid content and the algal biomass productivity, hence, lipid productivity. The inherent lipid content can be increased by stressing the algae following an initial growth phase, by cultivating them in a nitrogen-limited environment (Wijfels *et al*., 2010). This also implicates a change in lipid composition from free fatty acids to triacylglycerol (TAG), the latter of which is useful for the conversion into biodiesel. The only problem with increasing the lipid content by nitrogen limitation is the fact that the biomass productivity does not increase over time (Brennan and Owende, 2010; Pruvost *et al.,* 2009; Wijfels *et al., 2010).* This can lead to low oil productivities of the whole algae culture. However, the biomass productivity may be kept at high levels if the nutrient-limited environment is introduced after the algae culture has reached a sufficiently high cell density.

4.2.2.2 Feed for Animals and Aquaculture

Dried algal biomass may be used for protein extraction. Algae proteins are frequently used as supplements in feed for many aquaculture species and animals or for food. However, only a few selected algae species, such as Chlorella and Spirulina are suited for this purpose (Wolkers *et al*., 2011).
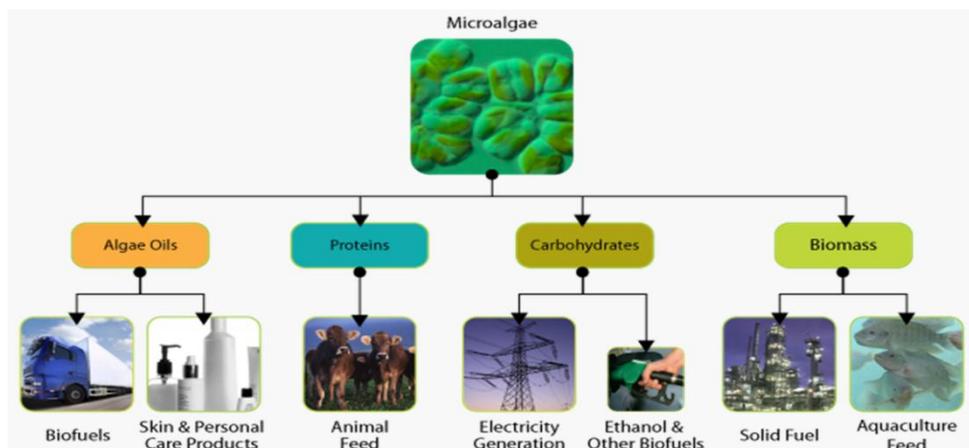
Figure 19 End products from microalgae (from http://www.atafood.com/ Innovative-Microalgae-Products.html)

4.2.2.3 Electricity

Microalgae are capable to produce hydrogen gas (H_2) photosynthetically that can be used for electricity generation. To this end, the algae need light and a minimal amount of oxygen. The oxygenic photosynthesis has to be declined so that the algae use all the dissolved oxygen and produce H_2 gas (Melis and Happe, 2001). This process requires a lot of monitoring and expertise. It is still under investigation and is, therefore, not practicable to date.

On the other hand, electricity can also be produced by combustion of algal biomass in a biogas plant. The combustion of algae can be combined with the combustion of crops or other feedstocks for the production of biogas and electricity. An example of a biogas plant near a farm is provided in Figure 20. The algae biomass can be harvested by harvesting methods explained in paragraph 4.2 and then converted to algae slurry. This slurry can directly be fed into the digester of the biogas plant. Table 5 gives an overview of all raw materials, including algae that can be used in a biogas plant to produce a certain amount of biogas yield.

Table 5 Biogas yield in m³/ton of raw material (http://www.patervis.com/index-2.html)

Raw material	Biogas yield (m³/t of raw material)
Cow manure	60
Pig manure	65
Chicken dung	130
Fat	1300
Distillery slop	70
Grain	500-560
Silage, plant tops, grass, algae	400
Milk whey	50
Fruit and sugar beet pulp	50-70
Technical glycerin	500
Brewer's grains	180
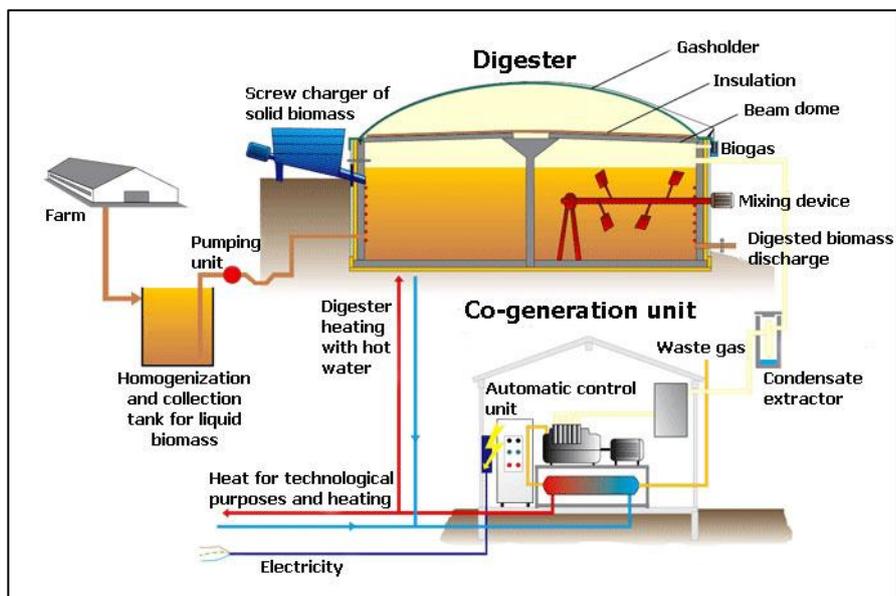
Figure 20 Example of a biogas plant near a farm (http://www.patervis.com/index-2.html)

4.2.3 Economic Aspects

With a technical advance in the bioprocessing of algal biomass it will be possible to reduce the costs of one kilogram algal biomass to €0.50, a level that is comparable to the current cost of palm oil (Wijfels *et al.*, 2010; Wolkers *et al.*, 2011). Nonetheless, it is important to bear in mind that, in general, only 40% of the algal biomass consists of oil. This means that the rest of the biomass also needs to be exploited in order to make algae production economically feasible. Producing more than one end product is a 'must'. If one considers that algal biomass consists of 40% lipids, 50% protein and 10% sugar, then part of the lipids can be used for biofuels. The other part can be used for the chemical industry like cosmetics industry. The proteins are useful for feed and food products while the sugars can also be used for various end products (Wolkers *et al.*, 2011). Figure 21 gives an overview of cost estimates for the algae biomass per 1000 kg after biorefinery (only producing bulk algae, extracting lipids and converting to biofuel is not considered) (Wijfels *et al.*, 2010). Producing food proteins from algae is the most expensive process while biofuel production, nitrogen removal and sugars exploitation are the cheapest. It can be concluded that algae cultivation can be economically feasible only if all the biomass is used for the generation of end products with a significant reduction in costs for biorefinery.
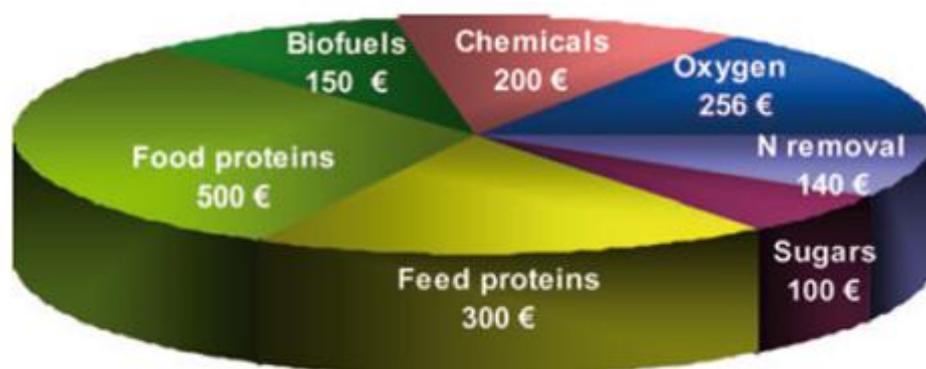
Figure 21 Value of 1000 kg algal biomass after biorefining (adapted from Wijffels et al*., 2010).*

5. The Products

5.1 Introduction

This chapter presents the feasibility study of an agrobusiness solution for the Veenkoloniën based on literature research. All product are designed on a single farm level (approximately 100 ha) to simplify the analysis of the effectiveness of the proposed solution prior to extrapolation to the whole Veenkoloniën area.

To assure enough fresh water for irrigation of arable plots in the Veenkoloniën in the future, the design of a water storage basin has been chosen as a final product. Different aspects relevant for the design of a water storage basin including the location, soil properties and ground water levels will be discussed. Finally, possibilities to collect big amounts of water in the basin and water retention will be presented.

The design of the solar energy system was based on the surface area of the water storage basin, the amount of solar energy that can be harvested in Veenkoloniën and the applications of this energy system. Both the technical and the economic aspects will be addressed. Technical aspects include the type and amount of solar panels, construction, spacing and shadowing effects and the electricity yield that may be achieved in the Veenkoloniën. For the economic analysis two different scenarios based on the amounts of subsidy will be discussed. In addition, the investments and energy production values will be presented for different area sizes.

Algae cultivation for commercial purposes is still very rare and examples are few. The technologies for algae cultivation are still under development and the costs of production are high. Despite those limitations, a microalgae species was selected for cultivation in the Veenkoloniën. Additionally, an example of an outdoor cultivation system was determined.

Eventually, options for the integration of the three systems and the benefits and problems related to the single scenarios will be summarized and visualized by systematic drawings.

5.2 Hydrology – Basin Design

It is expected that, in the future climate and during the summer months (1 April - 31 August), an extra supply of 74 mm will be required on 75% of the agricultural plots. This results in a required storage of approximately 55000 m³ of water per farmer. However, storing this amount of water is insufficient, as there will be a loss of water to the atmosphere (precipitation minus evaporation) and the soil or groundwater (seepage). When corrected for the loss, the stored volume of water on the 1st of April should be sufficient for supplying 55000 m³ of water without an extra input of water from the ditches into the basin.

In the next paragraphs, different aspects that are relevant for the design of a water storage basin will be discussed. Initially, the location will be introduced, as soil properties and ground water levels have an influence on the possibilities of constructing a basin. Next, actual construction of the basin will be presented. Combined with the soil properties and ground water levels, the method used to construct the basin largely determines the amount of seepage from the basin. Next, calculations determining the basin dimensions will be explained, and scenarios will be

created to demonstrate how the basin can be filled during winter months. Finally, a cost benefit analysis will elucidate the financial feasibility of water storage.

5.2.1 Location

It will not be useful to install water basins in the area with groundwater regime Glc-III*, since high water levels prevail throughout the whole year (Querner *et al*., 2011). Between January and March the average groundwater level for Glc-III* is between 0.40 m and 0.50 m below the soil surface, and between 1.00 m and 1.10 m below the soil surface from July through September. From a practical point of view it is not possible to install basins there, since the water level in the basin should be higher than the groundwater level to avoid damage to the foil caused by the groundwater pressure (www.pcsierteelt.be). This means the basin cannot be deeper than the deepest groundwater level, which is about 1.0 m in summer. If a deeper basin was installed most water could not be pumped out for irrigation. To install a basin here would, therefore, require a very large area (about 8 ha).

In winter months the average groundwater level for Glc-V is between 0.40 m and 0.60 m below the soil surface (Querner *et al*., 2011). In summer, the groundwater level is approximately 1.40 m below the soil surface at the beginning of July and 1.80 m below the soil surface in mid-August. Towards the end of August the groundwater level starts rising again and reaches a level of 1.70 m below the soil surface. The water level in the basin was assumed to be reduced during dry summers when groundwater levels will be low as well. Furthermore, the water level in the basin was expected to drop at an equal or slower rate than the groundwater level. Those assumptions are of importance for the maximum depth of the basin that can be realized. If a basin was installed in this area the maximum depth could be about 1.5 m. In this way, water levels in the basin will always be higher than the surrounding groundwater levels and no danger of damaging the foil exist.

