ACT project 1618 - Movable solar fields for arable farming

Technical and financial overview on combining solar panels with growing low revenue crops focused on the coming pilot project in Goeree-Overflakkee

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Preface

Since March 2016 the Academic Consultancy Training group 1618 (referred as ACT group hereinafter) followed the ACT course. This is a course that every student on Wageningen University once has to follow. The purpose of this course is to consult a company of institution about a problem that they are facing. The commissioners of this project is Marcel van der Voort. He is a researcher at the applied plant research institute and working on the ACCRES department. ACCRES is the application centre for renewable energy in the Netherlands. Together with Wim Steverink and Albert Jan Olijve they have an idea which they want to have worked out. Wim Steverink has his own construction company where he builds specific machineries. Albert Jan Olijve is the co-owner of 'Van tafel naar kavel'. A company which helps farmers to get ideas worked out on the field.

The academic advice presented in this paper concerned the combination of growing low revenue crops and the collection of solar energy. This topic about movable solar panels was quite new to all group members and for this more challenging. The group is composed by five master students of Wageningen University that chose to apply for this project among the other projects offered by the university. Stijn Bomers, Adrie Meeuwesen and Bernard Russchen were doing the Master Biosystems Engineering. Monica Salvioli and Tjeerd Wartena were doing the Master Management, Economics and Consumer Studies. Due to these two different studies there was a diversification in approaches, which is the additional value of this project.

The most challenging point for the project has been the sourcing for data and available literature. Due to the different disciplines within the group there was already some knowledge available. This available knowledge the team already had were the financial and solar energy calculations. Also the knowledge about crop growth was already available. This background knowledge is used and further improved during the project. There was also some literature available from fixed solar panel systems. This information is sometimes used to make assumptions for the movable solar panel system. The focus of this paper has been narrowed down to the Netherlands and the wheat crop cultivation.

Special thanks must go to the team coach Ronald Osinga and the assigned expert Bert van 't Ooster for their support along the work process, and the involved parties during the stakeholder workshop. These involved parties were Marcel van der Voort from ACRRES, Wim Steverink, who is responsible for the construction of the movable solar panels, and finally Albert-Jan Olijve, who is working for the Skylark foundation.

Summary

This report is the result of the ACT group 1618. During this project the team looked for possibilities to implement a movable solar panel system in combination with growing a low revenue crop. The report provides advice on design of movable systems, on the feasibility of the idea, and its influence from and on the society. The report includes the main bottlenecks associated with implementation of the idea.

To explore the potential of such a movable solar panel system within a common Dutch arable farm, the team first looked at available literature from previous research and existing technologies, constructions and patents. Next to that, the solar irradiation and crop growth underneath the panels were calculated with the help of models in order to calculate the financial revenue and profitability of the system. The solar irradiation was equal to 3304 MJ m^{-2} $year^{-1}$ and the crop growth reduction beneath solar panels is around 50% according to the model and available literature.

Also the legislation and aspects of social acceptability that have to dealt with regarding the topics within this project were analysed. This information was used among others as input for the Engineering Design process from Cross (Cross, 2008), that was used to come up with four different system designs. These designs are focused on 1) profit optimisation of the whole system, 2) lowest possible cost for installation, 3) reducing the environmental impact and 4) an ideal future vision. Subsequently the designs were scored on different aspects by the three Master Biosystems Engineering students. These subjective ranking resulted in one overall best design: the profit optimisation. The designs which were focussed on the environmental impact optimisation and the lowest possible cost for installation scored low on the technical aspect compared to the other two designs. The Future ideal system scored best on the Technical aspect because the system is most advanced, but the system is still too expensive which leads to a low scoring on the economic aspect. Therefore the profit optimisation is the most optimal design.

Financial calculations were applied on the profit optimisation design. This information is combined with the different applicable Business Models, to look at the economic feasibility and possibilities of the implementation. The average total costs were €0.15/kWh. This average total costs is most influenced by the inflation during the lifetime.

In the end, the main important bottlenecks were listed to highlight the topics that need more attention in further research. Those bottlenecks were focussed on the design which could lead to a long installation time or a too complicated design. Another possible bottleneck is the ripening of wheat beneath the solar panels which is not investigated yet. The connection to the grid which is €50,000 can also become a bottleneck for the system. Finally the social acceptability can become a bottleneck when the society is not willing to accept these systems in their environment.

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1 Introduction

Global warming is a hot topic nowadays. The population produces more CO_2 and as a result of that the temperature on earth will rise. The main reason for the increase in CO_2 production is the usage of fossil fuels. The CO_2 is stored the last centuries and escapes by burning the fuels in a relative short time. Promising solutions for the reduction of global warming is the production of sustainable energy and effective use of the nature sources. This project focus on the combination of both.

Farmers in the Netherlands are facing a crop rotation problem. Farmers used to include a wheat crop in their crop rotation plan, but less farmers include wheat despite of the second highest wheat yield per hectare worldwide (CBS, 2016). The reasons for this is the increasing labour cost of the Netherlands which is listed in the top 10 European countries and the land costs where the Netherlands has the highest price per hectare (CIBUS, 2010).

However, it is in another way beneficial to have a year of growing wheat on the field, because wheat is an extensive crop. Growing wheat gives the soil a less intensive year and therefore some rest. Within that year the soil is able to recover after a three or four years of intensive use and is maintained in a good condition to give high yields during the whole crop rotation.

To increase the profitability of growing wheat, the initiators of this project intended to combine a solar panel system on the same field at the same time. Next to the benefits of growing the wheat and the revenues from it, solar energy will be collected to be used on the farm or sold to the grid. It is however not sure if this will result in extra revenues, to make the growing wheat producing year profitable.

Another reason for placing solar panels in the field is to generate sustainable energy which is obtained can be used within the own farm system. Obtaining your own energy can be financially attractive and supports reduction of the global warming. Nowadays, fossil fuel prices are rising because the stock is decreasing rapidly. However, the total worldwide energy demand will still increase in the period 2004-2030 with 57% (Hall, 2008). Part of the goal to minimize global warming is to decrease the emission of CO2 in the world. One of the promising solutions for the mentioned problems is collecting energy from solar panels. Nowadays there are entrepreneurs who have fields of solar panels, to produce sustainable energy, especially in German. If such a common fixed system is built on a certain location, it is not possible anymore to grow crops on that field to produce feed. In that way, an increase in sustainable energy production will lead to a decrease in food producing area, while 800 million people worldwide suffer from hunger (WFP, 2016).

This discussion is going on and as a result, fixed solar systems gets more and more social resistance.

To design a system wherein the profitability of the farmers will increase by producing sustainable solar energy next to crop production, a new concept is found which takes the opinion of the society into account. Fortunately this project is not the first one which dives into this topic. Some comparable experiments are already done. These systems are so called 'agrivoltaic systems' (Dinesh and Pearce, 2016; Dupraz et al., 2011; Marrou et al., 2013). They all stated that the combination of agricultural production and photovoltaic systems can be financial effective. According to (Dinesh and Pearce, 2016), the combination of both the electric and crop production can create over 30% increase in economic value in comparison with a normal agricultural system. In the research of Marrou et al. (2013), the panels were installed on a frame at a height of 4 meter above ground level, so tractors were able to maintain the crop during the season. With these examples the implementation of such a system with movable solar panels is worth evaluating. The main objective of this project is to explore the potential of a combined system with wheat growing and solar energy production. With the collected information different systems will be designed and evaluated. After all for the end designs, economical calculations are done and three general business models will be discussed.

Important questions have to be answered to gain more knowledge about this concept. The research questions of this project therefore are:

- How can a movable solar system within a low revenue crop be designed technically feasible?
- How can be dealt with social resistance and (local) legislation according to the movable solar panel system on a Dutch arable farm?
- Is the design concept of a movable solar system combined with growing a low revenue crop financially feasible?
- What are the possible business models that can be applied on such a system and what are the strengths and weaknesses of each of them?

To answer these questions, the main challenges to overcome are:

- Get the optimal business model for selling/using the solar energy
- Design a robust system to use the panels in the field
- Make the system easily movable without harming the crop
- Minimizing the crop losses

This project focus on a first look inside the possibilities. The presented alternatives and ideas are not detailed worked out, but general concepts that could be implemented. The calculations on the connections and contracts with the grid are based on assumptions. These calculations could vary within different locations in the country. For the wheat yield model, available literature is used and based on that assumptions for the model are made. Therefore the outcome of the model is an approximation of the yield.

For this project four technical alternatives will be designed with financial calculations and analysis. The design process and the financial calculations takes into account legislation. In the end feasible designs are presented with a technical and financial analysis and business models for exploitation of these designs.

2 Background information

Before starting with the Design method, first some literature research was executed. This literature will be used in the different parts of the report and will be used as information. The literature consists for example of information about solar panels, construction, security and folding systems. After the literature research, the social acceptability, the different models, the economic aspects and the Reflective Interactive Design method will be executed.

2.1 Solar Panels

Different kinds of solar panels are available, the mono- and polycrystalline solar panels and the thin-film solar panels.

2.1.1 Monocrystalline and polycrystalline solar panels

The production of monocrystalline silicon photovoltaic cells is costly and requires more energy compared to the production of polycrystalline silicon photovoltaic cells. For the production of the monocrystalline solar panels thin discs are cut from a cylinder of pure clean silicon (Verhelst, 2012). Polycrystalline solar panels contain not one pure clear disc of silicon, but are crystalline grains which are melted together. Those crystalline grains lead to a lower efficiency, which is described in the next paragraph.

Monocrystalline silicon photovoltaic cells have got the highest efficiency compared to other kinds of solar panels. Those photovoltaic cells could reach an efficiency which varies around 22.9% (Green et al., 2015). However, the efficiency of complete assembled solar panels in practice is approximately between 15% and 17% (Tyagi et al., 2013). This upper value of the efficiency is corresponding with the highest possible efficiency indicated in Figure 2-1. The lower bound of the range is one percent lower than what was stated before, which is caused by the improved of solar panels while that research is done in 2012.

The efficiency of polycrystalline silicon photovoltaic cells vary between approximately 11.5% and 14% as can be seen in Figure 2-1.

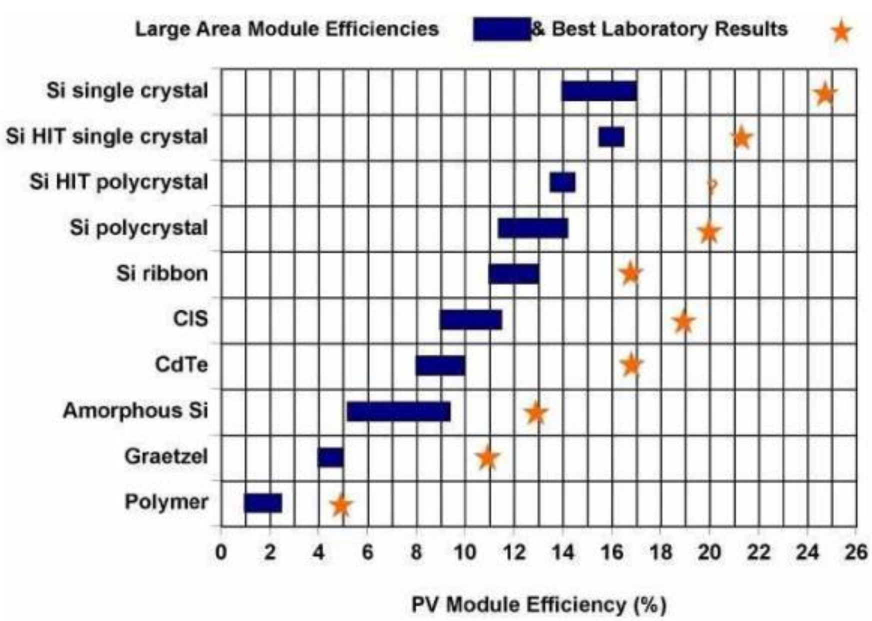


Figure 2-1 Efficiencies of several PV-modules (Verhelst, 2012)

The efficiency of solar panels will decrease during the lifetime, but within a short period the efficiency could also decrease by increasing temperature. As indicated in Table 2-1, the efficiency of monocrystalline solar panels changes with -0.48 %/°C. The efficiency of polycrystalline solar panels will change with -0.45 %/°C (Caes, 2012).

Table 2-1 An overview with technical characteristics of four different kind of solar panels (Caes, 2012)

	Monocrystalline	Polycrystalline	Microcrystalline	Monomorphic
Manufacturer	Suntech	Yingli	Sharp	Sanyo
Type	STP180S-24/Ac	YL 180 P-23b	NA-F121 (G5)	HIP-230HDE1
P_{max}	180	180	121	230
Module efficiency [%]	14.1	13.9	8.5	16.6
Temp. coeff. of P_{max} [%/°C]	-0.48	-0.45	-0.24	-0.3
Size [m*m]	0.808*1.580	0.990*1.1310	1.009*1.409	0.861*1.610
Surface [m^2]	1.277	1.297	1.422	1.386
Surface/kWp [m^2/kWp]	7.09	7.2	11.74	6.03
NOCT [°C]	45	46	44	45
Mass [kg]	15.5	15.8	19	16.5
Number of cells in series	72	48	180	x

Manufacturers

ReneSola produces three different kinds of polycrystalline solar panels which have got a maximum power which varies from 250 W till 260 W. The efficiency of these three solar panels varies between 15.4% and 16.0% according to their brochure (ReneSolar, 2014). The temperature coefficient of the open-circuit voltage (V_{oc}) is -0.22 %/°C for these polycrystalline solar panels, which means that the efficiency of the solar panel decreases with 0.22% when the temperature increases with one percent. The Dutch test centre of the Power Leaf Group BV located in Ede measured 0.8% more power than promised by the manufacturer (Power Leaf Group BV, 2015a).

Another manufacturer of polycrystalline solar panels is the Neo Solar Power Corporation. This firm has got 6 types of panels with a varying maximum power from 250 W till 275 W. These panels have got efficiencies from 15.4% till 16.9% as stated in their brochure (Neo Solar Power, 2014). The temperature coefficient of the V_{oc} of these panels is equal to -0.31 %/°C. These panels were also tested by the Dutch test centre in Ede, where they measured 1.0% more Power than the manufacturer mentioned Power Leaf Group BV (2015c).