For Glc-VI the average groundwater level in winter months is between 1.20 m and 1.40 m below the soil surface (Querner *et al*., 2011). In summer, the groundwater level is 2.00 m below the soil surface at the beginning of July and 2.60 m below the soil surface in mid-August. On average, after mid-August the groundwater level starts rising again and reaches a level of 2.50 m below the soil surface at the end of August. To avoid complications, the construction of the water storage basin should be carried out in summer with the bottom being well above the groundwater table (Weatherhead, 2008). Together with the condition that the groundwater level must be lower than the water level of the basin this requirement determines the maximum depth of the basin for this area, which is about 2.0 m. For the dryer areas, with Glc-VII, deeper basins can be installed corresponding to the deeper groundwater levels. Here, two scenarios were used corresponding to basin depths of 1.5 m and 2.0 m, respectively.

5.2.2 Construction of the basin

A lot of different water storage techniques are available, but most systems are meant for water storage on a smaller scale and are mainly used for water supply to greenhouses.

Basically two options are possible for installing large scale water basins. The first option is the application of an open pond. The requirements for implementation of an open pond are a low

permeability of the soil at the bottom of the basin and, preferably, a shallow surrounding groundwater level (www.pcsierteelt.be, 2012). Since the subsoil consists of cover sand (Stiboka, 1977) with a moderate permeability (Witteveen en Bos, 2011) the second requirement cannot be met. For the largest part of the area, especially in summer, the groundwater tables are relatively low and, hence, the second requirement cannot be met either.

The second option is the implementation of a lined basin. An impression of such a basin is displayed in Figure 22 (Weatherhead *et al.*, 2008). A basin can completely be lined with plastic foil (e.g. butyl or polypropylene), or a combination can be used in which the bottom will be lines with a layer of clay and the embankment with foil. Lining the basin entirely with clay is not possible, since clay will start to dry and shrinkage cracks will occur when the basin is not totally filled (Boels, 2002). This is also the reason why a basin with a bottom lining of clay should not be completely empty for a longer period of time.

Figure 22 Pictures of a lined basin (adapted from Weatherhead et al*., 2008)*

Previous experience with a bottom lining of clay in sandy areas showed that the seepage loss was quite large (larger than the precipitation excess) when the difference in water level in the basin and the groundwater level was relatively large (Boels, 2002). Since the water level in the storage basin should be higher than the groundwater level, seepage from the basin to the groundwater will occur. The amount of seepage depends on the water level difference, the permeability factor k of the clay and on the thickness D of the clay layer. For instance, if we assume a constant water level difference of 0.50 m between the basin and the groundwater and an hydraulic resistance c of 5,000 days ($c = D/k$) the seepage loss will amount to about 0.1 mm/day. The most suitable clay to use for lining is half ripened clay. Furthermore, the permeability of the clay should be lower than 0.09 mm/day. To eliminate seepage, foil can be used for lining the bottom of the basin as well.

When a lined basin is constructed, the basin can either be placed partially or completely below the soil surface. When the basin is placed totally below soil surface the excavated soil can be used on low-lying parts of the farm itself or be transported to another farm. In both cases the soil should meet certain quality standards and, therefore, a soil analysis should be carried out by an accredited specialist (www.pcsierteelt.be). An advantage of constructing a basin partly above the soil surface is that the soil that is excavated can be used to construct the dikes around the basin and creating a closed soil balance (no soil has to be disposed). However, the disadvantage is that all water to fill the basin has to be pumped in and no possibilities for water retention remain.

5.2.3 Basin Dimensions

As the total water volume is influenced by precipitation in and evaporation from the basin, the storage of 55000 m³ required for supplying 74 mm of extra water on 75% of the agricultural plots is not sufficient. During the summer months, there is a net loss of water from the basin to the atmosphere (precipitation – evaporation). Furthermore, there will be a loss due to seepage of approximately 0.1 mm day⁻¹. Since there is a net loss per square meter of basin, the correction on the storage volume is dependent on the area of the basin:

$$\Delta S = A_{basin} (P - E - q), \tag{2}$$

with ΔS the extra storage needed (m³), A_{basin} the area of the basin (m²), P and E, respectively, the amount of precipitation and evaporation (m) and q the amount of seepage. In order to calculate the correction on the volume; two different scenarios for the basin depth are used (see Section 5.2.1).

There are a number of reasons to maximize the depth of the basin, thereby decreasing its area:
- Minimize the loss of agricultural area;
- Minimize the meteorological loss (P-E);
- Minimize the amount of water that needs to be pumped into the basin during the winter months;
- More days during the year with the possibility for water retention

However, this approach has some disadvantages:
- Minimizing the area results in less area for solar energy production or other useful functions.
- When maximizing the depth, more foil is needed to cover the sides of the basin (which is relatively expensive compared to clay that is used to cover the bottom of the basin)
- Maximizing the depth increases the risk that the ground water level exceeds the basin level, possibly damaging the basin lining.

The last point is most important and, therefore, the choice for the basin depth is based on the groundwater level regime of the area in which the basin will be constructed. Based on the ground water level regimes (Section 5.2.1), we have chosen depths of 1.5 m and 2 m.

After the depth has been determined, we can continue with calculating the basin area and the evaporative loss from the basin. Deducing a value for $P - E$ from the data presented in Table 3 is not straightforward. First, the deviation of P and E from their long-term averages is poorly correlated. That means a year with little precipitation is not necessarily dry in terms of evaporation, as shown in Figure 23. Using both the extreme values of precipitation and evaporation would lead to over-designing the basin. Secondly, the
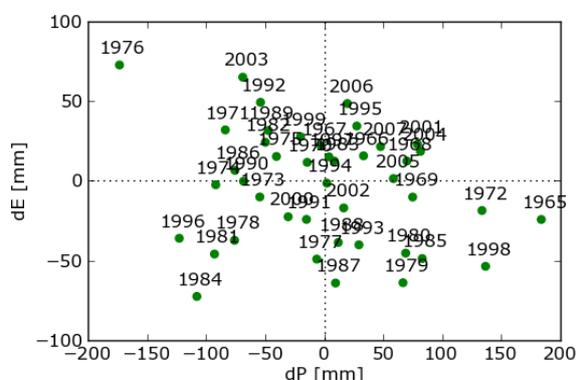
Figure 23 Yearly precipitation and evaporation offset from the long-term average (1965-2011).

statistics are biased because of the extremely dry year of 1976, during which precipitation was (extremely) low and evaporation was (extremely) high.

Despite the difficulties outlined above, a combination of evaporation of 550 mm and precipitation of 200 mm was chosen based on the *W+* scenario shown in Table 3. This results in a net daily loss of water equal to 2.3 mm day^{-1}. These values are still relatively high. However, given the uncertainties in the future climate and the fact that the clay lining might get damaged when drying out, it is better to be on the safe side.

Using *E = 550* mm, *P = 200* mm and an embankment angle of 45°, this yields dimensions for the basin as shown in Table 6.

Table 6 Dimensions basin based on 550 mm evaporation, 200 mm precipitation. ΔS in m³ is the extra storage needed to compensate for the net loss of water to the atmosphere, ΔS in % the increase in volume compared to the net storage needed for irrigation (55'000 m³).

Depth [m]	Area [ha]	Volume [m³]	ΔS [m³]	ΔS [%]
1.5	4.9	72'700	17'700	+32.2
2.0	3.5	67'600	12'600	+22.9

By decreasing the evaporation loss (e.g. by means of partially covering the basin), the area required for storage can be decreased. These scenarios will be further analyzed in Section 5.5.2.

5.2.4 Water Retention and Filling the Basin

As during the winter months evaporation is relatively low, the net amount of precipitation (precipitation minus evaporation) is positive. Averaged over the years 1965 - 2011, the cumulative precipitation and open water evaporation over the period 31 August - 1 April are 475 mm and 200 mm, respectively. As in the W+ climate both precipitation and evaporation are expected to increase (Table 2), the net precipitation excess stays relatively constant at 280 - 290 mm (1 November - 1 April: 200 mm).

There are two implications for filling the water basin during the winter months. First, a part of the basin will be filled automatically by direct precipitation into the basin. Secondly, as the Veenkoloniën area as a whole receives an excess of precipitation, water has to be collected from other parts of the Veenkoloniën area. Instead of removing the water, it can be retained within the basin. Using this method, the area becomes more self-sustained: the precipitation excess during the winter months will be used to bridge the shortage during summer and, as a side-effect, less water needs to be removed from the area.

The basin will, however, not fill itself. Assuming that each year (irrespective of the actual irrigation needs) 55000 m³ of water is removed from the basin, an average water level of 0.1 m will be left over on 31 August. Each year the surface water levels are decreased from -1 m to -1.4 m around October. If a part of this volume is used to fill the basin, by approximation only half of the basin (assuming a basin depth of 2 m) can be filled by gravitational flow from the ditches, as schematically shown in <mark>Error! Reference source not found.</mark>. If a water level of 1 m can be obtained in the basin at 31 October (assuming that the basin can be filled up to the summer surface water level) at which point the valve is shut, another 0.2 m is automatically added by

precipitation over the period 1 November - 1 April. This then requires pumping of water into the basin bypassing an elevation of approximately 0.8 m; for the basin with a depth of 2 m a volume of 24500 m^3. Over 150 days, this would require a constant pump flow rate of 233 m^3 day^{-1} or 1.9 l s^{-1}. If the basin is only filled up to the winter surface water level at 31 October (-1.4 m), a total of 1.2 m has to be pumped, equivalent to 42000 m^3 of water and a flow rate of 280 m^3 day^{-1} or 3.2 l s^{-1}.
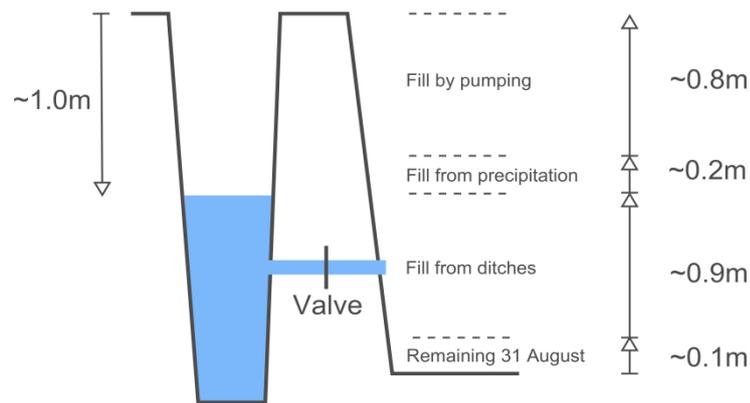
Figure 24 Schematic overview of the basin proportions filled from the ditches, from precipitation and by pumping for the basin of 2 m depth.

In addition to the retention possibility created during October, high surface water levels caused by precipitation peaks can be retained in the basin when the surface water levels exceed the basin level. These conditions are expected during the second half of summer when the basin level has sufficiently dropped. However, water retention during the winter months is difficult, except when water is pumped from the ditches to the basin.

5.2.5 Costs and Benefits of the Water Basin

5.2.5.1 Estimation of Costs
Costs for the design of water storage basins of different depths
Construction costs
Costs for excavating the soil and lining the basin with foil are approximately 3.50 € m^{-3} of water (Van Bakel *et al.*, 2009). This is the average cost of constructing a basin totally lined with foil. When clay can be obtained from the farm itself, it is usually cheaper than using synthetic lining. When clay has to be transported from outside the farm area, as will be the case for the farms in the Veenkoloniën, the costs for lining the bottom of the basin with clay will rise. Therefore the costs of a synthetically lined basin are used for calculating the lining costs. Importantly, the given lining costs usually do not differ that much, but the costs for excavating the soil can differ highly between different contractors.

For a storage basin of 1.5 m in depth the total amount of water stored has to be 73,700 m^3 (Table 14). Thus, the total construction costs are 257,950 €. For most synthetic liners a lifetime of 20 years is guaranteed. After that time the lining has to be replaced, since it will deteriorate due to solar radiation (Weatherhead *et al.*, 2008). Considering the lifetime and assuming that the depreciation of the basin is the same for every year, the costs for construction can be calculated as 12,898 € year^{-1} (total investment for constructing divided by lifetime). On the other hand, for a storage basin of 2.0 m in depth the total amount of water stored has to be 68,200 m^3 (Table 14). Thus, the costs for construction are 238,700 € with an annual investment of 11,935 €.

Loss of productive area
The construction of a 1.5 m-deep storage basin requires an area of 5.0 ha. When grassland is converted, the loss of revenue will be (5.0 ha x 2,000 €) 10,000 € year^{-1} (Van Bakel *et al.*, 2009).

Although land of low agricultural value should be converted, if possible, it is also likely that productive agricultural land will be used. Assuming that, on average, a farmer grows potatoes on 50% of his land, sugar beet on 25% and keep 25% bare, a loss of revenue of can be derived:

(0.50 * 2194[7]) + (0.25 * 3,300[1]) = 1,922 € ha[-1] and, thus, a total loss of 9,610 € year[-1].

For a 2.0 m-deep storage basin, instead, 3.5 ha of land is required for storage. In this case, the loss of revenue is 1,922 € ha[-1] giving a total loss of 6,727 € year[-1].

Pumping costs
The total amount of water that has to be pumped into the storage basin (1.5 m) is 60,000 m[3]. Assuming that pumping 1 m[3] of water costs approximately 1.6 €cents the pumping costs are approximately 938 € year[-1]. Similarly, for a deeper basin (2.0 m), the total amount of water that has to be pumped into the storage basin is 42,000 m[3] and pumping costs are approximately 656 € year[-1].

Total costs
For a basin of 1.5 meter in depth the total basic costs are approximately 23,446 € year[-1]. For a basin of 2.0 m in depth, on the other hand, the total basic costs are approximately 19,318 € year[-1]. However, there can be more costs that are not yet quantified (see paragraph 'other costs').

Other costs
In the calculation of the costs for constructing a storage basin presented here only the basic costs are taken into account, since the other costs either vary between years or are not easy to quantify due to other reasons.

For the construction phase the costs for soil analysis, hiring a consultant and/or engineer and costs for safety measures are not taken into account. Since the synthetic liner can become very slippery, fences should be placed around the basin and escape ladders made from ropes and old tires should be placed in the basin. This will also help to hold down the foil used for lining.

For the operating phase the costs for pumping the irrigation water out of the basin and the costs for the irrigation equipment are not accounted for. As the water demand will be different every year the costs for irrigation will vary accordingly. Furthermore, an official inspection of the basin might be necessary as is the case for basins in the Netherlands that are used for rinsing flower bulbs (Boels, 2002). Moreover, costs for occasional repairs of the synthetic liners, measures to avoid growth of harmful algae and costs for water treatment are not considered.

When a basin is constructed, a large investment is required. In case this investment is provided by the farmer himself, he likely requires a bank credit. However, in the calculation of the yearly costs the interest is not included. Furthermore, after 20 – 25 years the liner should be replaced creating additional costs (Weatherhead *et al.*, 2008). Therefore, an annual provision should be made that will then have to be included into cost analyses.

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[7] Van der Meer (2009) and De Bont *et al.* (2011)

5.2.5.2 Estimation of Benefits

The average starch potato yield for 2007 – 2011 was 42.2 ton ha^{-1}. In the same period the average price for starch potatoes was 52 € ton^{-1}. Thus, the average revenue was 2,194 € ha^{-1}. For sugar beets the average yield for 2007 – 2011 was 75.0 ton ha^{-1}. In the same period the average price for sugar beet was 44 € ton^{-1}. Thus, the average revenue was 3,300 € ha^{-1}.

When only surface water level management and no other form of irrigation is applied, the modeled average multiple-year reduction of crop evapotranspiration under the current climate and groundwater level class VI and VII is 15% for potatoes. A reduction in crop evapotranspiration is linearly related to crop yield loss. The loss of revenue then amounts to 329 € ha^{-1}. Assuming the same evapotranspiration reduction for sugar beets, the loss of revenue would amount to 495 € ha^{-1}. The loss of revenue for potatoes calculated here is in line with the increased revenue as result of irrigation that is given in a report of Aequator Groen & Ruimte as 300 € ha^{-1} (2010). However, an increased revenue of only 150 € ha^{-1} is given for sugar beets.

When a tentative calculation is made, based on the figures given by Aequator Groen & Ruimte (2010) the benefits from irrigation for the current situation are as follows:

50 ha of starch potatoes * 300 € ha^{-1} = €15,000
25 ha of sugar beets * 150 € ha^{-1} = €3,750

For a farm of 100 ha with 50% irrigated potatoes and 25% irrigated sugar beets, this gives a summed benefit of 18,750 €year^{-1} on average.

The expected yearly yield reduction for the Veenkoloniën area and the climate W$^+$ is between 20 and 30% in 2050 (De Haas and Niemeijer, 2007). A reduction of 20% would give a loss of 439 € ha^{-1} for potatoes and 660 € ha^{-1}for sugar beets. In the report of Equator Groen & Ruimte (2010) for the W$^+$ climate scenario an estimated increase of revenue of 500 € ha^{-1} for potatoes and 250 € ha^{-1} for sugar beets is given for 2050.

When the last mentioned figures are used for calculating the expected future situation the benefits from irrigation become as follows:

50 ha of starch potatoes * 500 € ha^{-1} = €25,000
25 ha of sugar beets * 250 € ha^{-1} = €6,250

For a farm of 100ha, whit 50% irrigated potatoes and 25% irrigated sugar beets this gives a summed benefit of 31,250 € year^{-1} on average.

5.2.5.3 Comparison of costs and benefits

All water boards in the Netherlands are obliged to create extra space for water retention in the coming years (personal communication, Jan den Besten). The water board might be willing to pay parts of the construction costs of a water storage basin when there is space for water retention as well. However, when the storage basins are constructed according to the dimensions given in this report they only have very limited capacity left for water retention. Thus, for the comparison of the costs and benefits of the water storage basin it is assumed that

the construction costs are not paid by the water board. For the farmers it might, therefore, be interesting to search for possibilities to enlarge the basin in such a way that space for water retention is created. Furthermore, it could be of interest to collaborate and share a basin with neighboring farmers.

An overview of the costs and benefits for different basin sizes and combinations with solar panels can be found in Table 7. When it is possible to cover the basins totally, thereby largely reducing evapotranspiration from the basin, and when the other costs are not taken into account, constructing a basin is profitable at this moment for both the basins of 1.5 m and 2.0 m depth. However, when the basins are not covered their construction will currently not be profitable. For the future situation (2050) the estimated benefit of irrigation is much larger than the current benefit and, thus, the construction of a water storage basin will be profitable even without the combination with solar panels at that time.

Table 7 Costs and benefits of water basins of different sizes

Depth	Solar panel coverage	Basic costs	Benefits	
			Current	2050
1.5 m	0%	≈ €23,500	≈ €18,800	≈ €31,800
1.5 m	100%	≈ €15,600	≈ €18,800	≈ €31,800
2.0 m	0%	≈ €19,300	≈ €18,800	≈ €31,800
2.0 m	100%	≈ €14,400	≈ €18,800	≈ €31,800

Cost benefit studies

In the framework of a study to sustainable 'water farming' (Waterhouderij) two scenarios for water storage were investigated (Aequator Groen & Ruimte, 2010). The first scenario was based on a typical farming case in the province of Brabant. Water storage for potato farming was combined with supplying the stored water to pig farms for use as cleaning water in the stables. The second scenario was based on a typical farming case in the province of Drenthe and combined water storage for potato farming with supplying cooling water for industry.

For both scenarios the water farming concept is only profitable when the following conditions are met (Aequator Groen & Ruimte, 2010):
1. sufficient income is retrieved from other users of the basin, like pig farmers or industry
2. use of groundwater is prohibited or temporarily not possible
3. the price of (raw) drinking water increases, so that water supply from the basin becomes more attractive
4. farmers change to another crop type that is more profitable
5. the basin can be constructed on an area of low agricultural value
6. the growth of toxic algae in the basin can be prevented
7. extra income can be earned from other activities, like recreation or growing algae or fish
8. the excavated soil from the basin can be sold

In a study to water reservoirs for irrigation by Van Bakel *et al.* (2009) conditions 2, 3 and 4 are mentioned as well.

For 25% of the Veenkoloniën area the second condition is met. Some of the conditions (e.g. 5, 6 and 8) can be met if enough effort is made. The remaining prerequisites cannot be influenced at

all or require much larger efforts. Since pig farms are present in the area (Rothengatter, 2011), some arable farms may use their water basin to store water both for irrigation and to supply water to the pig farm. In that case the first condition would be met.

5.3 Electricity from Solar PV Panels

5.3.1 Mounting Structures for PV Panels

The PV system must be designed for structural durability since the solar panels have to be stably carried for the duration of their lifetime (20 years). The mounting structure should be designed to withstand the weight of the PV panels, snowfall and peak wind, among other things.

Two options are considered for the design of mounting frames for PV systems in the Veenkoloniën area: Steel frames on a concrete foundation (Figure 25 and Figure 26) and floating mounting structures tied to four or more fixed posts submerged in the water basin (Figure 28 and Figure 27).

Figure 25 Single fixed supporting structure (Robert, 2005)

Figure 26 Multiple rows of PV frames on concrete foundation and at regular spacing (www.pvpowerway.com/news/ 769.html)

In Figure 26, a number of supporting frames are erected from a concrete foundation at regular intervals. With this design, the bed of the basin needs to be further excavated for to enable the installation of the concrete foundation for fixing the steel frames to hold the PV panels. Even if the material costs are lower than for single fixed supporting structures (Figure 25), the water in the basin cannot be covered completely due to the spacing requirement in between the rows. The lowest end of the PV panel should at a height just above the water level when the basin is full. Therefore, the height of the steel frame (relative to the basin bedding) needs to be equal to the average height of the low and high end of the PV panel. Depending on the height of the basin, this creates extra material costs.

With the options shown in Figure 25, it is possible to cover the whole area of the water basin with PV panels, maximizing the net gain per area. There is no need to provide spacing between the PV panels to avoid shadowing effect. However, because the surface are is very large assuming a 30° tilt angle, the mounting structures need to be very strong and, as such, the material cost becomes very high. It has to be very stable causing much higher material costs. Considering one PV array as shown in Figure 25 and a fully-covered 2.6 ha – 5.0 ha water surface area (basin), one end of the structure will be at the level of the water when the basin is full. The

elevation of the other end will, however, be 100 m above the water ($200 \times \sin(30)$), contributing to horizon pollution.

Floating PV panels are currently a subject of research. Studies are investigating possibilities to install PV systems on oceans and sea shores. The major challenge now is related to the stability of the retaining structure due to water currents, and access for maintenance. However, within a 2.6 ha – 5.0 ha basin, water currents due to wind are negligible and do not pose a threat to the stability of the supporting structure. A floating structure would be connected to the edge of the water basin by a small bridge as shown in Figure 27. The construction costs are relatively low, as a report on a 1 MW project in California has shown (current cost of installation only 4-5 million USD). With a floating PV system, the performance of the PV system can be maintained at a higher level due to the cooling effect of the water. Hence, it is suggested that floating frames as in Figure 28 and Figure 27 present an interesting option for the PV system in the Veenkoloniën area.

Figure 28 Floating PV panel in Italy (Trapani, 2011)

Figure 27 Floating PV panel in California, USA (http:// www.pge.com)

5.3.2 Spacing and Shadow Effect on PV Models for Optimum Performance

The electrical current produced by a PV module is determined by the least illuminated cell in the PV module. Shade is a critical factor, affecting the performance of a solar module. Even if a small portion of a PV panel is overshadowed, the whole panel's performance is jeopardized, which is not in proportion to the shaded area. On the other hand, the PV system must be designed such that panels are somewhat clustered together to minimize power losses in the cables, and to reduce costs. The closer the array is to the inverter panel, the less the power will be dissipated in the cables. The shading effect depends on the spacing between collectors, their height, the row length, the tilt angle and the latitude (Figure 29). Including many rows of collectors will increase the gross collector area (small spacing), but also increase the shading effect. An optimal spacing is needed for
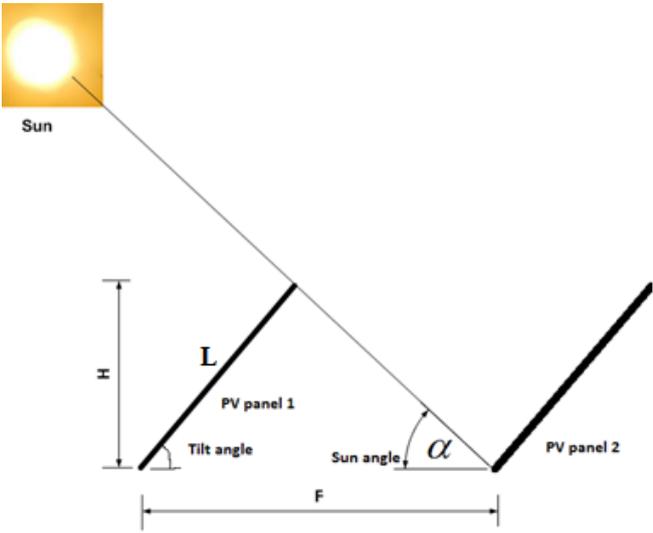
Figure 29 The effect of shadow on spacing PV panels

the deployment of the collectors in a given field area; from an economical as well as energy collection point of view.