2.1.2 Thin-Film solar panels

As the name of this solar panel type already indicated, the thin-film solar panel consists of a thin layer of photovoltaic material. Due to this thin layer this panel can be placed on a flexible substrate which makes the solar panel less fragile (Fernández et al., 2015). The efficiency of those panels is comparable with the efficiency of the polycrystalline silicon photovoltaic cells, which is 12.6% (Wang et al., 2014). Placing this thin photovoltaic film on a transparent substrate makes it possible to produce an almost transparent solar panel. According to Janczarek et al. (2015) the transparency is more than 90%. Those thin films consist of Titanium dioxide and, if appropriate mixed with Copper. The efficiency of the thin film with a layer of Titanium dioxide is slightly higher than 6%, as stated in Zhi et al. (2015) and Wang et al. (2015)

Manufacturers

Solar Frontier, a manufacturer of thin film solar panels, promised an efficiency up to 13.8% (Solar Frontier, 2014). The temperature coefficient of these panels is equal to a decrease of 0.30 %/°C. These solar panels were tested by the Dutch test centre of Power Leaf Group BV, and the power they measured in 2015 was 7.3% higher than promised by the manufacturer (Power Leaf Group BV, 2015b).

2.1.3 Liquid Solar Array solar panels

Sunengy is the first company which is developing floating solar systems. These systems use the technology of Concentrator Photovoltaic. This construction consists of a lens which concentrates the light into a small spot where some solar cells are placed, see Figure 2-2. Therefore, the construction is much lighter compared to traditional solar cells. Another advantage of these floating solar cells is the possibility to track the sun during the day, such as a sunflower.

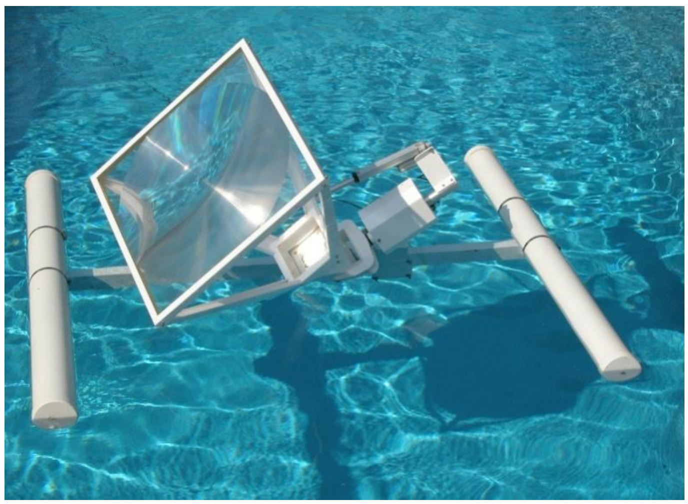


Figure 2-2 Liquid Solar Array solar panel system {Sunengy, 2016 #60}

This technology is used in a pilot project in India where the panels are placed on a hydropower storage dam (Sunengy, 2016). A disadvantage of these systems is the high price of the Concentrated Photovoltaic technology.

2.2 Movable

The system has to be a *movable* solar system. For this project, the system has to be movable in different kind of aspects. In this chapter these different approaches are explained and useful literature is presented.

2.2.1 Movable within a field

In the last years spraying and fertilizing the wheat is less often necessary due to improved breeding technologies (Jonkheer, 2011). In some experiments spraying is not done at all (Zeeuwse Vlegel, 2016). However, common arable farmers are used to a spraying scheme where farmers have to be able to drive across the field with their machines. Therefore, there is the need for the panel system to move within or move out of the field, to give the farmers the possibility to maintain their crop with machinery.

2.2.2 Movable to another field

Due to crop rotation the system will be temporarily used in the same field. The system has to be able to move to another field in a new season or to a storage place if not needed on the field. Because of that, the system has to be flexible to be compressed to relative easy movable units. It can be convenient and extensible to have a system that works with standardized units like shipping containers or pallets.

2.2.3 Legislation

If the system has to be transported, it needs to have the possibility to access the road. Therefore, the system needs to be safe, robust and can handle relative high speeds. The transportation system will be designed within the Dutch legislation 'Regeling voertuigen' (valid from 02-03-2016 till present), Article 5.14 (Minister of TPWWM, 2016).

According to the Dutch legislation, a trailer may not exceed the maximum sizes. These are:

- a length of 12 m
- a width of 2.55 m
- and a height of 4 m

The load on one specific wheel of trailers with air tires may not exceed the maximum of 5000 kg. If the trailer has massive tires, this value is 120 kg per centimetre of the wide of the contact surface with the ground.

Trailers with a total load of more than 3500 kg, needs to have a good working braking system. Trailers may not have sharp elements that can hurt people in case of a crash.

Next to the two mentioned requirements of the system, when it comes to movability one can think of movability in the design of the solar system.

2.2.4 Movable according to the sun

Fixed solar systems are depending on the application, mostly installed in a way that they will catch as much as possible sunlight. This optimal orientation to the sun changes during seasons and days. Nowadays most systems are installed in the average most optimal way. The panels are facing the south and placed under an angle of 20-25°. If the panel itself is movable within the system, one can always yield the highest irradiation with help of a model (Guo et al., 2010; Wang and Song, 2012; Zhang, 2012). The benefit of a sun tracking system can be till a 30% higher energy collection against a consumed energy amount for the total tracking system of 1.8% of the maximised energy (Mousazadeh et al., 2011). The same technique is already commercially available at different companies i.e. (LINAK, 2016).

2.3 Construction

All over the world there are a lot of different types of constructions used. The construction of the movable solar panel system, that has to be designed, must be strong and light in weight. Therefore, it is important to choose the right framework and the right materials. An example of a construction method that is used a lot is the truss structure. The truss structure is applicable in many ways, there are for example V-trusses, N-trusses, roof trusses & K-trusses, as graphically shown also in Figure 2-3 (Krenk and Høgsberg, 2013). In a truss structure, each bar is connected at a joint, where all the forces are acting on the frame. In this way, the structure is open and not many materials are needed. This leads to a light weight construction, which is desirable for the movable solar panel system. The truss structure has been designed hundreds of years ago. Some examples where the truss structures are still now applied are: bridges, radio masts, towers, center pivots and roof tops.

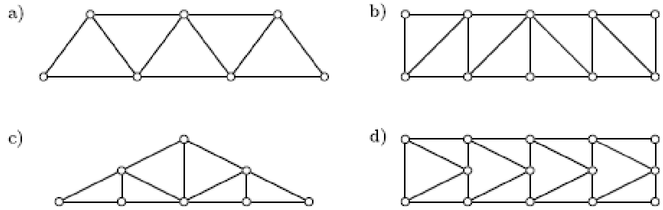


Figure 2-3 Example of trusses: a) V-truss, b) N-truss, c) Roof truss, d) K-truss

To have a structure that is both strong and light in weight, it is important to choose the right kind of material. The price of the material also has to be taken into account when choosing the type of material. Two types of materia**l**s that are used frequently are (stainless) steel and aluminium. The properties of stainless steel are, compared to standard steel, higher corrosion resistance, higher strength and hardness**,** and lower maintenance (Aalco Metals Ltd, 2013). The properties of aluminium are that it is light, a third of the density of steel. The strength of aluminium compared to steel is the same. So it is recommended to use aluminium instead of steel. Its corrosion resistance is also high, so rust won't be a problem (Aluminiumdesign.net, 2016). Besides the aluminium is sustainable because it is fully recyclable and has therefore a lower CO_2 footprint.

To withstand possible strong winds, it is important that the system doesn't catch a lot of wind. This can be done by giving the system a nice aerodynamic shape to let the wind flows easily across the panel system. Some good examples of shapes that are aerodynamic are the wing of an airplane and the solar race car. These are designed to have very little air resistance. The formula to calculate the drag force, equation [1], was invented by Lord Rayleigh (Batchelor, 1967):

$$F_D = \frac{1}{2}\rho v^2 C_D A \qquad [1]$$

Where:

F_D	Force on the object during movement [N]
ρ	Density of the medium where it is traveling [kg/m^3]
v	Relative speed of the object relative to the medium [m/s]
C_D	Drag coefficient of the object [-]
A	Cross sectional area of the object [m^2]

One of the important factors when designing the movable solar panel system is to have a low A, because this is the only parameter which can be influenced in making the design.

2.4 Security

Preventing theft of solar panels is very hard. There are some tools available, but is it not possible to prevent it for 100 percent. The first tool is a crushing nut (SolarNRG, 2011). This tool will be used to secure the PV cells. When a thief wants to disassemble the solar panel, the crushing nut will break down and a round bullet remains, which cannot be removed by a hand tools. Only a grinder can be used then, which will discourage the thieves because it will make a lot of noise. The costs for using crushing nuts will be around €3.71 per panel, when four nuts are used per panel (Jeveka, 2016). It is also possible to insert a small ball into the screw when the PV cells are installed with hex key screws (see Figure 2-4). These can also only be removed by use of a grinder.

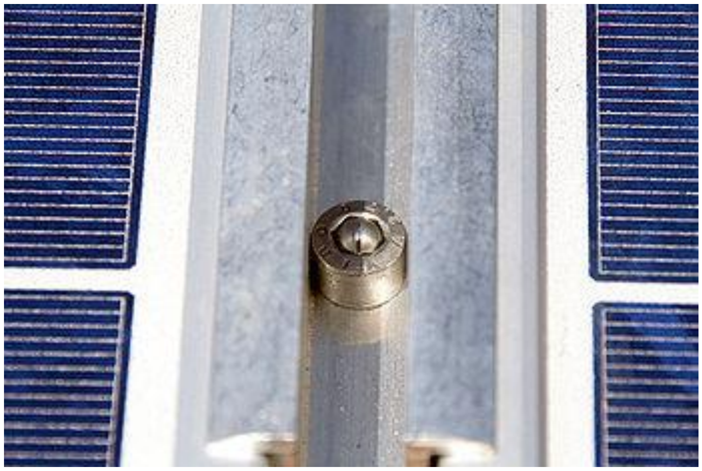


Figure 2-4 Theft-proof hex key screw with ball inserted (Energypedia.info, 2016)

Another way to prevent theft is by using a mechanical lock called SolarLock from the firm Akraboot, which locks the solar panels to the construction frame (see Figure 2-5) (Akraboot, 2016). The SolarLock will be mounted underneath the PV cells and to the construction frame. When the PV cells are placed, a wire will be placed through the SolarLock. In this way the PV cells are secured. The mechanical lock can also be combined with an alarm kit. This alarm kit can be mounted on the wire. When the wire is interrupted (like cutting it to remove the solar panels), automatically the system calls someone who has the task to personally control the site. While the SolarLock prevents solar panels to be stolen, it also secures the PV cells better in case of bad weather conditions like hard wind. The price of the SolarLock system is strongly depending on the amount of solar panels that is has to lock. The price per panel (with a message from a GSM Pocket) is €44 for a system with 20 panels and €12 for a system with 100 panels (Ecotiv, 2016).

Figure 2-5 The protection system of Akraboot

The last option is mainly used for big fixed solar panel fields. This option consists of a big fence around the solar panel system. By using high fences, it is hard to enter the solar panel fields. The fence is often used in combination with another prevention system like: video cameras, electric fence, radar detection and sensor cables (Vlems, 2015). There is also a system available which works with thermal cameras, that light up the field when it detects someone entering the area (Axis Communications, 2014). The price of a camera for security will cost around €1900 (Spywebshop, 2016).

2.5 Inverters

To convert the output of a photovoltaic (PV) solar panel, which is a direct current (DC), into a utility frequency alternating current (AC) of the grid, a PV inverter is needed. There are mainly three different types of inverter on the market: Centralized Inverters (String Inverters), Micro inverters and the Power optimizers (EnergySage, 2016).

Centralized Inverters are the ones that are used the most. When using a Centralized Inverter (Figure 2-6), a couple of PV cells are connected to one inverter. Because you do not need a lot of inverters, the financial investment is low. When using Micro Inverters (Figure 2-7), no central inverter is needed anymore. Instead, every PV cell has its own small inverter. The advantage is that the efficiency of every PV cell rises, which is useful when some PV cells have to deal with shadings. But this makes the solar panels also more expensive. Besides, these inverters are more sensitive to damage because they are exposed to higher temperatures. It is also hard to replace an inverter when one is broken down. The last type of inverter is the Power optimizer (Figure 2-8). The similarity with the micro inverters is that the power optimizers are also placed on every solar panel. In the Power Optimizer the DC of the solar panel will be converted first into another type of DC. However, the conversion from DC to AC takes places in the centralized inverter. The power optimizer has some of the advantages of the micro inverter, but is less expensive (Zonnefabriek, 2016).

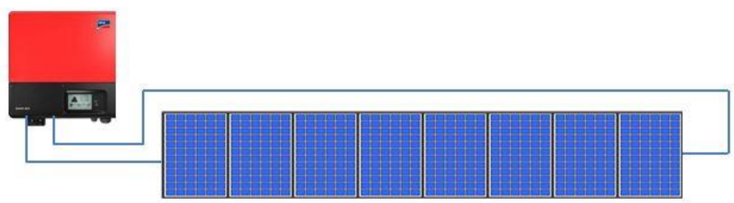


Figure 2-6 Example of a Centralized inverter

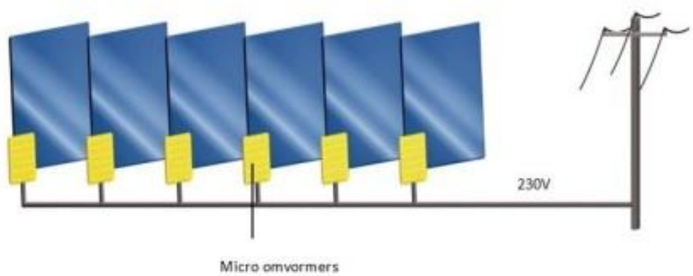


Figure 2-7 Example of a system with Micro Inverters

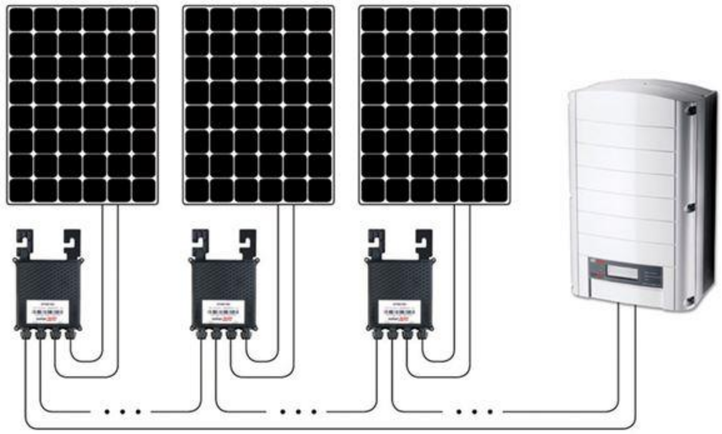


Figure 2-8 Example of a Power Optimizer system

Furthermore, there are eight points which have to take into consideration when choosing an inverter (Zonnepanelen.net, 2016):

Needed power of inverter

The needed power of the inverter is dependent of the size of the solar panel system and the number of inverter want to install. When choosing an inverter, a little over estimation can be made because the power is defined for ideal situations (25°C). This hardly ever the case in the Netherlands, so therefore it is possible to choose a smaller inverter. Also when the solar panels are not perfectly placed to the south, smaller inverters are applicable.