The shadow length, F is given by

$$F = L\cos\theta + \frac{H}{\tan\alpha}$$ (3)

Where
H=   Height of the top of the PV panel
L=   Length of PV panel on structure
α =   Angle of the sun
θ =   Tilt angle

5.3.3 Spacing between Rows of PV Panels

For the Veenkoloniën area, we consider the PV panels to be fully operational between 9:00 h and 16:00 h. At these times, the solar elevation angle ranges from 1.7° (9:00 h) and 0.8° (16:00 h) during December and January to 41° (9:00 h) and 48° (16:00 h) in June. The shadow effect will be maximal for low solar elevation angles, as shown by equation 3. During the summer, it is possible for the PV panel to work at an optimum rate before 9:00 h and after 16:00 h.

For January and December, a tilt angle of 30° (an optimum angle according to various reports), requires spacing of 53 m to 107 m apart. In contrast, during summer the solar elevation angle large enough so that a spacing of only 1.3 m is sufficient. As the amount of incoming energy during summer months greatly exceeds the incoming energy during winter, we suggest using a spacing that is optimal for the average spring and autumn months (4.0 m to 2.5 m for March and September, respectively).

5.3.4 Electricity Yield of a PV System in the Veenkoloniën Area

In Figure 30 the total daily solar energy (KWh m^{-2}) is plotted against each day of the year for the Veenkoloniën area. The daily solar radiation was calculated using the ERA-Interim reanalysis data (Dee *et al.,* 2011) from 1 January 1985 - 31 December 2010 to estimate the maximum daily incoming shortwave radiation for the Veenkoloniën area. This dataset provides daily values for the incoming shortwave radiation at 12:00 UTC. By averaging the dataset over time, average values for each day of the year were obtained.

To provide the daily variability, a radiation model was used (Stull, 1988). Given the day of the year, latitude, longitude, time (UTC) and cloud cover, the model provides a value for the incoming shortwave radiation. The ERA-Interim reanalysis data were used to tune the radiation model (i.e., to fit the daily variability of the radiation model to the 12:00 UTC values from the ERA-Interim reanalysis). By integrating the daily cycle of radiation, a total measure for the incoming radiation was obtained.

With a 12% efficient PV panel, the yearly supply of electricity is 133 kWh m^{-2}. With an area of 4 ha (Table 8), for instance, 5320 MWh can be generated.
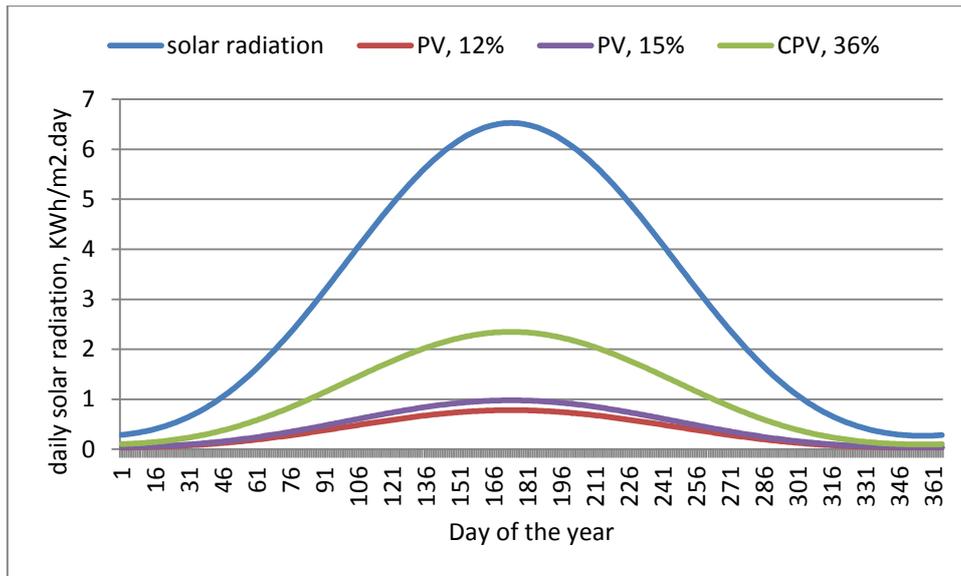
Figure 30 Daily cumulative solar radiation of the Veenkoloniën area from (meteorological data 1989 to 2012 for the area).

5.3.5 Final Design of the PV System

Based on the literature study, the most efficient solution is the use of flat panel Crystalline Silicon cells. For mounting the PV, a floating platform as in Figure 27 is suggested. Based on calculations presented above, the panels can be mounted on galvanized steel frames on the floating platform at an interval of 7 m within the water basin. The dimensions of the envisioned PV system are 3 m wide module constructs (i.e. two PV modules of 150x75 mm put end to end) joined to form 200 m arrays in length. The tilt angle of the construction is 30^0 causing a one-sided elevation of 1.5 m (3m x cos(30)). Table 8 summarizes the final design values of the PV panel system.

Table 8 Final design values of the PV system.

Design Attributes	Quantity	Unit	
PV module dimension (LxW)	150x75	cm	
Number of modules per frame	2	-	
Spacing between rows	7	m	
Available area of water basin	4	ha	
Number of rows of PV panels	28	-	
Projected area of one row of PV	520	m^2	
Total area of water basin under PV	1.5	ha	
Total area of water basin under floating material	4	ha	

5.3.6 Solar Panel Production and Payback Calculation

In the Netherlands, the policy regulating the application of subsidies for renewable energy is described by the Stimulering Duurzame Energieproductie (SDE). In 2012, the SDE will provide 1.7 billion € for all renewable energy categories in 5 different phases. Solar PV panels are in the "free category" and can be subsidised in any of these phases (Table 9). Since 2011, there are no longer subsidies available for solar-PV installations smaller than 15 kWp. Rather, subsidies have been made available for installations larger than 100KWp (Ministerie van Economische Zaken, Landbouw en Innovatie, 2011).

Table 9 Overview of the technologies and associated attributes for the production of renewable electricity in 2012 eligible for SDE subsidy (Maak Kennis met de SDE+ 2012, Agentschap NL) Highlighted fields indicate the phases that can be applied.

Renewable energy		Phase 1: 13 March 17:00h to 1 May 2012 17:00h	Phase 2: 1 May 17:00h to 18 June 2012 17:00h	Phase 3: 18 June 17:00h to 3 Sept 2012 17:00h	Phase 4: 3 Sept 17:00h to 5 Nov 2012 17:00h	Phase 5: 5 Nov17:00h to 27 Dec 2012 17:00h	Preliminary correction amount 2012 (€/kWh)	Maximum years of subsidy	Maximum amount *full* power hours (hours / year)	Final term commissioning (year)
		Base amount per Phase (€/kWh)								
Wind	Wind over land < 6MW (1.760 full hours)	0.0875	0.1125	0.120	0.120	0.120	0.058	15	1760	4
Energy	Wind over land < 6MW (2.120 full hours)	0.0875	0.106	0.106	0.106	0.106	0.058	15	2120	4
	Wind over land ≥ 6MW	0.0875	0.1125	0.120	0.120	0.120	0.060	15	2400	4
	Wind over lake	0.0875	0.1125	0.1375	0.154	0.154	0.060	15	2480	4
	Wind over sea	0.0875	0.1125	0.1375	0.1625	0.1875	0.0609	15	3200	4
Water	Water power ≥ 0.5m and < 5m	0.070	0.090	0.110	0.118	0.118	0.052	15	7000	4
Power	Water power ≥ 5m	0.070	0.071	0.071	0.071	0.071	0.052	15	4800	4
	Free flow energy ≤ 0.5 m	0.070	0.090	0.110	0.130	0.150	0.052	15	2800	4
Osmosis	Osmosis	0.070	0.090	0.110	0.130	0.150	0.052	15	8000	4
Solar PV	Solar PV ≥ 15 kWp	0.070	0.090	0.110	0.130	0.150	0.057	15	1000	3
AWZI/ RWZI	AWZI / RWZI thermal pressure hydrolysis	0.070	0.090	0.096	0.096	0.096	0.052	12	8000	4

Based on these findings, we perform the calculations on two scales differentiating between installations smaller than 15 kWp and installation bigger than 15 kWp. For both scenarios, we

assume that they are connected to the grid, such that no battery storage of electricity will be required. The main parameters for the calculations are shown in Table 10. The amount of incoming solar radiation is the average value of the annual solar radiation in the Veenkoloniën area. The PV-efficiency ranges from 12 to 15% (Alsema and de Wild-Scholten, 2006; Ito *et al.*, 2008). The performance rate equals 75% (Zahedi, 2009) with an annual electricity generation value of 900 kWh year[-1] (personal communication, Baysolar AG, Germany). The PV panel module retail price amounts to 1.45 € Wp[-1] in February 2012 (http://www.solergy.nl/zon-samen/).

Table 10 Basic parameters for solar PV installation in this case study. Information on the average Dutch household electricity use was retrieved from http://www.gaslicht.com/ energiebesparing/energieverbruik.aspx.

INPUT VARIABLES		VALUE	UNIT
Solar radiation		3.04	kWh m[-2].d[-1]
PV efficiency	Mono-crystalline silicon	15%	
	High efficient Poly-crystalline silicon	15%	
	Poly-crystalline silicon	12%	
Performance rate		75%	
Weather condition		0	0=Cloudy 1=Sunny
1KWp system electricity generation		900	kWh year[-1]
Retail Price		1.45	€ Wp[-1]
Basic Bank Interest (ABN AMRO)		2%	
Credit interest (ABN AMRO)		5%	
Average household electricity use		3480	kWh year[-1]
Electricity price for household		0.22	€ kWh[-1]

5.3.6.1 Scenario I – PV Panels <15 kWp

For this scenario, there will be no subsidy from the SDE; profit can only be generated by selling electricity to the grid. As mentioned above, the average annual household electricity consumption is 3480 kWh/year. Installation of a 4-5 kWp system is sufficient to cover the energy need of one household.

Details of the payback calculation for this system are shown in Table 11. The calculation is based on a maximum investment, in which case the installation can generate 13500 kWh year[-1] electricity. However, due to Dutch legislation, a private investor can only sell 3500- 5000 kWh per year. Therefore, electricity generated by a 15 kWp system should be shared between 2-3 houses. The sales price equals the price per kWh (0.22 €/kWh) sold by electricity companies.

Table 11 Installation information for PV system 15 kWp

VARIABLES		VALUE	UNIT
Installation		15	kWp
Energy Production		13500	kWh year^{-1}
Installation cost		21750	Euro
Area requirement	Mono	108.15	m^2
	Poly	135.18	
Life time		20	Year

As shown in Table B 1, there will be a net return starting from year 10 in case of private investment, whereas investments based on a credit will be profitable from year 14. In a period of 15 years, the final payback will be 11,025 € or 2,235 €, respectively. For this calculation, tax and inflation values have not been taken into account. In addition, return equity and redemption have not been considered due to missing information. Therefore, the real payback will differ from the data as indicated for this scenario. Thus, from an economic point of view, the installation of a solar PV panel system of less than 15 kWp is feasible on a small scale including a few households with a total return rate of 50.7%. On this scale, PV panels still generate profit after 15 years since the lifetime of single modules currently amounts to 20 years. Considering the lifetime of a solar panel installation, the total return will be 21,411 € for private investors. The profit of installations based on credit investments is difficult to calculate since there is no information on the development of interests within the coming 20 years.

Basic amount (Basisbedrag) calculations have been carried out using the ECN calculator[8] (Berekening basisbedragen hernieuwbare electriciteit; Table B 2), following the modification of the full load hour, investment, maintenance cost variable, and current market price parameters. According to these calculations, the basic amount equals -0.8 €cent kWh^{-1}, which means the investment would have a return equity (required return on equity) higher than 15%. Inflation rates are not considered since they would affect the market price index (personal communication, S. M. Lensink).

5.3.6.2 Scenario II – PV Panels >15 kWp

On a scale larger than 15 kWp, a private investigator is no longer allowed to sell the electricity to the national grid. Companies will be the main investor at this and larger scales. SDE subsidy can be obtained from 7-15 €cents kWh^{-1} (basic rate) and depends on the phase of application. The real subsidy is the value of basic rate subtracted from the correction rate where the correction rate equals the APX power market peak index value. As the subsidy period lasts for 15 years, we assume a PV panel lifetime of 15 years. In addition, companies may apply for tax deduction by

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[8] http://www.ecn.nl/units/ps/themes/renewable-energy/projects/sde/sde-2011/

energy saving or renewable energy investment (EIA; Energie Investerings Aftrek). In 2012, 41.5% of renewable energy investment costs can be deducted from taxable profits (Agentschap NL, Ministerie van Economische Zaken, Landbouw en Innovatie). Here, we consider 100 kWp systems as an example. The area covered by such an installation is smaller than 1000 m², far less than the size of the water basin (see Section 5.2.3). Hence, the spacing between the solar panels is not taken into account. Details about the energy payback calculation are shown in Table 12. With 100 kWp investment, annually 90 MWh of electricity will be generating. Therefore, a big electricity consumer or large electricity grid should be connected to the installation (Kamerbrief openstelling SDE 2012).

Table 12 Installation information for 100 kWp PV system

VARIABLES	VALUE		UNIT
Installation		100	kWp
Energy Production		90,000	kWh year^{-1}
Installation cost		145,000	Euro
Area requirement	Mono	721	m²
	Poly	901	
Lifetime		15	Year

Table B 4 shows that, at this scale, the installation is non-profitable. The basic amount (Basisbedrag) will be 19.5 €cents kWh^{-1} according to the ECN calculator[9]. The SDE 2012 maximally offers 15 €cent kWh^{-1} resulting in 4.3 €cent kWh^{-1} basic amount (Basisbedrag) and, thus, 0% in return equity (required return on equity). As for scenario I, the inflation rate is not included in the calculation. Additionally, the retail price will be lower for large-scale installations. If the retail price can reach to 1.075 € Wp^{-1}, the return equity will amount to 15%. It is important to note that in some cases companies invest into the installation of PV panels because they require a greener image or because their customers demand a smaller carbon footprint. In other cases, large companies may invest because they want to lower their profit for tax reasons (F. Debets, personal communication, Feb. 26th 2012).

All calculations are based on the availability of subsidy. However, the SDE has its financial limitations and distributes subsidies based on a first-come- first-serve principle. Applying for subsidy in phase 5 decreases the deficit but increases the chance to be rejected.

5.4 Algae – Applications for the Veenkoloniën

Due to the geographic and climate characteristics of the Veenkoloniën, great care has to be taken for the selection of a suitable algae strain and an appropriate cultivation method. Due to the economic benefits, we suggest that the major part of the algal biomass be used for the production of biofuels. Especially the selection of the appropriate strain is an important factor in successful biofuel production. Ideally this strain has the following characteristics:

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[9] http://www.ecn.nl/units/ps/themes/renewable-energy/projects/sde/sde-2012/

1. High lipid content
2. Robustness; surviving shear stresses in the photobioreactors; if cultivated in open ponds it needs to be able to dominate other wild strains and survive a certain amount of unforeseen contamination
3. High CO_2 sink capacity
4. Low nutrient requirements
5. Tolerant to a wide range of temperatures
6. Fast productivity cycle
7. Provide valuable co products
8. High photosynthetic capacity (PE)
9. Self-flocculation characteristics

Currently there is no strain that is known to display all of the above characteristics. In an attempt to integrate the given limitations of the area as well as the availability of algae species, we selected a suitable microalgae strain and a cultivation method.

5.4.1 Species Selection – *Neochloris oleoabundans*

Neochloris oleoabundans belongs to the class of Chlorophyceae, a class of green algae, and has been isolated from a sand dune in Saudi Arabia in 1962. Its average size is below 10 μM (Figure 31). The strain most commonly used in studies (UTEX # 1185, USA) can be purchased from the algae culture collection at the University of Texas, Austin, USA.

N. oleoabundans is a fresh water organism and can be cultivated in soil extract medium (UTEX: http://web.biosci.utexas.edu/ utex/mediaDetail.aspx?mediaID=4) consisting of bristol medium and soilwater. The optimum temperature is 25°C at a pH of 7.5. Culture media can be supplemented with carbon dioxide by enriching the air led into the reactor with 2-5% CO_2 at a flow rate of 0.5 vvm (volume gas/ (volume liquid/min)) buffering the media pH. An air inlet at the bottom of the reactor will help mixing the culture. This helps to keep the cells homogeneously distributed in culture providing the maximum amount of light and nutrients to each single cell.

Figure 31 Microscopic image of the microalga N. oleoabundans (from http://web.biosci.utexas.edu/utex/ algaeDetail.aspx?algaeID=3623)

However, culture conditions differ widely between studies. Growth media compositions can be adjusted to meet the requirements of the desired end products. In particular, since *N. oleoabundans* is renowned for its high lipid-content (29%) in comparison to other commonly used microalgae species (Table 13) and its increased lipid productivity at low nitrogen concentrations, media may be prepared to grow the microalgae under N-deficient conditions (Gouveia and Oliveira, 2009). This may increase the oil content of up to 50% of dry biomass (Gouveia and Oliveira, 2009). The characteristic elevation in lipid production makes this species a highly valuable feedstock or for the production of biofuel and other oil-based products.

Growth parameters such as pH, temperature, O_2 and CO_2 levels, airflow speed, and optical density may be controlled with an Ez-controller equipped with Bioexpert© Software (Applikon Biotechnology, The Netherlands). The culture density is essential to provide an even light regime and is ideally kept at 0.55 CU controlled by a turbidity sensor (ASD19-N) (Sousa *et al.*, 2012).At sub-saturating light conditions with an average of 210 µmol m^{-2} s^{-1} (Figure 32), *N. oleoabundans* produces high biomass yields (Provost *et al.*, 2009; Sousa *et al.*, 2012). Red LED lights emitting at 627 nm (SL3500, Photon Systems Instruments, Czech Republic) can be used for artificial illumination. Prior to running the cultivation system, the incident light intensity measured with a PAR sensor has to be determined at several positions to balance the light distribution and to determine the average incident photon flux density (PFD$_{avg}$) (Sousa *et al.*, 2012).

Table 13 Lipid content of several microalgae species in % dry matter (adapted from Becker, 1994; Miao and Wu, 2006; Natrah et al., 2008; Spolaore et al., 2006; Tornabene et al., 1983; Xiong et al., 2008).

Species	Lipids
Scenedesmus obliquus	11–22/35–55
Scenedesmus dimorphus	6–7/16–40
Chlorella vulgaris	14–40/56
Chlorella emersonii	63
Chlorella protothecoides	23/55
Chlorella sorokiana	22
Chlorella minutissima	57
Dunaliella bioculata	8
Dunaliella salina	14–20
Neochloris oleoabundans	35–65
Spirulina maxima	4–9
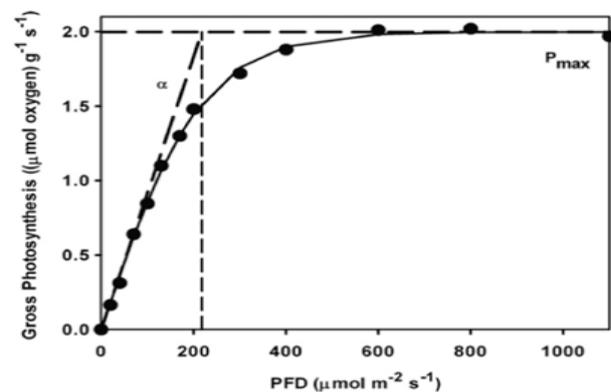
Figure 32 Photosynthetic rate of N. oleoabundans *against the irradiance in µmol oxygen (g DW)$^{-1}$ s^{-1} at different photon flux densities (PFD) (adapted from Sousa* et al.*, 2012).*

5.4.2 Selection of Cultivation Method – Vertical Flat Plate Photobioreactors

For the Veenkoloniën most probably the flat plate photobioreactors (PBRs) are most applicable. This choice is made based on the following arguments:

- Contamination (for example by other algae species) can be prevented. Contamination is an important factor that needs to be considered when growing algae outside in the open area. In this way higher value algae biomass can be produced compared to an open pond.
- Flat plate reactors consist out of large illumination surfaces which enable a good light path in the reactors. This has the advantage that the algae can absorb more sunlight, especially in temperate regions like the Veenkoloniën where the sunlight intensities are not optimal all the time (Mata *et al*, 2010; Brennan and Owende, 2010).
- Flat plate reactors allow at the same time for more biomass grow or high biomass productivities , compared to tubular reactors because of the large space and better light path (Mata *et al*, 2010; Brennan and Owende, 2010)
- Different grow parameters like nutrient amount, temperature, pH can be controlled. Therefore one is able to optimize the production and the quality of the products.
- Flat plate reactors are relatively cheap, easy to clean and suited for outdoor cultivation of algae (Mata *et al*, 2010)
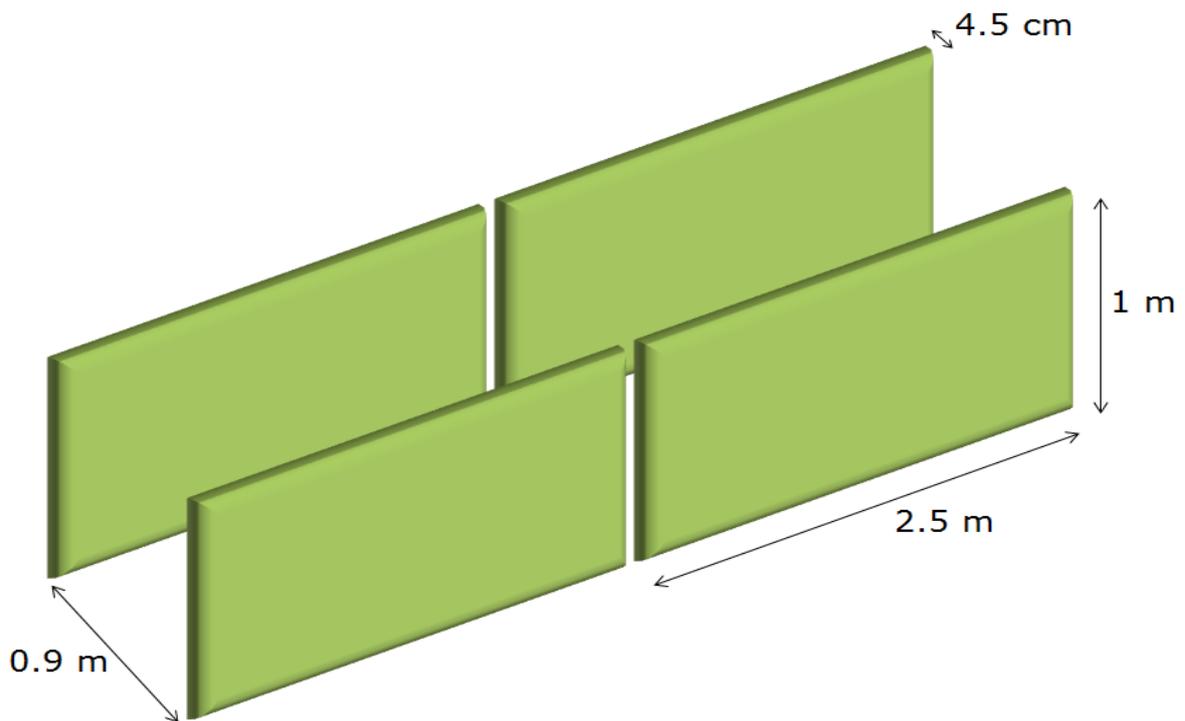
Figure 33 Example setup of a flat plate photobioreactor system for the Veenkoloniën (adapted from Rodolfi et al., 2010).