Use of transformer

Inverters are for sale with and without a transformer. The inverters without a transformer have a less loss of energy, so a higher efficiency. There are also some solar panels available who has to be installed to an inverter with a transformer because otherwise accelerated degeneration takes place, which has a negative influence on the efficiency.

Dealing with shade?

Shade is a very important factor for the efficiency of the solar panel system. To deal with shade, it is commonly recommended to use the previously described Power Optimizers or the Micro Inverters.

What kind of main connection?

The size of the main connection is also important, in the Netherlands the current of a circuit has to be lower with a 1.6 factor compared to the main connection.

Noise of inverter

Inverters are also producing some noise. The noise is dependent of the needed cooling of the inverter. The inverter has to be cooled down more when it produces more electricity.

Monitoring yield

Monitoring the yield is important to check if the system still works properly or if some changes have to be made. Monitoring the yield via the inverter is possible in different ways. Reading out the yield is possible via for example Bluetooth, Ethernet, Wi-Fi, USB or an Embedded Web Server.

Warranty

When buying an inverter, the warranty is normally for a period of 5 years. Often it is possible to buy an additional warranty of 5 years for possible break downs. So choosing an inverter it is important to determine what the change is of a possible break down. When the changes are low, it is not wise to buy an additional warranty because it will only cost money.

Brand

The brand of an inverter can also be important. Especially not all brands from China have a good reputation in building inverter. They are cheap but the chances of them going broke are also higher. When you want a reliable inverter, it is recommended to choose for an inverter which is made in Europe.

2.5.1 Connection to the grid

To receive electricity from the grid, a grid connection is needed. The size of the grid connection is depending on the amount of energy that will be consumed by a firm of household. Therefore, a distinction is made between small consumption and bulk consumption, where the border is at a connection of 3 x 80 Ampere (DeEnergieGids.nl, 2012). Small consumption consumers are better protected than bulk consumers. This is done by the special permit ACM (Autoriteit Consument & Markt: Authority Consumer and Market), which is needed for an energy supplier to deliver energy to small consumption consumers. In this permit there is also a distinction between consumers and business customers, because of the termination fee (ConsuWijzer, 2016). It is important to choose the right connection, because the prices of the connection are depending on the size. A larger connection has a higher price than a smaller connection. Besides the grid connection itself, there are also monthly costs like transport costs (Liander, 2015).

The connection costs for a bulk consumption connection is very depending on the size of the connection. The smallest bulk connection costs around €2,800 (>3 x 80 A till 3 x 125 A) and the largest costs around €240,000 (>3,000 kVA till 10,000 kVA), where the yearly costs vary between €64 and €6,956. To make a connection, often it is necessary to make a connection between the grid and the grid connection. At Stedin, the grid supplier at Goeree-Overflakkee, the first 25 meters are included in the connection costs. When you exceed the 25 meter, you have to pay extra money, varying from €41.95 till €140.83 per meter (Stedin.net, 2015). So for determining the size of the movable solar panel system it is important to choose the right connection when the costs have to be low. Still the location is a very important variable.

2.6 Compress Size

To make the system more compact, elements have to move in one way or another. This can be done in a lot of different ways, like manually, hydraulic, mechanical, electric, etc. In this chapter some working examples with different approaches are shown.

Extending

In the EcoSphere PowerCube project (Ecosphere Technologies, 2016), extendable systems are used to increase the solar panel surface of the container that is used, as can be seen in Figure 2-9. These panels are able to move out of the relative small size containers by using a sliding rail. The contact area with the sun can be increased by using this system, but the different panels have to be placed underneath each other in order to slide in and out. Therefore, the thickness of the total package is quiet big. An advantage of the sliding technic is that the risk of harming the panels is minimalised.

Figure 2-9 Ecosphere PowerCube

Folding

The Pearsalagroup (Pearsala Group Co, 2012) uses a standard trailer to transport a foldable solar panel system (Figure 2-10). Next to a sliding technic to increase the contact area, they fold the grouped panels mechanically towards each other to install the panels on the frame in the best suitable way. It is not required to store the panels facing to the same side as they are when used.

Figure 2-10 Solar Panel system of Pearsalagroup

Luxaflex

Using the Luxaflex principle is also possible as a method to decrease the storage space, like seen by sun shades with loose wooden bars next to each other with some space in between, shown in Figure 2-11. The panels need axes and can be turned easily to decrease storage size. This type of system can be combined with the sliding technic like described earlier. Like a Luxaflex, the elements can be stored directly next to each other after turned in the parallel position.

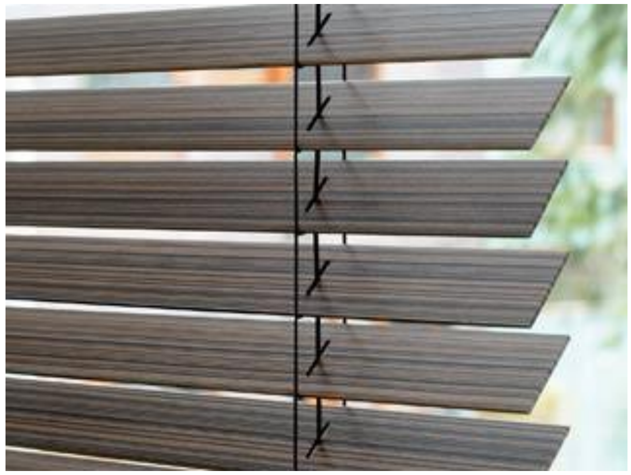


Figure 2-11 Luxaflex in front of a window {Luxaflex, 2016 #61}

A possible application of the turning system is the ability to move the panels in order to control the sun irradiance on the crop. Solar panels efficiency is decreasing with increasing panel temperature. Therefore, a controller can be designed to decide whether it is more efficient to face the panels perpendicular to the irradiation angle of the sun, or to face the panels parallel to the sun in order to give the crop access to the full sunlight.

3 Problem description

In the following chapter the current problem and the desired future system will be described. The current problems are described in chapter 3.1. The current system is further described in chapter 3.2. Finally the future ideal system is described in chapter 3.3 with the corresponding objectives.

3.1 Current problems

The currently used cultivation system faces problems which prevents the application of solar panels in fields. This main problem is divided into three sub-problems.

Expensive solar panels

Producing energy by solar panels is still an expensive technique compared to the use of fossil fuels (SPITF, 2016). At the other hand, for fossil fuels there are additional costs, which are caused by the climate change. The international Monetary Fund (IMF) calculated an amount of 4,650 billion Euros of additional costs which are not paid by the consumer of fossil fuels (Coady, 2015). If these additional costs are also taken into account, the production of solar energy could probably become cheaper than fossil fuels. But these differences in health costs are in this case not considered. The difference in price for the solar panel systems is caused by the higher investment costs of solar panels and the lower energy producing efficiency compared to fossil fuel. For this reason, subsidy is often needed for solar energy to compete with fossil fuels (Gordon, 2015). Although, the efficiency of solar panels is still increasing while the production costs decrease (Mearian, 2015). Due to these phenomena the production costs of solar energy will decrease.

Another costly effect could be the space which is required to collect solar energy with fixed solar panel systems in open fields. Therefore, placing solar panels on existing roofs is nowadays regularly done which reduces this cost effect and makes the roof more useful. A disadvantage of fixed solar panel systems is the usage of arable land for producing solar energy, instead of cultivating crops. This disadvantage leads to social resistance as described before in the chapter about "Social acceptability".

Low efficiency of solar panels

The efficiency of solar panels, mostly below 20%, is still low. Due to technical improvements these efficiencies are still increasing. At the other hand this efficiency will decrease when the solar panels are getting older. Another important issue which influence the efficiency of the solar panels is the dirtiness, which can reduce the peak power up to 18% (Sulaiman et al., 2011). To prevent a high loss in efficiency the panels have to be cleaned regularly.

Difficult to store electrical energy

Storing the energy is necessary as the solar energy is mostly produced during the day, while the energy consumption is higher during the early morning and evenings. A storage of electrical energy could solve this problem, but this is still one of the most striking (Panzer, 2013). Big batteries are needed to store these forms of energy. Therefore, batteries will be also financial rewarding, while the energy prices will drop when the production is high and vice versa. The production of energy out of fossil energy sources could simply be adapted to the energy consumption. When the energy consumption decreases, the power plants, such as coals plants, can reduce their capacity and vice versa. This adaptation to energy consumption is not possible with solar panels, while the production is depending on the sun. Improvements in energy storing would give solar energy production a high boost.

3.2 System Analysis

In the system analysis, all the different systems that are dealing with the movable solar panel system, will be mentioned and discussed. First of all the sub-systems, elements and the environment will be defined. Also a 3 Circle chart will be made to show the relations between the systems, sub-systems, elements and the environment. These relations will clarify the relation between all the involved parties. First of all the following sub-systems are defined:

- Farm
- Grid
- Crop
- Solar panel system
- Field Labour

The elements of these systems are:

- Solar panels
- Inverter
- Construction
- Cables
- Grid connection
- Plant
- Field

The aspects that have to do with parts of the different (sub-)systems are:

- Social
- Environment
- Economical
- Technology
- Legislation

3.2.1 The need

The movable solar panels are needed to increase the profitability of the land during the cultivation of a low revenue crop. The low revenue crop is needed to give the soil some rest after growing intensive crops like potatoes and sugar beets (DLV Plant, 2013). By placing solar panels on the field, green energy can be produced and delivered to the grid besides growing a crop and having a big influence on the profitability of the crop.

3.2.2 Aspects

The functional environment of the movable solar panel system can be divided in different aspects like shown before. Hereunder the different aspects will be described individually.

Social

The social environment is composed by consumers of green energy, the neighbours and the society who are in direct contact with the system. These people are very important because they have to deal with the system when it is placed in the field. These people can also give their opinion or counteract the project during the permission process. In the end the consumers can also be the buyers of your final 'green' product.

Economic

The profitability of a field with solar panels can be split up in two parts. The first part is the profitability of the crop, which could be partly influenced when placing solar panels on the field. The second part is dealing with harvesting the sun light, which is depending on the system and on the weather conditions. When considering the size of the solar panel system, it is important to take into account the conditions for the delivered electricity settled by the electric company. The fluctuating price during the day is very important, where a negative price of electricity during the day is possible. A negative price will decrease the profitability of the system.

Technical

The technical environment has to deal with the feasibility of the design of the system. Not every design can be translated into a good easy to handle system. Besides they can handle to work on the field and being able to be orientated into the right direction (south) for optimal sun irradiation. Also the limited size of the system which is defined by regulation, influences the design. Finally a wide spread system will need a much stronger frame construction, then a compact system with less panels.

Legislation

Another aspect that influences the movable solar panel system is the legislation, which is determined by the government. This legislation gives the windows where the choices for the design have to fit in. The legislation has influences on the design and implementation of the system. For implementation purposes the following questions needs to be answered: What is the maximum size of the system? Is it possible to place solar panels on a field without changing the land use plan? However the legislation can be influenced/changed by politics.

3.2.3 3 Circle chart

In this chapter a 3 circle chart will be drawn which consist the previous defined elements and sub-systems. The solar panel system is divided into 3 sub-circles which represent the solar panel system itself, the link with the local environment and the link with the national environment called the Netherlands. In Figure 13-1 in paragraph 13.1 the 3 Circle chart is presented.

Solar Panel System

The first circle is about the main goal of the research: the solar panel system. In this circle all the important parts which has to do with the whole system are taken into consideration. As can been seen in Figure 13-1, the construction is a very important issue of the system. For the construction 7 different issues have to be kept in mind which are also mentioned in the literature chapter of this report. The issues are: wind, PV cells, regulations, moving in field, transportation, folding & the inverter. These issues are important when designing the system. Another item of the Solar panel system shown in Figure 13-1 which has a lot of inputs, is the profit. First of all, the owner of the land with the movable solar panel system wants to make money with the system. Therefore, it is important to have high revenues and low costs. The profit of the system is depending on six different inputs, the possible subsidy, the costs of the construction, the amount of electricity produced, the price of the electricity market, the amount of electricity directly used by the owner of the system and finally the revenue from the crop in the field.

Environment

The solar panel system will influence the local environment such as the field, surroundings and the atmosphere. The solar panel sub-system on the field should be able to deal with growing crops, crop maintenance and the unevenness of the ground. The surroundings of the solar panel systems can be trees standing at the edge of the field and houses or barns. These surroundings can cause shade which influences the energy output. The atmosphere, in other words the weather conditions, influences the construction of the solar panels and on the electricity yield. Also the farm and the connection to the grid are important issues, these 2 aspects are the environment in which the solar panel system has to fit. If the farm is not equipped well or the connection is too expensive, the solar panel system would not work properly and the revenues won't be so high as expected.

The Netherlands

The biggest circle is defined as the environment of the solar panel system. The environment for this system is The Netherlands. The system has mainly to deal with the politics and the energy market which are part of the environment. The politicians defines the legislation and regulation, which can be influenced by the regulations from the EU and public opinions.

For the solar panel system is it also possible to work with subsidies to improve the profitability of the system. In that case the government provides a subsidy fund to increase the amount of renewable energy that will be produced. With this political instrument they try to generate more sustainable energy in the coming years. The customers which are part of the society, are an important of the environment. The customers can also be an energy supplier by having solar panels on the roof of their house. In this way they can have an influence on the electricity market. This way of local energy production is small compared to the electricity plants. The solar panel system is really depending on this environment and has no influence on it.