The setup proposed for the cultivation of algae in Veenkoloniën is shown in Figure 33. Rodolfi presents the outdoor cultivation of a marine species in flat plate PBRs and ways of optimizing the lipid production. The flat plate PBRs consisted of 110L GWP or culture chambers made of 0.3 mm thick flexible LDPE film enclosed in a rectangular metal frame. Each flat plate or module was 1 m high, 2.5 m long and on average 4.5 cm thick. Therefore, on an area of 1 ha, it is possible to place 4,444 modules. Each reactor module has an inlet with a perforated tube placed at the bottom to transport air bubbles into the reactors for mixing and CO_2 supply. To regulate the temperature water was sprayed on the reactors when the temperature exceeded its limit. Should be noted that lower temperatures are not so harmful to the culture than temperatures higher than the optimal temperature for cultivation (mostly the limit is 30°C). For the Veenkoloniën one should realize that temperatures are between 12°C to 20°C on average, and that, at such low temperatures, the algae likely remain below their optimal biomass productivity. To prevent this, another mechanism for temperature control should be thought of. One option is to use artificial light (red LED) during cold days or circulate warm water around the modules by developing a special material around the whole or part of the modules where the water can be kept, like a jacket that keeps the reactors warm.

5.5 Integration Scenario

The surface of the water storage basin provides an area that potentially can be utilized by floating solar energy production or algae cultivation systems, as shown in Figure 34. Independent on which system is integrated, a floating mechanism with a closed surface (i.e.

acting as a closed lid, Figure 35) will decrease the evaporation over the covered area to zero. This has direct implications for the needed amount of storage. Outlined in Table 14 are the properties of the 1.5 and 2 m deep basin when the area is covered between 0 - 100 %. For example; the size of a basin of 1.5 m deep can be decreased with 1 ha when covered for 50% by the floating structure.
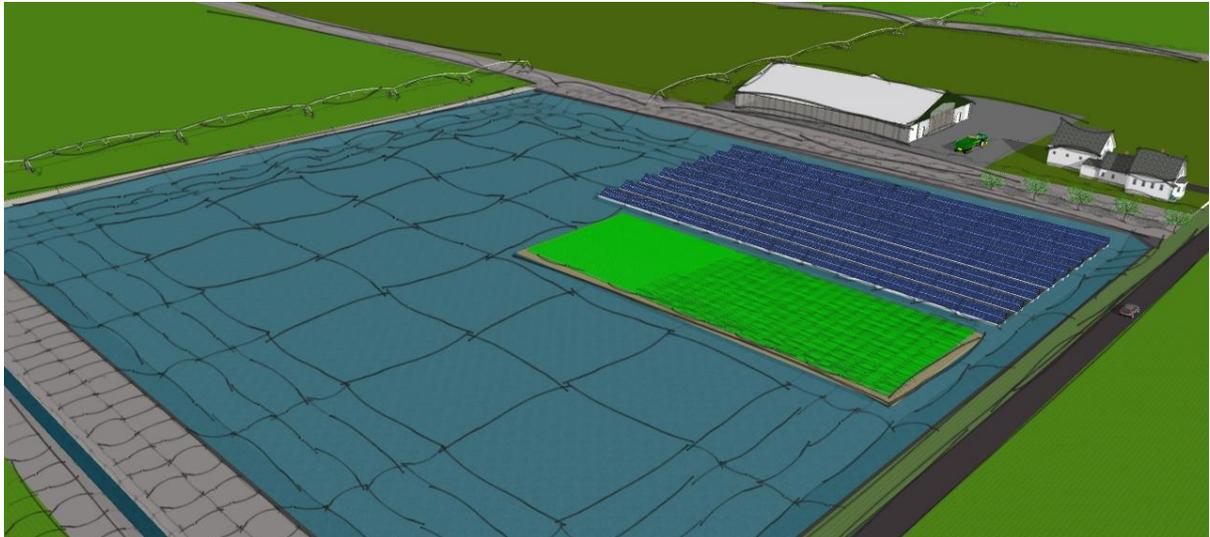
Figure 34 Artist impression of the integration scenario with floating solar panels and algae cultivation plate.
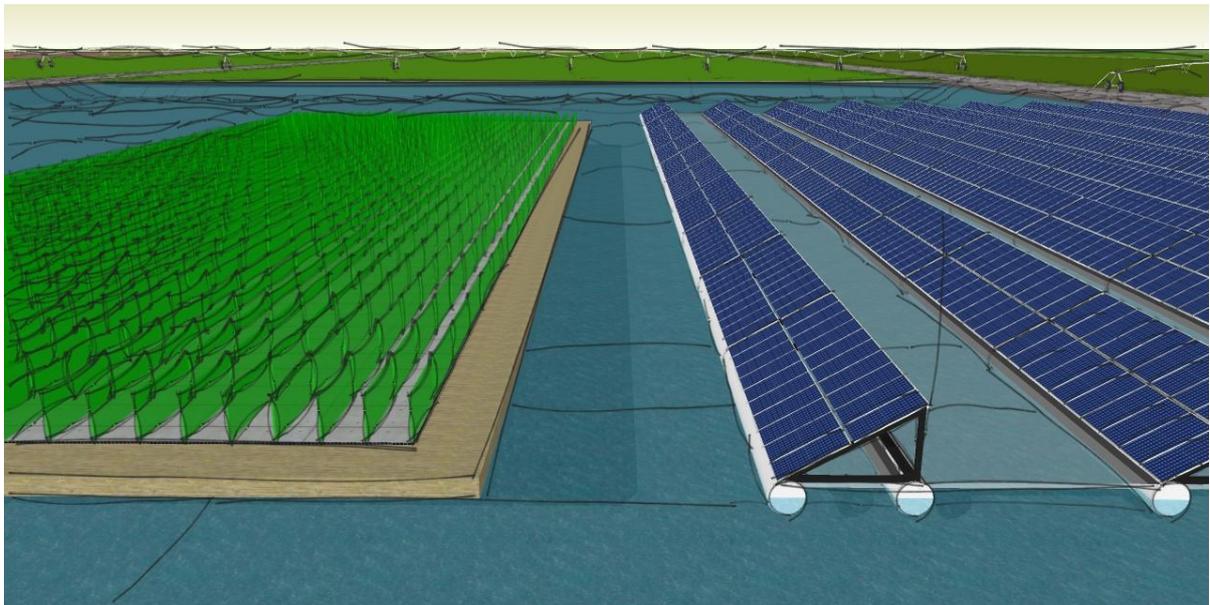
Figure 35 Both the flat plate algae reactors and solar panels floating on the basin.

Even further integration of the individual systems is possible, as outlined in Figure 36. As mentioned in Section 3.2.3.2, the efficiency of solar PV panels decreases as the panels get overheated. With a vast amount of water available directly underneath the panels, cooling of the panels can reduce the loss of efficiency. In return, the electricity produced by the solar panels can directly be used to pump water into the basin, or provide electricity for the algae cultivation. This way, the self-sufficiency of the system can be improved.

Table 14 Dimensions and water balance for the integration scenarios using a basin depth of 1.5m (top) and 2.0m (bottom). A_{cover} denotes the covered area (ha), A the area of the basin (ha), f the covered percentage, V the stored volume at 1 April (m³x1000), dE the loss by evaporation (m³x1000), dP the gain by precipitation (m³x1000), dS the loss by seepage (m³x1000) and dV the total loss (m³x1000).

A_{cover}	A	f	V	dE	dP	dS	dV
0.0	5.0	0.0	73.7	-27.4	10.0	-0.8	-18.2
0.5	4.7	10.6	70.0	-23.3	9.5	-0.7	-14.5
1.0	4.5	22.2	66.4	-19.2	9.0	-0.7	-10.9
2.0	4.0	50	59.1	-11.0	8.0	-0.6	-3.6
3.0	3.5	85.6	51.8	-2.8	7.0	-0.5	3.7
3.3	3.3	100.0	49.3	0.0	6.7	-0.5	6.2

A_{cover}	A	f	V	dE	dP	dS	dV
0.0	3.5	0.0	68.2	-19.2	7.0	-0.5	-12.7
0.5	3.3	15.2	64.9	-15.5	6.6	-0.5	-9.4
1.0	3.1	32.3	61.5	-11.8	6.3	-0.5	-6.0
2.0	2.8	71.4	54.7	-4.4	5.6	-0.4	0.8
2.6	2.6	100.0	50.7	0.0	5.2	-0.4	4.8

Based on the covered areas presented in Table 14, it is possible to calculate the amount of produced energy. As, at this moment, algae cultivation is not feasible, the calculations are only performed for solar energy.
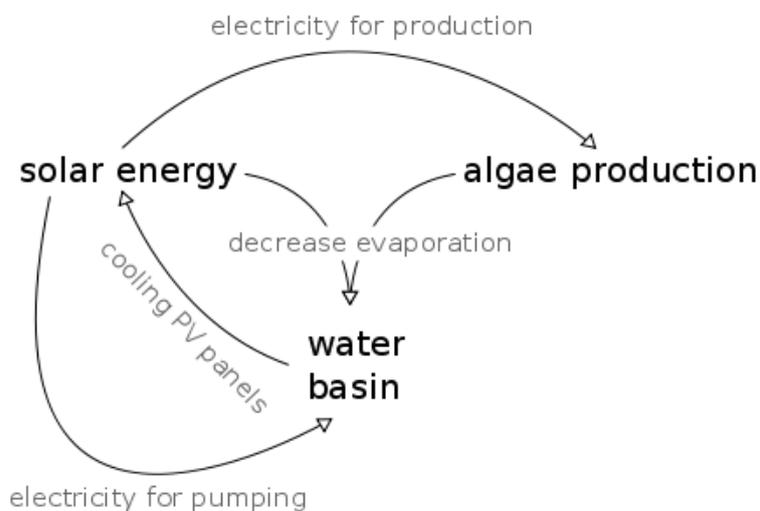
Figure 36 Scheme for the integration of the different systems

Integration scenarios for solar panels

For the area covered with solar panels, a spacing of 7 m between two rows of solar panels was used (Table 8). We also assume that we can successfully apply for phase 5 of the SDE 2012 subsidy. For an installation of this scale, the retail price per PV module may decrease. This can have an influence on the outcome of the calculations. However as detailed information on these discounts is missing, we do not take it into account. Calculations of the investment and annually generated electricity, as shown in Table 15, are based on a secondary source investigation. Details on the cash flow are presented in Appendix B (Table B 6, Table B 7, Table B 8, Table B 9).

Table 15 Calculation for PV based on the basin design.

Area (ha)	Investment (k€)		Energy production (mWh y^{-1})		Panel size (m²)
	Mono	Poly	Mono	Poly	
0.5	673	538	262	210	2,100
1	1,346	1,077	524	419	4,200
2	2,691	2,153	1,049	839	8,400
3	4,806	3,230	1,572	1,258	12,600

As SDE and EIA are subsidies at a company level, mainly companies will realize these large scale PV installation. Because of that, local inhabitants may not have a strong incentive to participate. They can however participate by renting the storage basins´ surface to companies. Another option for farmers is to invest in their own small (<15 kWp) solar PV system. As a 15 kWp system can produce 13500 kWh year^{-1}, (Table 11), an average household uses 3480 kWh year^{-1} (Table 10) and pumping of water into the basin consumes approximately 3600 kWh year^{-1} (Section 5.2.5.1), 6420 kWh year^{-1} is left over for other uses such as pumping water for irrigation.

6. Conclusions and Recommendations

Based on the hydrological research, it can be concluded that a volume of approximately 55,000 m³ water per farm of 100 ha will have to be stored to bridge the gap between the future water demand and supply. When compensated for evaporative and seepage losses, this results in a lined basin with an area between 3.5 ha and 5 ha, depending on the choice of depth (1.5 m or 2.0 m). Uncertainties associated with the design of the water reservoir for a farm in the Veenkoloniën area are mainly associated with future climate changes. Although it is certain that the global temperatures are increasing, details on the seasonal changes, especially in precipitation and evaporation, are unknown. Furthermore, with limited knowledge on the seasonal and annual changes in surface and ground water levels and soil moisture content, calculations of the actual water demand of crops is difficult. Therefore, the amount of water to be stored was chosen to allow an excess storage.

The setup of the solar system can be beneficial if the installation is small in scale (<15 kWp) and connected to the electricity grid. The electricity can partly be sold, after which the remainder is available for private use (household, water pumping, artificial light for algae growth, etc.). A large-scale PV installation, even when subsidized, is not economically feasible. The main advantage of using solar instead of wind energy is the limited impact on the landscape: our design is just 1.5 m high.