3.3 Future ideal system

In the future ideal system, a group of arable farmers will try to use solar panels simultaneously with growing low revenue crops. With this research some advice will be provided for a pilot project which is going to combine these elements. When it is successful, more applications of the movable solar system could be tested and applied on arable farms. It could be tested to grow different other crops beneath the solar panels. This described desired situation, where the collaboration of growing crops and collecting solar energy is possible, can beneficial to the production of renewable energy.

This positive effect of supporting renewable (solar) energy production will reduce the negative effects of producing fossil energy. The negative effects, which come along with fossil fuels, are the emission of greenhouse gases, which causes climate change. These disadvantage is intervening with the global warming goal to not exceed 2 °C according to Christophe McGlade (2015). Another disadvantage are the fluctuating prices of fossil fuels. Last decade the price of crude oil varied between 32 $/barrel till even 140 $/barrel (Nasdaq, 2015). Due to these changing prices of fossil fuel, renewable energy will become more and more attractive in the future. This is caused by the more constant price of the production of for example renewable solar energy. The availability of solar energy can change due to the weather conditions, although the production over the season is quite constant. Therefor the production of solar energy will be a good possible alternative and solution.

Compared to fossil fuels, solar energy has got a lot of advantages. Producing solar energy will emit 50 gram CO_2/kWh including the production of the solar panels itself. To produce energy from coal combustion the emission is 900 gram CO_2/kWh. Gas combustion causes an emission of 400 gram CO_2/kWh (Milie centraal, 2016). These emissions are very high compared to the emission of the production of solar panels as indicated before.

Besides the mentioned advantage of solar panels, the desired situation will have a lot of potential, such as the availability of solar energy. Solar energy is every day and everywhere available, compared to spot specific fossil energy sources. However, due to the weather circumstances such as a cloudy sky, the solar energy production could be lower. Therefore, the production of solar energy is a good alternative but definitely not the only one. Presumably, the available solar energy could be transformed in a more efficient way due to technical improvements of solar panels. This possible increasing in efficiency of solar panels will further increase the opportunities of solar energy in the future energy market.

If the possibility to combine growing low revenue crops with solar energy is proved, this will also bring more potential. There could be an ideal situation where growing crops is possible together with collecting solar energy in a profitable way. This profitability will stimulate the farmer to produce solar energy and gives a positive input towards the goal of producing 45.5 Peta (10^{15}) Joule solar energy in 2030 (Michiel Hekkenberg, 2014).

3.4 Three of Objectives

From the tree of objectives, the design challenges that earns the most attention are listed below. A descript of the Three of Objectives is given in paragraph 13.2 in the Appendix.

1. Set up a good business model for selling the solar energy.
2. Reduce the CO_2 production of the total system.
3. Reduce land costs by sharing purposes on the same field.
4. Minimize the energy costs by using the own produced energy.
5. Maximize the crop production and revenues.

4 Social acceptance of Photovoltaic systems

Generally, when planning a pilot project of a new technology in a specific area, it is important for its future success to study how it will be considered by the public opinion, especially at the local level. Even if new energy technologies may be attractive for a variety of reasons from a collective perspective, the local community can be against the proposed technology for a variety of reasons. Therefore, local projects have to deal with local interests as well. A successful project is expected to have a high level of social acceptance. Social acceptance is considered to be met when: (1) a concrete application does not meet significant resistance from local policy-makers, residents, the NGO community or other representatives of social interests, and (2) when ordinary people are willing and prepared to adopt the new technology in their own contexts and to support them with positive actions whenever the opportunity arises (Raven et al., 2009).

The attitude toward the installed system from the local population may not correspond with the common public opinion toward photovoltaic energy projects. This divergence was already observed in several projects, as in the scientific literature report of Raven et al. (2009). Public opinion surveys collected from 27 European energy projects (two Dutch projects included) show widespread support for renewable energy sources and energy efficiency in the European country, since they play an important role in combating climate change, reducing the depletion of fossil fuels and other unsustainable effects of current energy systems. However the local community may have a negative and conflictual approach. It is due to a so called “Not In My Back Yard” (NIMBY) effect (van der Horst, 2007), that is a natural reaction to any new project that makes changes to their everyday environment. It is normal that people tend to resist changes, out of a personal fear for a loss of quality of life (Hofman, 2015). As suggested by Dütschke and Wesche (2014), a strategy to go beyond the NIMBY effect is to share the benefits coming from the project. This can either mean a direct financial compensation, local co-ownership within the project, or benefits in kind, as direct local improvements. A practical example of what stated could be found in Germany, where it is already a common solution to finance the installed PV system via funding with the option of the public to participate (Zoellner et al., 2008). The application of such a shared principle can be seen in a community shares business model, that involves the population as shareholder of the project. This business model will be further explained and analyzed in section 4.2 later on.

The attitude of people towards new technologies and their reaction is not constant since it depends on a great variety of aspects. The second determinant aspect that can influence the reaction is the level of knowledge and awareness of climate change within the population. Indeed a higher level of awareness in the local community generally increases the willingness to counteract climate change and to accept the application of climate-friendly technologies (Hofman, 2015). Also the familiarity with the renewable energy technology and some technical knowledge is important, since the experience accumulated in years of projects shows that potentially useful technologies will not be positively considered if the public is not familiar with them. People with no specific experience with renewables are more likely to oppose them, overestimate their social cost, and underestimate their benefits. And obviously the more expensive a group of people perceive a particular project, the more they are likely to oppose it in their community (Sovacool and Ratan, 2012).

At this point it is interesting to notice how the energetic policy of Goeree-Overflakkee is extremely propositive toward renewable energy technologies, creating a favorable situation for the PV pilot project. At this regard, a recent interview with Lennard Seriese, from the Municipality of Goeree-Overflakkee, has been published on 11th June 2016 by Pondera Consult. There, the article presents the perspectives of two remarkable municipalities, Goeree-Overflakkee and Almere, each of which has “a historical and future connection to wind energy” (Pondera Consult, 2016). A practical example of what stated is the Energy Festival of the 5th September 2015 hosted in Goeree-Overflakkee, and the claim from this municipality to become fully energy neutral within 2020 (Zoellner et al., 2008). This public image contributes to a positive environment in the island to execute the pilot project. Policy cultures and stability of the policy process are an essential element highlighted also by Raven et al. (2009). It may be concluded however that more complete specific knowledge needs to be provided in the targeted area in order to give to stakeholders the right expectations, and raise the probability of success of the project.

Another factor that influences the acceptability of a project is the perceived fairness of the preparatory and decision-making processes (Hofman, 2015). Experience, coming also from projects in a similar field of renewable energy technology as windmill turbines, shows that procedures are considered to be fair when there is (Dütschke and Wesche, 2014):

- Openness: all relevant information are shared between the stakeholders
- Inclusiveness: interaction with all the stakeholders
- Responsiveness: willingness to listen to the community and stakeholder concerns
- Accountability: ongoing process of monitoring, evaluation and participation
- Flexibility: to be prepared for local requests and be open to amendments

It is important during the implementation of a project to deeper analyze the level of aggregation and agreement of the involved neighboring communities. The agreement between stakeholders is an important factor that can affect the ease and speed of negotiations (Zoellner et al., 2008).

Finally, the level of trust in decision-makers is directly correlated with all the social aspects discussed above, as it influences and is in turn also influenced by them (Hofman, 2015). With public trust in stakeholders is meant the perception of their organizational competence and integrity. Pre-existing levels of mistrust in local political institutions and processes may undermine support for the siting of renewable energy technologies (Devine-Wright, 2007).

Among others, common practical issues faced by solar fields and reported in literature are: nature conservation, noise and safety issues, and competition for land functions (Raven et al., 2009). Moreover, nature protection organizations disagreed often upon the environmental sustainability of the planned PV system, and there are cases in which this argumentation was used by citizen's initiatives to convince the public to oppose the projects (Zoellner et al., 2008).

However, a movable solar system has the advantage to present already a solution to some of those main problems: for example there is no competition for land space, since the agricultural and energetic functions are expected to occur simultaneously. In this way there will also be no decrease in total arable land, an important aspect in prevision of increased future needs and a targeted objective of the European Legislator, an actual issue since it has already started been discussed in July 2010 in a French law regarding agriculture (Thévenot, 2012).

Finally the social opinion considers the visual aspect. It must be taken into account during the location selection that: the visual impact of a solar field could causes complaints in case it would affect natural protected areas and remarkable landscapes. Another problematic area is in the immediate vicinity of residential areas. Indeed there is empirical evidence that if the location of the planned PV installation is not directly visible for the public, the social resistances will decrease (Zoellner et al., 2008). However since the project is regarding only agricultural anthropic territory, the visual impact of the panel system it is assumed will not be an issue. In addition, due to the movable concept implemented, the eventual inconvenience of a solar field would be temporary, since the occupation of the land is intended as not permanent, but to be associated with crop rotation. It can be assumed therefore a lower level of social resistance for the mentioned reasons.

It could be taken for granted that the economic aspect of the project is one of the most important criteria that all stakeholders use for evaluating a new technology (i.e. media, neighbors, municipalities etc.). This means that the individual's assumptions that, for example, due to renewable energy utilization new jobs are created or in the long run renewable energy utilizations is cheaper than other energy technologies, will effect positively the attitude formation process. Thus, reports of the media about costs and financial risks may have an impact on the individual's estimation and in this way individual's acceptance (Zoellner et al., 2008). But in addition the direct economic aspects, others factors in the societal structure can deeply influence the project output. Therefore, a short discussion of the main aspects, unanimously recognized by the scientific literature, will be presented below.

Given those assumptions, the pilot project should not face big issues, but it is still highly recommended to interview the stakeholders before the project starts and take into account their opinion and expectations during the implementation, since successful processes (referred to the way the project interacts with stakeholders) are likely to contribute to successful outcomes, and unsuccessful processes to unsuccessful outcomes (Raven et al., 2009). In this respect Raven et al. also suggest a set of questions that help projects to increase the likelihood of creating societal acceptance, to be considered already at the design stage and during the implementation phase. This useful literature is being synthetically reported below, with the points that are of considerable interest for the pilot project in Goeree-Overflakkee.

<u>Questions to be answered during the design stage:</u>

- ➢ How does the project interact with the local context, or the alternative contexts considered:
    - In which ways might it benefit or harm the local context (physical, economic, social or symbolic) and how equitably are the benefits and risks distributed?
    - What synergies or competition may the project involve with other ongoing developments?
- ➢ Who might the project influence and who might exert an influence in it?
- ➢ How will stakeholders be involved and their concerns addressed:
    - How will stakeholders be informed about the project and how will its vision be communicated?
    - How will information about stakeholder's concerns be collected?
    - How early can stakeholders be involved in the project and what aspects of the project design could they influence?
    - How will different stakeholder's interests be represented?
    - How will stakeholder involvement be integrated in the time frame of the project?

<u>Questions to be answered during implementation:</u>

- ➢ How are communications managed on an ongoing basis:
    - How does the project keep 'in touch' with its stakeholders (formal and informal channels)?
    - Do new stakeholders emerge as the project evolves?
    - How can stakeholders monitor the progress of the project and the unfolding of its impacts
- ➢ How is competence developed during the project?
    - In what ways can stakeholders interact with the project as it unfolds?

- Is there evidence of mutual learning and adaptation?

➢ How does the project deal with issues that arise during the project:
  - Issues of representation and division of responsibilities and powers?
  - Resolving potential conflicts among different stakeholder's interests?
  - Dividing attention between stakeholder management and other aspects of project management (technical, operation, market, financial, etc.)

➢ When and how should the project 'take stock' and reflect on achievements and remaining problems:
  - Evaluation and milestones?
  - Opportunities for modifying the project according to lessons learned?

Answers for those questions will come from a stakeholder analysis, that is presented in paragraph 4.1. This analysis is essential either for the design phase of the project, either for its next application in the future. However, for this next step, first a precise location, business model and project management organization must be selected; all elements not yet available in the considered first phase, so a further research is needed.

4.1 Stakeholder Analysis

In this chapter the different key actors involved in the project are described, with their needs and restrictions, to formulate a total view of the project stakeholders. This overview is important for the next phase of design and implementation, since it is a base for the Nigel-Cross method run later in chapter 7

The typology of the stakeholder will be defined according to the definitions of Mitchell et al. (1997). Thirteen key actors have been identified and divided into height categories according to their level of urgency, legitimacy and power upon this project. A combination of more than one mentioned aspect within a same stakeholder is also possible. Figure 4-1 represents graphically the groups and their roles. The more elements an actor has, the more important he is for the project. An overview of all the stakeholder is given in Table 4-1.

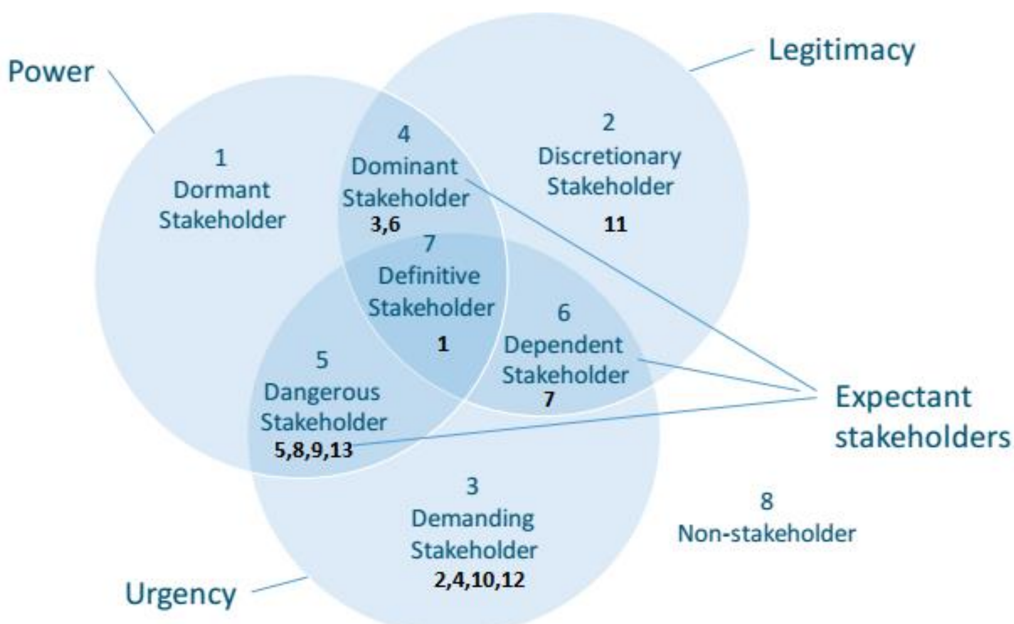


Figure 4-1 Overview of Stakeholder Typology

Table 4-1 Legend with all the different stakeholders

Legend			
1	Primary producer	*8*	Grid Operator
2	Knowledge Institute	*9*	Energy Supplier
3	Societal representative	*10*	Constructor of Equipment and Machinery
4	Consumer	*11*	Knowledge Institute (ACT Group 1618)
5	Neighbours	*12*	Feedstuff supplier
6	Funder	*13*	Public representative and policymaker
7	Employee		

4.1.1 Stakeholder description and relation

According to the stakeholder analysis, the five most important stakeholders for the movable solar panel system are: Primary Producer, Neighbours, Grid Operator, Energy supplier and Public representative and policymaker. These stakeholders are chosen because of their importance when the system is in charge. The transitory moment while developing/constructing the system is not been taken into account for this study.

Primary Producer

The Primary Producer taken into consideration is the Skylark farmer. The influence of this stakeholder on the project is high since he has to work with the system and, in case of owned business model, he is charged with the risk of investment. Therefore he will only buy the system when the profits will compensate the risk taken and the labour spent. It is assumed the farmer will move and transport the system on his own, so the solar panel system should be easy to handle. This is one main challenge that the system design must take into account.

Neighbours

Another important stakeholder will be the Neighbours, that are the ones that have to face the solar panel system for some time when the system will be placed on a piece of land in their surroundings. As concluded in the beginning of chapter 4, it is important to take the opinion of the Neighbours into consideration while designing the system. The design of the system can have a big influence on the acceptability.

Grid Operator

The Grid Operator is a stakeholder with a big influence on the financial feasibility of the project. The connection to the grid is important to deliver the harvested electricity to the community. The connection to the grid is normally at the farms place, but in the case for the movable solar panel system the connection will be somewhere at the edge of a field. This means that an extra connection has to be installed, and its costs of connection depends on: the size of the connection, and on the distance from the field to the grid. The economic implication of this will be further explained in the economical part in chapter 0.

Energy Supplier

The electricity that has been delivered to the grid, has to be paid. This will be done by the Energy Supplier that receives the electricity from the grid and distributes it to the consumers. Because the electricity price is not equal for every Energy Supplier, it is important to take into consideration which Energy Supplier will be involved. It is also very important to know what the requirements are about supplying energy to the grid: do you get the actual changing price or get you a fixed price for every kWh produced?

Public representative and policymaker

The last main stakeholder considered is the Policymaker, or in general the Government. The policymaker defines the laws and regulations which the system has to fulfil before it may be implemented, affecting the final output. This aspect will be further investigated in paragraph 4.3 about Legislative regulations.

4.2 Business models

A business model is an important tool to analyse how a business operates, or should operate, and put in evidence its key strengths and weaknesses. Therefore the following discussion can give an important advice to ensure a better perform of its output's future application in the market.

4.2.1 Main business models available for PV solar panel systems

The concept of business models has been applied and developed in many different contexts. Among others, also the photovoltaic sector in the Netherlands has made extensive use of it. A research conducted by Huijben and Verbong (2013) observed the following three main types of business models adopted:

1. Customer-Owned PV business models, both applicable to households and micro, small and medium-sized enterprises (also referred as SMEs) that invest individually in the PV system. In that case the farmers are expected to be directly the owners of the installed system.
2. Community Solar or Solar Shares business models, which account for multiple users lacking the proper on-site resource, fiscal possibilities or building ownership rights, that purchase a portion of their electricity from a solar facility located off-site (Asmus, 2008). The main difference with the previous category lies in the ownership contract.

   This business model would be applied in case the local community would be involved in the movable solar project as shareholder, having the possibility to invest and share the advantages of the project.
3. Third Party business models, in which third party PV companies own and operate customer-sited PV systems and either lease PV equipment or sell PV electricity to the building occupant(Drury et al., 2012). This is the case when the PV system is leased to the farmers, but owned by a third part company.

Let's proceed now analysing more in detail the advantages and issues that characterize each of these options, in order to depict a clear overview of the possibilities.

4.2.2 The Customer-Owned PV business model

The first point of the list addresses customer-owned PV business models. Among the PV projects in the Netherlands this kind of business model is the most common and applied.

The customer segment interested in this project would be a farmer with the economic possibility to make by himself the initial investment to purchase the solar panels. As an alternative source of investment, presenting a positive credit score, banks can grant the farmer a loan to enable him to make the investment. Because of governmental support, these loans have relatively low interest rates {De Vrieze, 2012 #29}. To sharpen the customer segment more, it must be noticed that the studied solar system has the property to be movable. This ensures a business advantage if it will be combined with field crops, since it can address a market niche that the classical fixed systems cannot. Therefore the targeted customer segment this project should address is a medium-size farm, with crop rotation cultivation system where it is possible to combine the proposed movable panels.

Considering the value proposition of this project, the additional benefit a farmer wants to get by installing a PV system is economical. This will come by two ways: first the solar energy produced will permit him/her to reach the energetic self-sufficiency, by using the produced energy within the farm, so gaining through saving bills. Second it can allow them to sell the exceeding power to the grid at a given price, making profit from this business while not renouncing to the cultivation of the field. This specific kind of business model adds the value of the ownership to the project, and for that reason it is especially suitable for those customers willing to have as much independence and self-management as possible.

Literature reports that in previous initiatives it was highly appreciated to have a customized service (Huijben and Verbong, 2013), that permits each farm to choose between several pre-fixed packages, depending on their size, expectations on outputs and desired level of involvement within the project. The best way to give personalized advice is when suppliers meet with customers individually to check their farm and provide customized recommendations (Huijben and Verbong, 2013). It must be carefully considered that the large scale benefits from a bigger market share, as cost efficiency, will be more difficult to be applied without lowering the customer satisfaction.

It is worth indicating that a subcategory of this model recently appeared and quickly spreading in the Netherlands comprehends collective initiatives (Huijben and Verbong, 2013). A large number of interested customers organize themselves and collectively buy, install, maintain and insure PV systems. In this way they decrease purchasing and maintenance costs with scale cost reductions for larger systems, making the investments attractive even without subsidies (Huijben and Verbong, 2013). This option, even if actually it is not common among farmers, must be taken into account as a competitive organization for the business. However, it is reported by literature that the great pitfall of this initiatives is the difficult management and organization part. On the other hand this same business if carried by a company, as in the case presented at the beginning of the paragraph, instead of a cooperative, will meet less difficulties of that kind, due to a more centralized decision making process.

4.2.3 The Solar Shares business model

A second option is the solar shares business model. Also within this case, by collective participation larger and more efficient projects are realized, leading to cost efficiencies.

The option to share the investment cost and the ownership is not common in the existing projects in the Netherlands: Huijben & Verbong (2013) report less than 10 examples observable in 2013. Indeed the major problem for these projects is the absence of national legislation that allows for off-site or virtual net metering. Net metering policies allow distributed generation customers to sell excess electricity to a utility at a retail rate and receive credit on their utility bill (Poullikkas et al., 2013). It is for the absence of this kind of legislative regulation in the Netherlands that the pilot project called Boerenbuur in November 2011 was stopped, since the Dutch tax authorities indicated that its activity was in conflict with the current Dutch electricity law (Huijben and Verbong, 2013).

Despite this difficulty, several new experimental projects have been started since then. Interestingly, in some cases the local governments, in contradiction with the national government, have supported these experiments by providing funds in case virtual net metering is not allowed and energy tax payments have to be made afterwards (4NewEnergy, 2012). So the local authorities support is an important factor to be checked before the application phase for the future feasibility of the project.

The economic return on investment (ROI) of projects with this business model is lower compared to the other business models applied, according to (De Vrieze, 2012). For this reason currently the operating projects are mostly carried out by environmentally driven volunteers that aim at supporting and making the Dutch PV market more accessible. Commercial parties do not initiate these kinds of projects but rather go for easier business models (Huijben and Verbong, 2013).

On the other hand such a structured project has some advantages. Firstly the number of farms that potentially can be involved is much higher, since the main requirement becomes the ownership of a crop field to combine with movable solar panels. The availability of initial large cash liquidity or the access to a bank loan are not necessary anymore. In addition, the costs can be decreased by scale efficiencies, the more farmers are involved in the project, the bigger it is.

Another advantage is the increased probability of social acceptability of the solar panel systems from the local community. The social acceptability raise as the personal involvement increase and the community has the possibility to be represented at the decision phases. In this kind of projects the private citizens of the neighbourhoods willing to finance will be addressed as shareholders. Their repayment on the initial investment will come through energy bill savings (Huijben and Verbong, 2013), through an agreement with the local energy supplier.

An important key activity in these kinds of projects which must be ensured is a centralized coordination that guarantees against information gaps and technological risks. Those risks are the main issues perceived by end-users (Huijben and Verbong, 2013).

4.2.4 The Third Party business model

The last business model considered by literature for a PV system is a leasing model. Several examples in the Netherlands can be found where the customers, in the case of this project the farmers to which the system is supplied and installed, pay a fixed price per month for a determined period (the expected lifetime of the system). The repayment of the total investment comes via energy bill savings, while the extra energy supplied to the grid can be compensated or not, depending on the contract offered by the local energy company. Customers can eventually cancel the contract after few years by paying off the remaining investment (Huijben and Verbong, 2013).

This leasing business is upcoming in the recent years, and commonly the projects receive the initial investment from third parties such as banks, energy companies and investors in general. To give an idea of feasible size for such a leasing model, the pilot project of the energy company Greenchoice started in 2011 included 500 households, each of them with a leasing contract of 20 years for a roof PV system (Huijben and Verbong, 2013).

There is also the possibility to have the participation of a crowd fund, i.e. from a group of farms. This last option is seen as a response and evolution from the failed projects in which virtual net metering was needed for a profitable business case but, was not allowed by the Dutch tax authorities (see paragraph 4.2.2). The main difference of Third Party with Solar Share projects lies on the ownership contract: they do not involve shared ownership and responsibilities, but have clear contract boundaries.

The main advantage of this utility is the customer binding. The main bottleneck observed is the complexity of the arrangements that the organization must find between investors and end users. To carry on this project high organizational resources (e.g. time and employees) are needed.

Finally, it must be noted that only a few organizations in the Netherlands are currently offering lease contracts to their customers. Mostly these have the form of financial lease, meaning that the lessee will have ownership over the PV system after the contract (Huijben and Verbong, 2013).

A summary table containing the main aspects that characterize the three business models is reported in paragraph 13.3 of the Appendix, for a simpler visualization of their strengths and weaknesses.

4.3 Legislation

In the following part the legislation aspects towards the movable solar panel project will be analyzed. The general governmental policy, subsidy and permissions in regarding to solar energy will be discussed.

The Dutch government set the goal to have a completely sustainable energy production till 2050. They stated their energy policy in the energy report of December 2015. Following up to their policy the Dutch government supports projects where consumers and producers are working together. The law was changed to allow local cooperation's for energy production. Within these, the consumers are expected to pay less for their electric bills and producers receive a tax discount of 9 cents/kWh (Rijksdienst voor Ondernemend Nederland, 2016a).

Next to tax benefits, the Dutch government runs a subsidy program to stimulate the production of renewable energy, the SDE+(stimulation renewable energy) subsidy. The SDE+ program grants an extra subsidy for a certain amount of produced electric energy. Regardless of variations in producing due to radiation differences within a day and month, the amount of subsidy is based on the total output level of a system in kWh times the full load hours. However if the systems total output level is bigger than 500 kW, extra permits will be needed. This permissions includes the local environment license and request, a clarification of the landlord if the system owner doesn't own the land and a feasibility study. The feasibility study is composed of a list of costs involving the project, a profitability analysis and a plan for financing (Rijksdienst voor Ondernemend Nederland, 2016b). By consequence, the later section presenting the financial calculations of a movable solar panel (chapter 0) are based on the assumption of a system producing less than 500 kWh. There is also made a second assumption, to work without subsidy, to explore the investment feasibility.

In order to install any kind of solar installation on a rooftop or in the open field, respective laws and permissions have to be indicated and fulfilled. In most cases a permission to build solar panels is not needed. However if they are not placed on the roof, a local environment license will be needed. The building law as well as the civil law will be in charge, if someone wants to get the local environment license. These legislations are always in charge if someone wants to build a certain construction which requires permissions to be placed or build. An exception is made when the construction is less than 5 meters high and when it is not in conflict with the usage plan. The usage plan set locally the roles, which purpose each land fraction has and how it may be used. Each land plan is displayed in the plan regulation of the local land. The usage plan of the land in which the solar panels will be placed is agriculture. For the movable solar project it could indicate, that the usage plan for the including lands has to be changed (Ministerie van Binnenlandse Zaken en Koninkrijkrelaties, 2012).

5 Models

As an input for further calculations two models were used which calculated the solar irradiation and the reduction in crop growth. In the first chapter the total solar irradiation on a solar panel is calculated by a model called SunShade. In the second chapter the influence of shade on crop growth in calculated.

5.1 Energy yield solar panels

For the calculations of the total captured solar energy on a yearly basis a programme called SunShade 2013 is used. This programme is developed by Bert van ‘t Ooster working for the Farm Technology group at Wageningen University ('t Ooster, 2013). This model is used and further explained during the course Building Physics and Climate Engineering ('t Ooster, 2016). The expert of this project provided the model which was very comprehensive, therefore this calculation model is chosen. For a building the solar irradiation on all surfaces is calculated on an hourly basis.

Within a day the sun position is changing from East to West which is called the azimuth angle. This angle is indicated in Figure 5-1. Also the sun height is changing over the season. This angle is called the altitude and indicated with α_s in Figure 5-1. Due to this changing angle during the year there were differences in day length and temperature over the year. These two varying angles were taken into account by the calculations of the model, which results in an hourly based calculation.