Based on a literature study, we conclude that algae production is economically not feasible. Algae cultivation for commercial purposes is still in an experimental stage and the technology for processing the algal biomass is still in development. Raw materials are mostly used to produce biofuel. However, if algal biomass is entirely exploited including the use of proteins and carbohydrates, high-quality chemicals can be produced significantly increasing the value of algal biomass.

As described in Section 5.5, integration of the three systems is technically feasible. Algae cultivation systems and solar panels can be installed on floating devices covering parts of the water surface (different dimensions are possible). The electricity generated by the PV system can be used to cover the energy requirements both of the algae and the water supply systems, creating an energy-neutral model. In addition, the spatial integration reduces the area of arable land that would have to be converted. Nonetheless, the economic feasibility of the integration will have to be investigated further, since information on the energy requirements of an algae growth plant is scarce.

For future studies we have a number of recommendations:

- In this study the water balance was limited to the scale of a single basin. As such, precipitation, which is intercepted by the fields and which could partly be transported to the basin, is not taken into account. If the water balance is scaled up to include ground and surface water levels as well as soil moisture contents, a more realistic simulation including precipitation, evaporation, irrigation and basin water levels could be performed. Such a simulation could be used both to optimize the basin dimensions and to study the possibilities of water retention.

- No attention has been given to the actual implementation of the agrobusiness solution in the Veenkoloniën area. By studying the spatial distribution of soil types, ground water

levels, elevation data and areas of low agricultural value by means of a GIS study; a map with potentially interesting areas can be produced.

- No attention has been given to the water quality in the basin. Especially, when the water is stagnant and not replenished for a couple of months, (toxic) algae and other microorganisms may grow inside the basin. Furthermore, if water is transported from the ditches to the basin, nutrients, pesticides and herbicides may accumulate. Finally, (partially) covering the basin can also influence the quality of the water. All these topics will have to be addressed in a future study.

- All cost-benefit analyses performed in this study only provide a first economical estimate. Further and more detailed study on this subject is required to obtain a complete insight into the economic feasibilities of the different solutions.

- Due to the mostly technical nature of this study, the social acceptance (NIMBY attitude) of creating water storage and using solar energy and algae production as additional sources of income has not been studied. It will be necessary to further investigate the attitude of the areas' inhabitants on the proposed solutions, as well as differences in attitude compared to energy production by means of wind turbines.

- Especially, when covering a large part of the basin with solar panels, the system will have to be connected to the electricity grid. However, the cooperation with the grid company (public utility), selling energy to the electricity companies and the technical background of the connection should be studied further.

- To make algae production more feasible in the future, additional research has to be carried out on commercial cultivation of algae; both in open door environments as well as possibilities for cultivation in greenhouses. Experimental plots can be installed to test the efficiency. For this, farmers should be educated on the use of algae and algae cultivation systems. This also provides a possibility to study the integration of algae production into the farm system, e.g., using wastewater. Finally, the option of producing biogas and electricity from algal and crop biomass combustion on farm level should be investigated. In turn, fuel gas CO_2 from the biogas plant could be used to cover the algae carbon requirements.

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Appendices

Appendix A – Soil Map of the Veenkoloniën
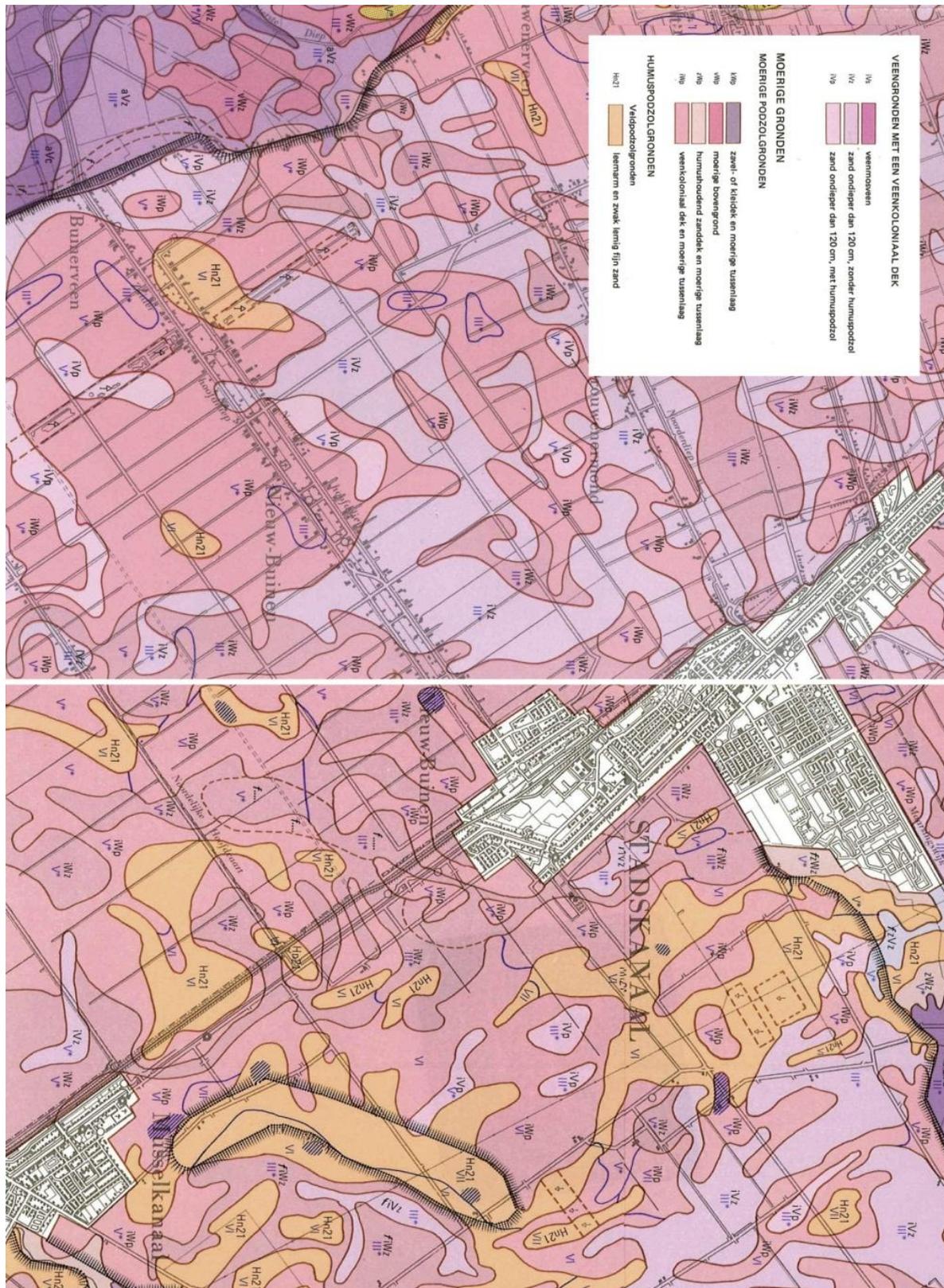
Figure A 1 Map displaying the soil characteristics of the Veenkoloniën (from Stiboka, 1977)

Appendix B –Payback Calculations for the Solar Panel Systems

Table B 1 Payback calculations for a 15 kWp solar PV system (in 1000€)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment (€)	-34.7															
Electricity Revenue (Kwh)		13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Operational cost (€)		-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28
Electricity market value (€)		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Total income (€)		2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Mean pay back (€)		-19.1	-16.4	-13.7	-11	-8.3	-5.6	-2.9	-2.6	2.4	5.1	7.8	10.5	13.2	15.9	18.6
Interest (€)		-0.44	-0.44	-0.45	-0.46	-0.47	-0.48	-0.49	-0.5	-0.51	-0.52	-0.53	-0.54	-0.55	-0.56	-0.57
Real pay back (€)	*	-19.5	-17.3	-15	-12.8	-10.6	-8.4	-6.2	-4	-1.8	0.35	0.25	0.47	0.68	0.89	11
Loan interest (€)		-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1
Loan pay back (€)	**	-20.2	-18.6	-17	-15.4	-13.8	-12.2	-10.6	-9	-7.4	-5.8	-4.2	-2.6	-0.96	0.64	2.2

* Personal investment, ** Credit from bank

Table B 2 ECN calculator input/output for 15 kWp PV system

INPUT VARIABLE	VALUE	UNIT	COMMENT
Install size	15	kWe	
Install size (electricity)	15	kWe	
Full load hour	900	hour/year	
Economic lifetime	15	Year	
Investment	1450	Euro/kWe	Including BTW
Maintenance cost variable	0.025	Euro/kWe	Including BTW
Current market price	0.220	Euro/kWh	
Cost of imbalanced		Euro/kWh	
EIA applied?	**No**		Fill in : Yes or No
EIA	42%		Maximum portion of the investment eligible for EIA
EIA max	48,840,00 0	Euro	Maximum investment
EIA max	0	Euro/kWe	Maximum investment
Part of the investment eligible EIA			
Part of the investment with EIA	0.0%		
Inflation	0%		
Interest loan	5.000%		
Required return on equity	15.000%		
Equity share in investment securities including EIA	20%		
Debt share in investing incl. EIA effect	80%		
Cooperation	25.5%		
Loan term	15	year	
Depreciation period	15	year	
Policy period	15	year	Period for which SDE subsidy granted
OUTPUT	**Value**	**Unit**	
Production Cost	-0.76	Eurocent/kWh	
Transaction costs	0	Eurocent/kWh	
Base price premium	0	Eurocent/kWh	
Basic amount	**-0.8**	Eurocent/kWh	

Table B 3 Cash flow for 15kWp solar PV according to the ECN calculator

Pos. values=beneficial to the producer	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Investment (€)	-21,750															
	Electricity revenue (kWh)		13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500
A	Operational cost (€)		-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338
B	Fuel Cost (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Primary fuel savings (ton of m³)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	Primary fuel savings (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	Electricity market value (€)		2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970
	CHP vol equivalent heat value (m³)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	CHP heat value (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	Total income (€)	C+D+E	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970	2,970
G	Total cost (€)	A+B	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338	-338
H	**Gross income (€)**	F+G	2,633	2,633	2,633	2,633	2,633	2,633	2,633	2,633	2,633	2,633	2,633	2,633	2,633	2,633	2,633
J	Depreciation (€)		-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450	-1,450
K	Interest (€)		-870	-830	-787	-743	-696	-647	-596	-542	-485	-425	-363	-297	-228	-156	-80
L	Redemption (€)		-806	-847	-889	-933	-980	-1,029	-1,081	-1,135	-1,191	-1,251	-1,313	-1,379	-1,448	-1,521	-1,597
M	Total loan charges (€)	K+L	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676	-1,676
	Taxable income (€)	H+J+K	313	353	395	440	486	535	587	641	697	757	820	885	954	1,027	1,103
N	Tax amount (€)		-80	-90	-101	-112	-124	-136	-150	-163	-178	-193	-209	-226	-243	-262	-281
	Net income after tax (€)	H+M+N	**876**	**866**	**855**	**844**	**832**	**820**	**807**	**793**	**778**	**763**	**747**	**730**	**713**	**694**	**675**

Total investment	21.8
Project interest rate (€)	6.0%
Investment eligible for EIA (€)	0
Energy Investment Deduction (€)	0
NCW(EIA) (€)	0
Share credit (€)	17.4
Share of equity (€)	4.4

Table B 4 ECN calculator for 100 kWp PV system

INPUT VARIABLES	VALUE	UNIT	COMMENT
Install size	100	kWe	
Install size (electricity)	100	kWe	
Full load hour	900	hours/year	
economic lifetime	15	Year	
Costs avoid fuel used CHP		€/m³	
Investment	1450	€/kWe	
Maintenance cost fixed	0	€/kWe	
Maintenance cost variable	0.021	€/kWh	
Current market price	0.150	€/kWh	
Cost of imbalanced		€/kWh	
EIA applied?	Yes		Enter: Yes or No
EIA	42%		Maximum portion of the investment eligible for EIA
EIA max	48,840,000	€	Maximum investment
EIA max	3,000	€/kWe	Maximum investment
Part of the investment eligible EIA	100.0%		
Part of the investment with EIA	100.0%		
Inflation	0%		
Interest loan	5.0%		
Required return on equity	15%		
Equity share in investment securities including EIA	20%		
Debt share in investing incl. EIA effect	80%		
Cooperation	25.5%		
Loan term	15	Year	
Depreciation period	15	Year	
Policy period	15	Year	Period for which SDE subsidy granted