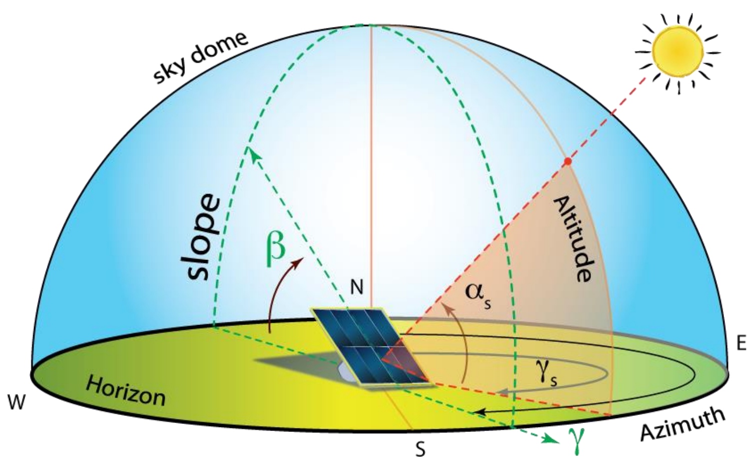


Figure 5-1 An overview of the angles from an object relative to the sun. The azimuth angle is varying during the day, while the sun rises at the East and the sun goes down at the West. The Altitude angle is height of the sun, which is higher during summer compared to winter and autumn. {Brownson, 2016 #62}

The roof of the building is defined as the solar panel as can be seen in Figure 5-2. The angle of the solar panel is varied between 0 and 90 degrees. Due to the assumption the system will be used during the whole year, time was not a parameter to vary. The energy yield is calculated per square meter solar panel which makes it unnecessary to vary the density of panels. This varying density can be done for the calculations later on. The result of this model will be used for the financial calculations. The results for varying the angle are discussed in the next paragraph.

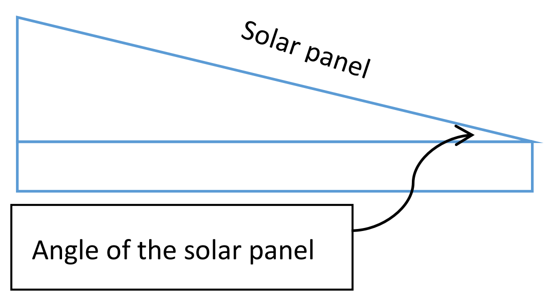


Figure 5-2 The construction of the building used to calculate the solar irradiation on the roof/solar panel. For this building a lean to roof is used with a varying angle of the roof.

The total sum of solar radiation on a horizontal plane calculated with the model which uses reference weather data was equal to 3304 MJ m^{-2} $year^{-1}$. The used reference data consists of weather data such as the direct and diffuse solar irradiation on an hourly basis. This information is used by the model to calculate the solar irradiation on a building during the day.

The real solar radiation on a yearly basis is also measured by weather stations in the Netherlands. From 1981 till 2010 the average yearly solar irradiation of 20 different weather stations is equal to 3335 MJ m^{-2} $year^{-1}$ (KNMI, 1981-2010). This average solar irradiation is used to validate the model for a horizontal placed solar panel, if the calculations were right.

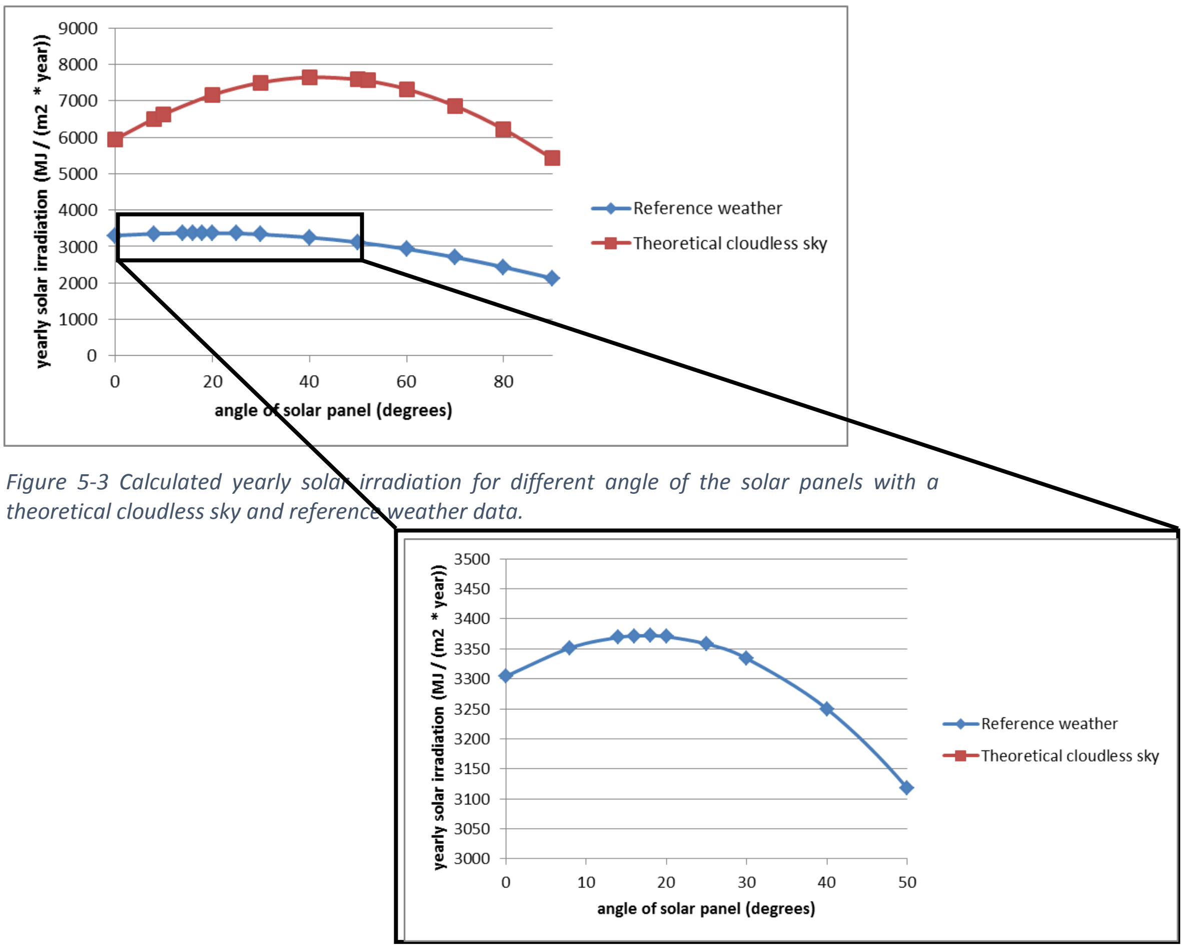


Figure 5-3 Calculated yearly solar irradiation for different angle of the solar panels with a theoretical cloudless sky and reference weather data.

As stated before, the calculated solar irradiation is equal to 3304 MJ m^{-2} $year^{-1}$, which is comparable with the calculated solar irradiation of 3335 MJ m^{-2} $year^{-1}$. As can be seen in Figure 5-3, the theoretical available solar irradiation with a cloudless sky is much higher than with the reference weather data. This is caused by the large amount of diffuse light in the Netherlands. For direct light, the ideal theoretical situation with a cloudless sky, the optimal angle of the solar panel will approximately be 45 degrees, more or less comparable to the latitude of the Netherlands which is 52 degrees. For reference weather data with the available diffuse light the optimal angle is much lower and approximately 18 degrees as can be seen in Figure 5-3For diffuse light most energy is captured when the solar panel is placed horizontally. According to the model, 54% of the time only diffuse light is available. Due to this long period of only diffuse light without direct light, the optimal angle calculated by the model is less than half compared to the theoretically cloudless sky with only direct light.

The total solar energy yield with an angle of 18 degrees is equal to 3372 MJ m^{-2} $year^{-1}$, which is only 2 percent higher than with a horizontal plane. Horizontal placed panels would not cause any shade on other panels. This means all the energy which is captured by a horizontal placed solar panel will not be influenced by shade of other panels due to the changing position of the sun. As stated before, a horizontal placed solar panel will capture 3304 MJ m^{-2} $year^{-1}$. This value will be used in the calculations.

5.2 Crop yield underneath panels

Before implementing the model, some literature research was performed on the influence of light intensity and shade on the crop growth.

5.2.1 Wheat Yield

In the Netherlands, the total average gross yield per hectare in 2015 for wheat was 9,100 kg. For winter wheat this was 9,400 kg and for summer wheat this amount was 7,000 kg (CBS, 2016). According to other countries in the world, the Dutch arable farms are doing good. In data from all registered countries in the world, 23 countries had an average yield below 1,000 kg per hectare in 2014. Only fourteen countries had an average yield higher than 7,000 kg. Under the 10,000 kg Belgium is the first with 9,500 kg, followed by the Netherlands. Some countries have production far higher than 10,000 kg per hectare but these are countries with a climate that is totally different than the Dutch climate, so they can grow all year round (FAO, 2016).

5.2.2 Solar Yield

The average day sum of solar irradiation in Vlissingen (The Netherlands) (Velds, 1990) for the four seasons can be seen in Table 5-1:

Table 5-1 Average day sum of solar irradiation in Vlissingen (The Netherlands)

Period	**Average day sum solar irradiation Vlissingen (MJ *m^{-2})**
Winter	3.16
Spring	13.28
Summer	17.78
Autumn	6.89
June	19.20
June (only diffuse light)	9.60
June (only direct light)	9.60
March (only diffuse light)	6.8_a

5.2.3 Effect of shade

According to Marrou et al. (2013), the only significant parameter that will change in an agrivoltaic system (AV) is the reduction of available light. If a solar panel system is applied on the field, the crop has to deal with a certain level of shade caused by the panels above the crop. Shade will lead to less PAR (Photosynthetically active radiation) that reaches the crop and PAR is needed for the crop to grow (Acevedo, 1992). Due to the decrease of direct light and increase of diffuse light by shading, the amount of blue light within the total PAR will increase where the amount of red light will decrease at the same time (Li et al., 2010). Marrou et al. (2013) also stated that light reduction in AVs are not necessarily detrimental for crop production. This can be explained by the fact that the shade causes an increase in radiation interception efficiency (RIE). However by a full density panels the yield underneath the panels will be around 50% (Dinesh and Pearce, 2016). Two crops are used in the research of Marrou et al. (2013). One was lettuce, which has high adaptation possibilities. For wheat the possibility to adapt is low.

5.2.4 Yield decrease by shading

In Li et al. (2010), two different cultivars of wheat were treated with different levels of shade. Shade is applied as a decreasing percentage of no shade which equals 100% available PAR light. The yield reduction or increases are given as percentage from the control group, which means the yield at 100% available PAR. Yield of the two wheat types decreased with respectively 6% and 7% at the 77% PAR level compared to normal. With higher levels of PAR (92%), the grain yield will increase in comparison with the control group. Also the wheat cultivar influences the sensitivity of lower light intensities to yield. Wheat crop is able to adapt to slight changes in PAR. The canopy size will increase due to a higher LAI. With lower levels of available PAR light, the crop will increase the efficiency of light use, which results in more effective localisation of leaves which results in more leaf area per floor area (LAI).

Lakshmanakumar (2014) showed that grain yield of four different varieties decreases on average with severe shade (33%) from 4290 kg/ha to 2990 and to 2060 kg/ha at 66% shade compared to full irradiation, see Table 5-2. That is a yield reduction of 52% by a 66% reduction in solar radiation. It can be generally stated that the percentage of yield loss is less than the percentage of decrease in PAR.

Table 5-2 Average loss of yield of wheat varieties PBW 233, UP 2684 and UP2526 due to shade (Lakshmanakumar, 2014)

Interaction	**L_0**	**L_1 (33% shading)**	**L_2 (66% shading)**
*Average Yield [kg*ha^{-1}]*	4290	2990	2060
Percentage [%]	100	53	48

Li et al. (2010) found effects of different lower levels of shading on the grain yield, see Table 5-3. The shading levels mentioned are 8%,15% and 23%.

Table 5-3 Average effect of different shading levels on grain yield of the cultivars YM 158 and YM 11 (Li et al., 2010)

Interaction	**S_0**	**S_1 (8% shading)**	**S_2 (15% shading)**	**S_3 (23% shading)**
*Average Yield [kg*ha^{-1}]*	5866	5930	5838	5479
Percentage [%]	100	101	96	93

One can see that very low (8%) shading can lead to a small increase in grain yield.

5.2.5 Moment of applying shade

Savin (1991) shows that the moment of the growth period of applying the shade influence the wheat yield with small amounts. In this research all plots (S_1-S_3) were treated with a shading of 50% in Argentina. Each experiment has other applying times:

S_1: shaded from beginning of stem elongation to anthesis.
S_2: shaded from anthesis to maturity
S_3: shaded from beginning of stem elongation to maturity.

The results are shown in Table 5-4.

Table 5-4 Effect of shade on different moments in the growth of wheat (Savin, 1991)

Interaction	**S_0**	**S_1**	**S_2**	**S_3**
*Average Yield [kg*ha^{-1}]*	4150	3040	2890	2550
Percentage [%]	100	73	70	61

Marrou et al. (2013) stated in his research that an important period of the growth is the young phase of the wheat plants. If plants get too much shading at this phase, it will influence the whole growing cycle significantly. From these information it can be concluded that the shade is harming less if it is applied from beginning of stem elongation to maturity.

5.2.6 Positive effects of shade

Besides the negative effect of shade on the crop growth, the shading will also lead to lower canopy temperatures up to 3.3°C less by an incident solar irradiation of 77% (PAR) of the control group (Li et al., 2010). The decreasing temperature will avoid a crop to get temperatures above average, which would shorten the growing period and lead to a decrease in yield (Nonhebel, 1993). A temperature increase of 3°C, can lead up to 3,000 kg yield decrease per hectare per year.

5.3 Crop Yield Model

Like mentioned in the introduction the crop yield underneath the solar panels will decrease as a result of the shading that the panels will have on the field (Dinesh and Pearce, 2016; Dupraz et al., 2011; Marrou et al., 2013; Savin, 1991). Crop yield together with the price are the main issues that estimate the revenues from the crop for a farmer. Therefore, the knowledge about production decrease as a result of shade could be an important factor for the feasibility of the project, however the solar energy part probably has a bigger financial impact. For an approximation of the yield of the crop under the panels a model is used and the results are compared with values that are found in the literature.

The model GTa CropGrowth is used for the calculations of the total dry matter (DM) production of several greenhouse crops. This model is developed for the course Greenhouse Technology of the Farm Technology Group (FTE). Since this project focus mainly on the growth of wheat which is an outside growing crop, the model needed to be adapted for wheat growth.

This adapted model uses the following input data, collected by literature research. The maximum leaf area index (LAI) of the crop is estimated at 5 (FAO, 2016) and increases with the development of leaves. The day sum irradiation I_s in (MJ*m^2*d^{-1}) and the temperature in (°C) of Vlissingen is collected from the databases of the Koninklijk Nederlands Meteorologisch Instituut (KNMI, 2016). The data is obtained from Vlissingen because geographically that is the most nearby location with a meteorological station and free available weather data. The plant density is 250 plants per m^2 (Darwinkel, 1997a; Spink et al., 2000). The CO_2 concentration is assumed to be 400 ppm (Nonhebel, 1993). The light use efficiency (LUE) of the wheat crop is estimated as a function of the Photosynthetically Active Radiation (PAR) light, which is 0.47 I_s. The LUE is calculated with equation [2]:

$$LUE = \frac{1}{0.25 + 0.035 * PAR} \qquad [2]$$

From the mentioned data the following graph is obtained for global irradiation during the growing season of wheat (October 15th till August 1st).

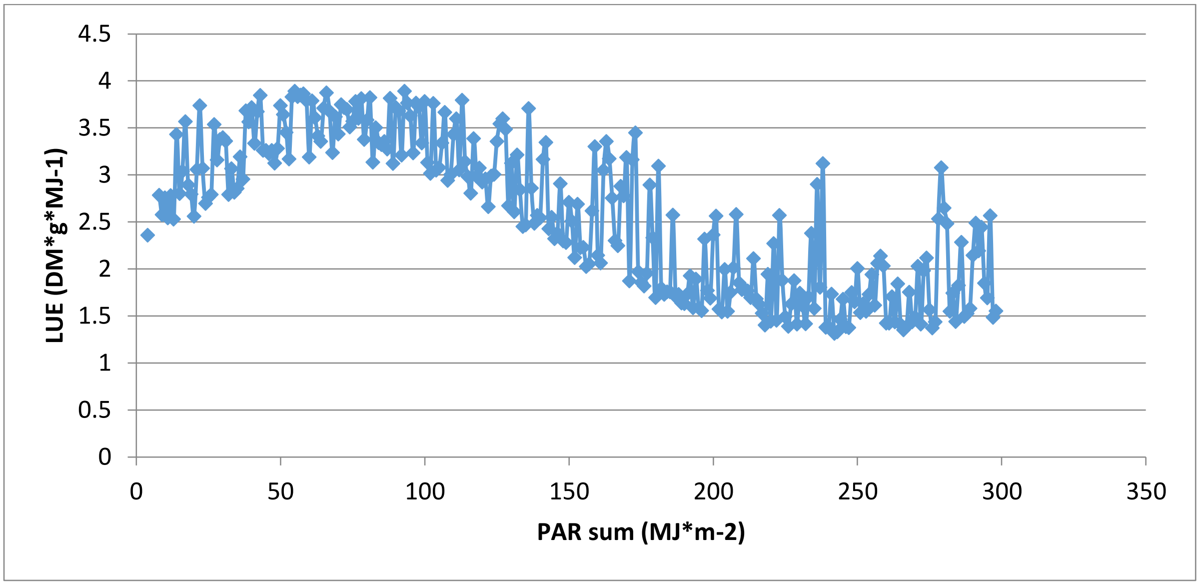


Figure 5-4 Modelled Light Use Efficiency of wheat during growing season.

The LUE varies between 1.3 and 3.9. That is comparable with data found in the literature. Indeed according to (Charles-Edwards, 1982), this value for wheat should vary between 1.3 and 4.2 $g*MJ^{-1}$.

In order to know the yield of the wheat (the weight of the grain of the wheat), the total product weight (total weight of the grains per hectare) has to be calculated. This is done by multiplying the total DM of the wheat by the harvest index 0.35 in order to get the DM of harvestable grain (Engel, 2005). The fresh weight percentage of the grain after drying is 0.85 (Darwinkel, 1997b) and so, the total grain weight yield is calculated. In the following table the results of the simulations are shown for the shading treatments that are comparable with literature. For every treatment, a percentage is shown what is the shading percentage. In every experiment, the total global irradiation is reduced by a certain percentage in order to calculate the effect of shade on the crop. In Table 5-5 and Figure 5-5, the different values for the different literature researches are compared with the results of the developed model. The differences between the two experiments is due to the fact that they are done at different places, which has other light irradiations during the day. Also the wheat varieties differs, which has different effects on the growth.

Table 5-5 Results of the model simulation for wheat growth under different shading treatments. The 0 percentage shade is the reference. Percentages with the subscript 'a' are from the research of Li et al. (2010). Percentages with 'b' from Lakshmanakumar (2014).

Shade % on PAR	0	8[a]	15[a]	23[a]	33[b]	66[b]
DM total	2095	2009	1927	1826	1687	1083
Grain yield ($kg*ha^{-1}$)	863	827	793	752	695	446
Decrease %	0	4	8	13	19	48
Literature	0	-1	4	7	47	52

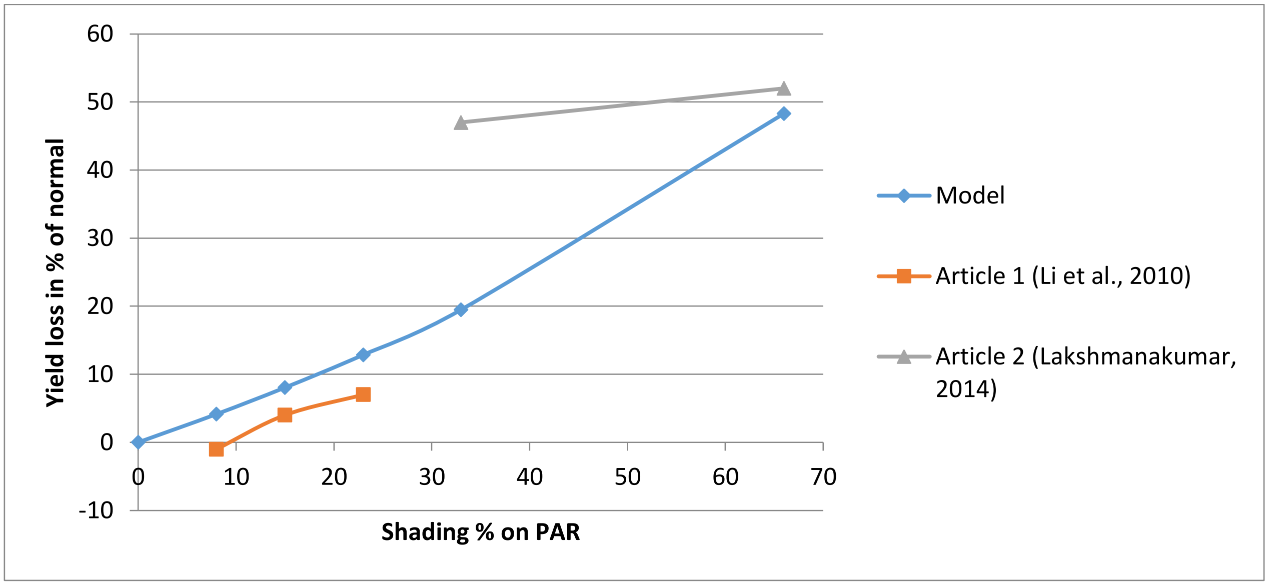


Figure 5-5 Relative yield loss indicators by the adapted GTa CropGrowth model and literature values

From the results it can be seen that the values obtained with the model and the found values in the literature are differing. Especially the 33% shading percentage lays totally out of line with the other experiments. For the 66% shading the model got a good approximation. At the experiment of Marrou et al. (2013), an agrivoltaic system was tested. The daily radiation below the solar panels by a full installation density of panels during the wheat growing season is equal to 68%. Seen the situation in that research, it is assumed that this shading percentage is comparable to the full density parts of the system observed in this project. At 68% shade the crop yield is approximately 50% of the yield at full sun irradiation. Since the average wheat yield per hectare in the Netherlands is 9,100 kg (CBS, 2016), after implementing a movable solar system, the yield will approximately become around 4,500 kg grains per hectare.

6 Economical aspect

In order to make conclusions about the feasibility of the movable solar panel project, a financial analysis of the profitability is needed. Therefore a calculation of the net present value (NPV), internal rate of return (IRR) as well as the Levelized Cost Of Electricity (LCOE) will be made. With the results of the calculations an overview of the feasibility of the project will be given. It allows us to compare the project with other investments. Furthermore a sensitivity analysis will take place to show changes on the profitability of the project under different scenarios and future development of the solar market. In this chapter the different steps of the calculations are shown. At first the variables are defined, followed by the mathematical model and finally the results will be presented.

Nomenclature Variables:

CF_t	Cash flow in the year t (€)
C_v	Variable cost (€)
E_t	Electrical energy generated in the year t (€)
F_t	Fuel expenditures in the year t (€)
FC	Fixed cost (€)
G	Insolation (kW/m^2)
I	Total investment costs (€)
M_t	Operations and maintenance expenditures in the year t (€)
η	Conversion efficiency (%)
n	years
P_i	Price of outputs (€)
r	Discounted rate (%)
SSA	Specific Surface Area (m^2)
t	Years
Y	Annual energy (kWh)

6.1 Mathematical models

The annual energy production of a solar panel system (Y, in kWh) is the sum of the conversion efficiency (η, in %) times the annual insolation energy (G, in kWh/m^2) times the surface area (in m^2) (Chiaroni et al., 2014). The annual energy production is written as:

$$Y = \mathrm{SSA} \sum_{t=0}^{n} \mathrm{G}\,\eta \qquad [3]$$

The LCOE [€/kWh] can also be regarded as the minimum cost at which electricity must be sold in order to have a Break Even Value over the lifetime of the project. With the results of the LCOE, solar energy will be also comparable with other energy producing sources. The comparison with other energy sources support decision making of which energy source should be adopted. The LCOE can be defined from the break-even point as the sum of costs over a lifetime divided by the sum of electrical energy produced over a lifetime(Short et al., 2005). It can be writer as follows:

$$LCOE = \frac{sum\ of\ costs\ over\ lifetime}{some\ of\ electrical\ energy\ produced\ over\ lifetime} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad [4]$$

The net present value (NPV, in €) is the difference between the present cash inflows and outflows. The NPV shows if an investment in a certain objective is profitable or makes a loss (Investopedia, 2016a). The NPV is written as:

$$NPV = -I + \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} \qquad [5]$$

Cash flow (CF, in €) is the difference between net cash value that flows into an investment (P_i, in €) and cash that flows out of an investment (C_v, FC, in €). With the value of the cash flow a statement can be made about the liquidity of an investment. A positive cash flow means that the liquidity of an investment is increasing. The liquidity can be used to pay a dividend to the investor (Investopedia, 2016b). The cash flow is calculated as follows:

$$CF_t = P_i - C_v - FC \qquad [6]$$

The internal rate of return (IRR, in %) is another evaluation tool, in order to make a decision about the investing worthiness. The IRR is calculated by setting the NPV equal to zero and then the equation has to be solved for the discounted rate. It can be stated as follows (Investopedia, 2016c):

$$0 = -I + \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} \qquad [7]$$

6.1.1 Input Variables

For the feasibility calculations different variables have to be used. The variables were found with the help of a literature research and are written down in Appendix 13.4. For most of the variables credible sources could be found. However due to the uniqueness and not jet in practice realized project, for some variables an assumption had to be made.

In order to show the feasibility of the system, the calculation was based on a standardized system of 500 kW and a electricity price of 0.16 €/kWh delivered to the grid. For the calculations two different solar panels were taken into account. On the one hand monocrystalline panels with a yield of 300 Wp, 19.7% efficiency and a surface of 1.66 m^2 and on the other hand polycrystalline panels with a yield of 260 Wp, 16.2% efficiency and a surface of 1.62 m^2 (Solar, 2016). It is assumed that yield of both systems is decreasing by 0.8% per year (Lasnier, 1990). Talavera et al. stated in their paper that the operation and maintenance cost (M) are equal to an inflation rate of 3.3% (Talavera et al., 2011). However for a movable solar system it should be expected that the M are at least 5%. This is caused by the characteristic of the object, which has to be moved to another place at least once a year. (Mehta and Maycock, 2010) calculated that the mounting structure of a conventional solar panel system on a roof is 6% of the total system cost. An average system costs 1280 €/kWp (Fraunhofer ISE, 2016), which means that for the mounting system a price of 76.8 €/kWp can be assumed. For the movable solar system an assumption of the mounting structure needs to be made. It is assumed that the cost will increase to 150€/kWp. This is due the construction which will be placed in the fields, in a way that crops can grow underneath it. Therefore it cannot be assured that a connection to the grid always exists in the direct surrounding of the system. At Stedin.net the price of a connection for a 500 kW solar system connection can be found. The investment of a 630-1000 kVA connection is 33857.89 €. An extra 100 m has to be taken into account for connection cables. 100m is the distance between the solar system and the grid connection can be. Therefore an extra 8696 € (86.96 €/m) needs to be invested. Furthermore annually cost of 590 € for the grid maintenance and a fixed transportation service fee of 36.5€ are occurring (Stedin.net, 2016).

6.2 Outputs

Table 6-1 Result of financial calculations

	Monocrystalline Solar panel		Polycrystalline Solar panel	
Modul	European	Chinese	European	Chinese
Yield (kWh)	654,035,70	604,035.70	649,035.70	594,035.70
Total Investment cost (€)	645,035.70	604,035.70	649,035.70	594,035.70
LCOE (€/kWh)	0.149	0.146	0.160	0.156
CF (€)	155,492.49	205,492.49	4139.23	59,139.23
NPV 0.16(€)	-526,188.07	-441,361.78	-627,944.33	-534,635.41
NPV 0.19(€)	--	-138,728.30	--	--
NPV 0.22(€)	--	163,905.17	--	--
IRR 0.16(%)	--	-10.08	--	--
IRR 0.19(%)	--	0.45	--	--
IRR 0.22(%)	--	5.57	--	--

The Outputs for the assumed standardized system resulted in negative NPVs. For example the NPV of the European polycrystalline panels was almost with €-627,944.33 as much as its investment cost of €649,035.70. This means that an investor would loses almost all his invested money on that specific project. The outputs are based on a lifetime expectancy of 25 years. With the lifetime of 25 years an inflation rate of 3% has an big influence on the outcomes. It can be seen in table 5-1 a positive cash flow over the lifetime. However due the inflation rate, the total NPV will be negative. The NPV was calculated with an energy price of €0.16 for all systems and €0.19, €0.22 for the monocrystalline Chinese panels. The NPV calculation with €0.19 and €0.22 was done to find a positive NPV for the system. With an energy price of €0.22 a positive NPV can be found. This positive NPV of €163,905.17 has an IRR of 5.57%. With an IRR of 5.57%, the initial investment cost will be paid back within 18 years.