OUTPUT	VALUE	UNIT
Production Cost	3.97	€cent/kWh
Transaction costs	0.09	€cent/kWh
Base price premium	0.25	€cent/kWh
Basic amount	4.3	€cent/kWh

Table B 5 Cash flow for 100 kWp solar PV according to the ECN calculator (in 1000 €)

Pos. values=beneficial to the producer	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Investment (€)	-145															
	Electricity Revenue		90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
A	Operational Cost (€)		-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9
B	Fuel Cost (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Primary fuel savings (ton of m^3)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	Primary fuel savings (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	Electricity market value (€)		13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
	CHP vol equivalent heat value (m^3)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	CHP heat value (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	Total income (€) C+D+E		13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
G	Total cost (€) A+B		-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9
H	**Gross income (€) F+G**		**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**
J	Depreciation (€)		-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7
K	Interest (€)		-5.1	-4.8	-4.6	-4.3	-4.1	-3.8	-3.5	-3.2	-2.8	-2.5	-2.1	-1.8	-1.3	-0.91	-0.47
L	Redemption (€)		-4.7	-4.9	-5.2	-5.4	-5.7	-6	-6.3	-6.6	-7 -9.8	-7.3	-7.7	-8.1	-8.5	-8.9	-9.3
M	Total loan charges (€) K+L		-9.8	-9.8	-9.8	-9.8	-9.8	-9.8	-9.8	-9.8		-9.8	-9.8	-9.8	-9.8	-9.8	-9.8
	Taxable income (€) H+J+K		-3.1	-2.9	-2.7	-2.4	-2.1	-1.8	-1.5	-1.2	-0.89	-0.54	-0.17	0.21	0.61	1	1.5
N	Tax amount (€)		0.8	0.74	0.68	0.61	0.54	0.47	0.39	0.31	0.23	0.14	0.04	-0.05	-0.16	-0.26	-0.38
	Net income after tax (€) H+M+N		**2.6**	**2.6**	**2.5**	**2.4**	**2.4**	**2.3**	**2.2**	**2.1**	**2.1**	**2**	**1.9**	**1.8**	**1.7**	**1.6**	**1.5**
	Net Present Value Net Income (€)	13.5	2.3	1.9	1.7	1.4	1.2	0.99	0.84	0.7	0.58	0.49	0.4	0.33	0.27	0.22	0.18
	Discounted energy produce	39.2	58.3	50.7	44.1	38.3	33.3	29	25.2	22	19.1	16.6	14.4	12.5	10.9	9.5	8.2

Total investment (€)	145
Project interest rate	6.0%
Investment eligible for EIA (€)	145
Energy Investment Deduction (€)	60,175
NCW(EIA) (€)	14.5
Share loan (€)	101.5
Share of equity (€)	29

Table B 6 Cash flow for 0.5 ha solar PV according to the ECN calculator (in 1000 €).

Pos. values=beneficial to the producer	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment (€)		-362															
Electricity Revenue (MWh)			225	225	225	225	225	225	225	225	225	225	225	225	225	225	225
A Operational Cost (€)			-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7
B Fuel Cost (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Primary fuel savings (ton of m³)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C Primary fuel savings (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D Electricity market value (€)			33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8
CHP vol equivalent heat value (m³)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E CHP heat value (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F Total income (€)	C+D+E		33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8
G Total cost (€)	A+B		-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7
H Gross income (€)	**F+G**		**29**	**29**	**29**	**29**	**29**	**29**	**29**	**29**	**29**	**29**	**29**	**29**	**29**	**29**	**29**
J Depreciation (€)			-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2	-24.2
K Interest (€)			-12.7	-12.1	-11.5	-10.9	-10.2	-9.4	-8.7	-7.9	-7.1	-6.3	-5.3	-4.3	-3.3	-2.3	-1.2
L Redemption (€)			-11.8	-12.4	-13	-13.6	-14.3	-15	-15.8	-16.6	-17.4	-18.2	-19.2	-20.1	-21.1	-22.2	-23.3
M Total loan charges (€)	K+L		-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5	-24.5
Taxable income (€)	H+J+K		-7.8	-7.2	-6.6	-6	-5.3	-4.6	-3.8	-3	-2.2	-1.3	-0.4	0.5	1.5	2.6	3.7
N Tax amount (€)			2	1.8	1.7	1.5	1.4	1.2	1	0.8	0.6	0.3	0.1	-0.1	-0.4	-0.7	-0.9
Net income after tax (€)	**H+M+N**		**6.6**	**6.4**	**6.3**	**6.1**	**5.9**	**5.7**	**5.6**	**5.3**	**5.1**	**5.0**	**4.7**	**4.4**	**4.2**	**3.9**	**3.6**
Net Present Value Net Income (€)		33.6	5.7	4.9	4.1	3.5	2.9	2.5	2.1	1.7	1.5	1.2	1	0.8	0.7	0.6	0.4
Discounted energy produce		980.2	145.8	126.7	110.2	95.8	83.3	72.5	63	54.8	47.6	41.4	36	31.3	27.2	23.7	20.6

Total investment (€)	362.5
Project interest rate	6.0%
Investment eligible for EIA (€)	362.5
Energy Investment Deduction (€)	150.4
NCW(EIA) (€)	36.2
Share loan (€)	253.8
Share of equity (€)	72.5

Table B 7 Cash flow for 1 ha solar PV according to the ECN calculator (in 1000 €).

Pos. values=beneficial to the producer		Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Investment (€)		-725															
	Electricity Revenue (MWh)			450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
A	Operational Cost (€)			-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5
B	Fuel Cost (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Primary fuel savings (ton of m³)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	Primary fuel savings (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	Electricity market value (€)			67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	33.8
	CHP vol equivalent heat value (m³)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	CHP heat value (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	Total income (€)	C+D+E		67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5
G	Total cost (€)	A+B		-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5
H	**Gross income (€)**	**F+G**		**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**	**58.1**
J	Depreciation (€)			-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3	-48.3
K	Interest (€)			`-25.4	-24.2	-23	-21.7	-20.3	-18.9	-17.4	-15.8	-14.1	-12.4	-10.6	-8.7	-6.7	-4.5	-2.3
L	Redemption (€)			-23.5	-24.7	-25.9	-27.2	-28.6	-30	-31.5	-33.1	-34.8	-36.5	-38.3	-40.2	-42.2	-44.4	-46.6
M	Total loan charges (€)	K+L		-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9	-48.9
	Taxable income (€)	H+J+K		-15.7	-14.5	-13.3	-12	-10.6	-9.2	-7.7	-6.1	-4.4	-2.7	0.9	1	3.1	5.2	7.4
N	Tax amount (€)			4	3.7	3.4	3	2.7	2.3	2	1.6	1.1	0.7	0.2	-0.3	-0.8	-1.3	-1.9
	Net income after tax (€)	**H+M+N**		**13.1**	**12.8**	**12.5**	**12.2**	**11.8**	**11.5**	**11.1**	**10.7**	**10.3**	**9.8**	**9.4**	**8.9**	**8.4**	**7.8**	**7.3**
	Net Present Value Net Income (€)		67.3	11.4	9.7	8.2	7	5.9	5	4.2	3.5	2.9	2.4	2	1.7	1.4	1.1	0.9
	Discounted energy produce		1960	291.5	253.5	220.4	191.7	166.7	145	126	110	95.3	82.9	72.1	62.7	54.5	47.4	41.2

Total investment (€)	725
Project interest rate	6.0%
Investment eligible for EIA (€)	725
Energy Investment Deduction (€)	300.9
NCW(EIA) (€)	72.4
Share loan (€)	507.6
Share of equity (€)	145

Table B 8 Cash flow for 2 ha solar PV according to the ECN calculator (in 1000 €).

Pos. values=beneficial to the producer		Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Investment (€)		-1450															
	Electricity Revenue (MWh)			900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
A	Operational Cost (€)			-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9
B	Fuel Cost (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Primary fuel savings (ton of m³)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	Primary fuel savings (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	Electricity market value (€)			135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
	CHP vol equivalent heat value (m³)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	CHP heat value (€)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	Total income (€)	C+D+E		135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
G	Total cost (€)	A+B		-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9	-18.9
H	**Gross income (€)**	**F+G**		**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**	**116.1**
J	Depreciation (€)			-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7	-96.7
K	Interest (€)			-50.8	-48.4	-46	-43.3	-40.6	-37.8	-34.8	-31.6	-28.3	-24.8	-21.2	-17.3	-13.3	-9.1	-4.7
L	Redemption (€)			-47	-49.4	-51.9	-54.5	-57.2	-60	-63	-66.2	-69.5	-73	-76.6	-80.5	-84.5	-88.7	-93.2
M	Total loan charges (€)	K+L		-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8	-97.8
	Taxable income (€)	H+J+K		-31.3	-29	-26.5	-24	-21.2	-18.3	-15.3	-12.2	-8.9	-5.4	-1.7	2.1	6.1	10.3	14.8
N	Tax amount (€)			8	7.4	6.8	6.1	5.4	4.7	3.9	3.1	2.3	1.4	0.4	-0.5	-1.6	-2.6	-3.8
	Net income after tax (€)	**H+M+N**		**26.3**	**25.7**	**25.1**	**24.4**	**23.7**	**23**	**22.2**	**21.4**	**20.6**	**19.7**	**18.7**	**17.8**	**16.7**	**15.7**	**14.5**
	Net Present Value Net Income (€)		134.5	22.9	19.4	16.5	13.9	11.8	9.9	8.3	7	5.8	4.9	4	3.3	2.7	2.2	1.8
	Discounted energy produce		3921	583	507	440.9	383.4	333.4	289.9	252.1	219.2	190.6	165.7	144.1	125.3	109	94.8	82.4

Total investment (€)	1450
Project interest rate	6.0%
Investment eligible for EIA (€)	1450
Energy Investment Deduction (€)	601.8
NCW(EIA) (€)	144.8
Share loan (€)	1015.2
Share of equity (€)	290

Table B 9 Cash flow for 3 ha solar PV according to the ECN calculator (in 1000 €).

Pos. values=beneficial to the producer	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Investment (€)		-2175															
Electricity Revenue (MWh)			1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
A	Operational Cost (€)		-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4
B	Fuel Cost (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Primary fuel savings (ton of m³)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	Primary fuel savings (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	Electricity market value (€)		202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5
	CHP vol equivalent heat value (m³)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	CHP heat value (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	Total income (€) C+D+E		202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5
G	Total cost (€) A+B		-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4	-28.4
H	**Gross income (€) F+G**		**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**	**174.2**
J	Depreciation (€)		-145	-145	-145	-145	-145	-145	-145	-145	-145	-145	-145	-145	-145	-145	-145
K	Interest (€)		-76.1	-72.6	-68.9	-65	-60.9	-56.6	-52.1	-47.4	-42.4	-37.2	-31.8	-26	-20	-13.6	-7
L	Redemption (€)		-70.6	-7401	-77.8	-81.7	-85.8	-90	-94.6	-99.3	-104.3	-109.5	-115	-120.7	-126.7	-133.1	-139.7
M	Total loan charges (€) K+L		-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7	-146.7
	Taxable income (€) H+J+K		-47	-43.5	-39.8	-35.9	-31.8	-27.5	-23	-18.3	-13.3	-8.1	-2.6	3.1	9.2	15.5	22.2
N	Tax amount (€)		12	11.1	10.1	9.1	8.1	7	5.9	4.7	3.4	2.1	0.7	-0.8	-2.3	-4	-5.7
	Net income after tax (€) H+M+N		**39.4**	**38.5**	**37.6**	**36.6**	**35.5**	**34.4**	**33.3**	**32.1**	**30.8**	**29.5**	**28.1**	**26.6**	**25.1**	**23.5**	**21.8**
	Net Present Value Net Income (€)	201.8	34.3	29.1	24.7	20.9	17.7	14.9	12.5	10.5	8.8	7.3	6	5	4.1	3.3	2.7
	Discounted energy produce	5881	874.6	760.5	661.3	575	500	434.8	378.1	328.8	285.9	248.6	216.2	188	163.5	142.1	123.6

Total investment (€)	2175
Project interest rate	6.0%
Investment eligible for EIA (€)	2175
Energy Investment Deduction (€)	902.6
NCW(EIA) (€)	217.2
Share loan (€)	1522.8
Share of equity (€)	435