6.3 Sensitivity analysis

The sensitivity analysis was done to show how some specific variables are influencing the outputs. All sensitivity analysis are based on the Chinese monocrystalline panels system, since these has the lowest LCOE and will be the most likely system to be used in practice. In the diagram 5-2 the solar panel cost was reduce in steps of 5% percent to see the influence on the LCOE. The outcomes show that an reduction of 40% in panels cost will reduce the LCOE by less than 1 cent. A greater influence was assumed since literature suggested that the panel price has a high influence on the profitability. The diagram 5-3 shows the influence of an increasing grid connection price by steps of €10,000. An increase by €100,000, which is three times the initial assumed cost of €50,000, increases the LCOE by almost 1 cent. Since the lifetime of 25 years is assumed the influence of the inflation rate was analysed in diagram 5-4. It can be seen that a higher inflation rate has bigger influence on higher energy prices environments. However it effects both low and high price NPV negatively.

Table 6-2 Result of financial calculations

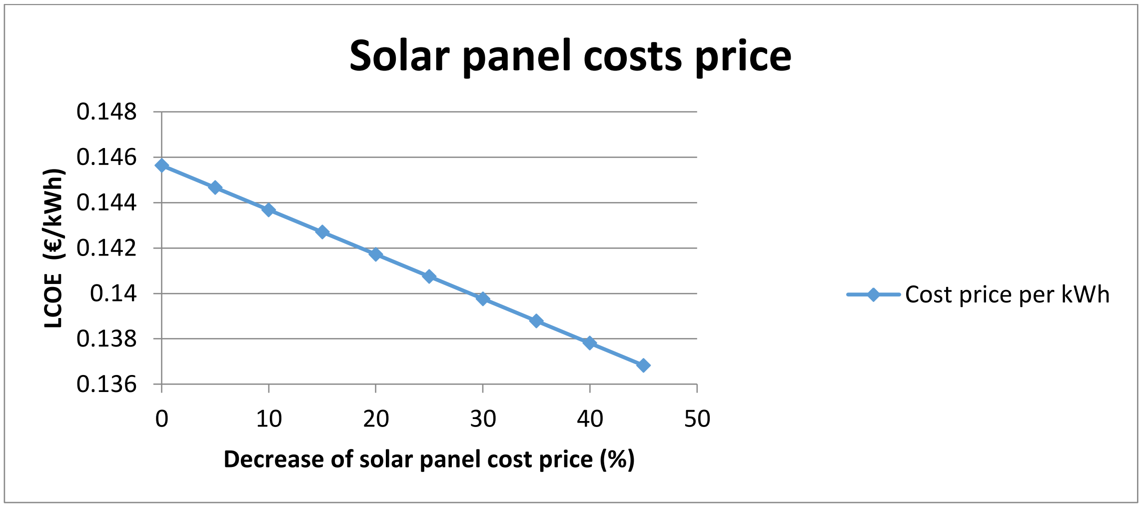


Table 6-3 Result of financial calculations

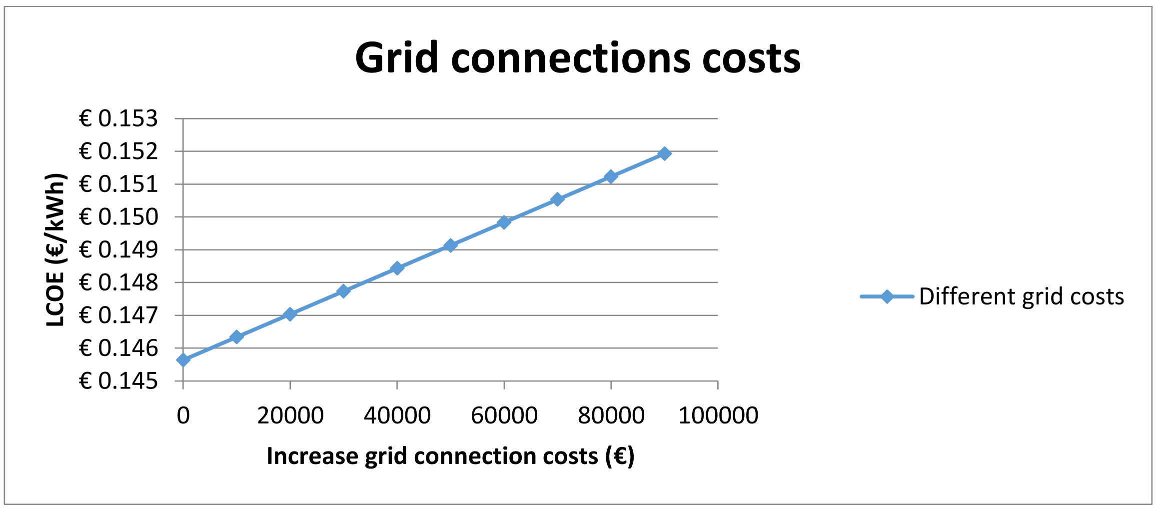
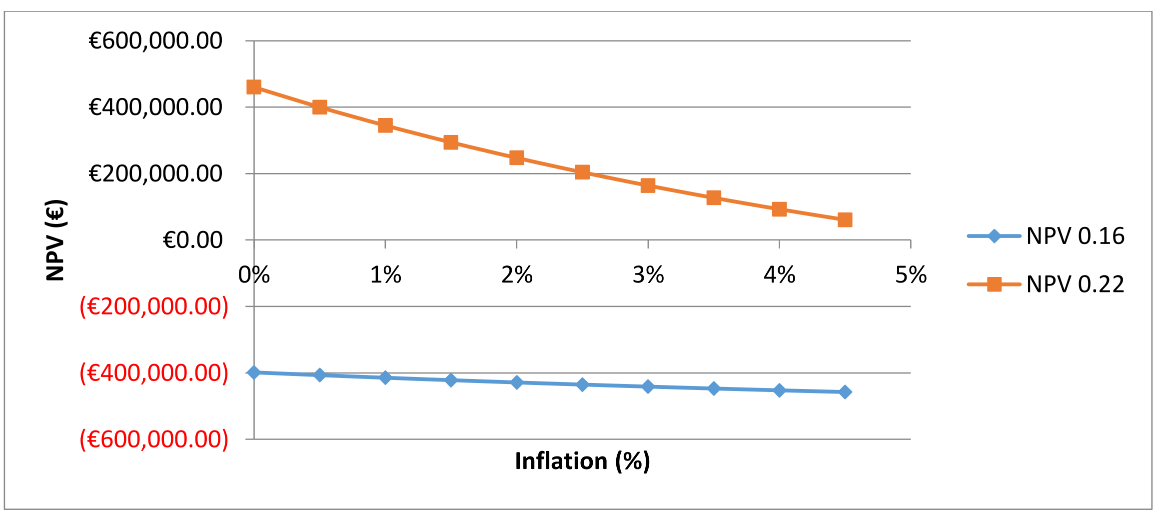


Table 6-4 Result of financial calculations



7 Design method

7.1 Reflective Interactive Design

7.1.1 Introduction to Reflective Interactive Design

In this part of the project the Engineering Design Methods of the Reflective Interacive Design (RIO) (Bos and Groot Koerkamp, 2009) will be used, which consist of the Nigel Cross Method (Cross, 2008). They are used to bring the general concepts which were thought about by the initiators into detailed technical designs. In Figure 7-1 a visual representation of the RIO method is given. The different tasks until I will be executed and discussed in the following paragraphs.

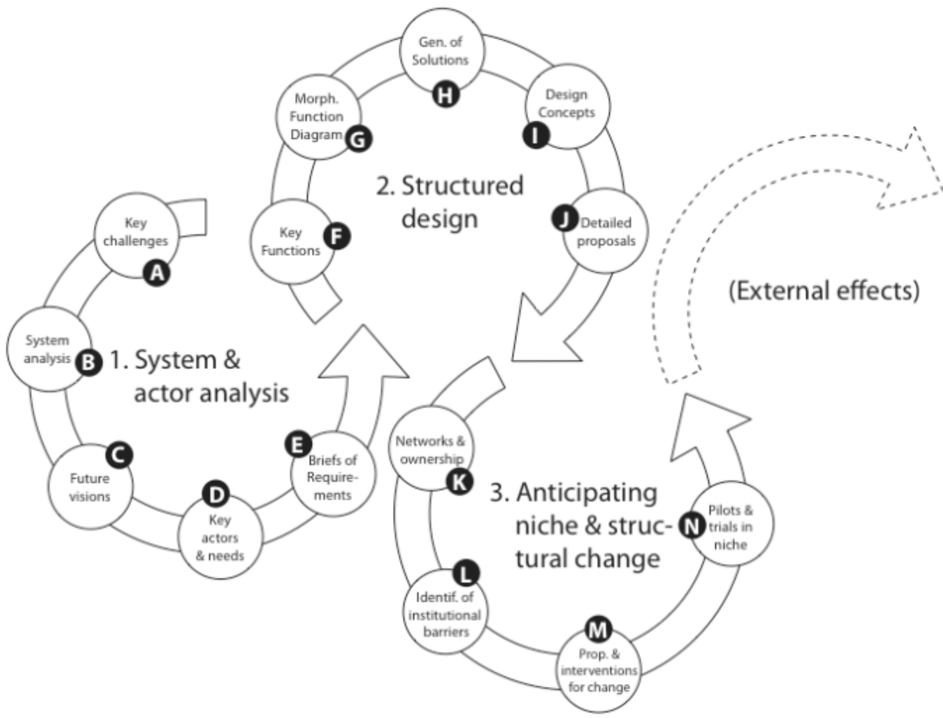


Figure 7-1 Structure of the RIO Method (Bos and Groot Koerkamp, 2009)

Nigel Cross is a professor who is a leading man in the world of design research and methodology. The Engineering Design Methods is a clearly written book, which makes it useful for students to use. The book is also used in the course Biosystems Design at Wageningen University.

The initial concept of the movable solar system is poorly worked out and the purpose of this part of the project is to come up with designs that fulfill all the wishes of the involved stakeholders and all important issues that the system could met should be taken into account. To do so, eight main steps will be done to collect all the building blocks and information that is used. These eight main steps will be explained and extended here. The explanations are based on lecture slides from the course Biosystems Design, which is lectured at the Wageningen University and written and organized by Dr. Ir. Van ‘t Ooster ('t Ooster, 2015).

Part A till D are done by the design team but as background and knowledge base for the further work in the project. Therefore these four parts are merged into the introduction parts together with information that is not part of the RIO. For the understand ability of the used methods these four will also be explained here.

Key challenges

In the Key challenges different channels are used to collect background information of the problem, to get known with the problem. Next to that the need of the commissioner is converted into the real design problem that the project is facing. The need is also formulated as key challenges that have to be overcome.

To know the need of the commissioner and to define them into a design problem, a root cause analysis (RCA) is done. In this RCA, the initial stated problems are analyzed and for every problem the 'root problem' is mentioned and in small steps the real problem(s) are getting clear.

System analysis

In this part of the design process the system is explored and placed within his functional environment. The problem that the commissioner is facing occurs in a certain system, with boundaries and environments. In this part the system is defined for the problem with respect to different aspects. After all, the system is visualized in the three circle chart, where relevant different systems are placed in perspective with each other. Potential difficult links between parts of (sub)systems are identified.

Future visions

Now the key challenges are clear and the system is defined, one is going to define the to be situation. What will be the idealized future for the system is described in this part. The desired situation have to be ambitious but feasible to reach within the near future. Also from these future visions, the main challenges to overcome are derived. These are derived from the objective tree, which present the objectives of the system with their importance.

Key actors and needs

Within this part the key actors that are involved in one or another way are listed and some typology of the actors according to the system are mentioned. For the features one can think of the urgency, legitimacy and power of a certain stakeholder.

Brief of requirements

Here the requirements of the system are correctly listed in the Brief of Requirements (BoR). Requirements can be fixed, a wish or variable. If a requirement is variable, the desired value and the maximum or minimum value have to be given. The requirements are jointed to a certain aspects and actor. With use of the Brief of requirements all of them are ranked according to their importance and on their aspect/actor. In the end, one has all requirements that the system have to fulfil are listed with an overview of more and less important ones.

Key functions

From the BoR, functions are defined or, if they are already there redefined to fit in the designed system. In this stage the real functions of the system are produced. These functions has to help to solve the initial problem. The functions are presented in a function matrix.

To present the functions in a visual way and with that obtain important connections between these functions and how they are placed within the total system, a Device Model will be made in design program Goldfire. Here all functions are listed and described about the content. In the end the selected most important 12 functions are listed: the key functions.

Morphologic function diagram

This is the first stage were concrete solutions for problems are presented. First one looks into already existing patents. This is done for inspiration and to know what is possible to do and what not, according to other patents. For the design process important patents are described, explained why they contribute to the process and the level of protection of the patent is mentioned.

Then the morphologic function diagram is built up. For every generated function of the Key Functions, different solutions to complete that functions are mentioned. Visual presentation in the way of a small picture of drawing are added to the solution.

Generation & evaluation of solutions

With all the generated sub solutions for each function the system has to fulfil, one can make scenario's for which designs will be generated. The generation is done by choosing one or more sub solutions for every function out of all solutions by looking which fits best within the described scenario. In the end, each scenario is converted into a design, where for every function one or more solutions are given. When the solutions are generated, sketches are made for the visual representation and the designs are evaluated to the previous work that was done.

7.2 Brief of Requirements

The design of the movable solar panel system has to meet several requirements. In this chapter all the important fixed and variable requirements are shown. The full list of Brief of Requirements (BoR) is available in Appendix 13.6**.** A requirement is fixed when the system has to meet this requirement, otherwise the system cannot work properly. Variable requirements have got a minimum, a maximum and a target value. The variable requirements are mainly dealing with the size of the system and the financial aspects of the system. There are also some requirements which are desirable, but these will not be taken into account to rank the design. Without fulfilling these desirability requirements, the system can still work properly, therefor they are not used for the ranking as described before.

The requirements are determined first by the ACT Group 1618. When the list of requirements was ready, the BoR was sent to the involved stakeholders of this project. These involved stakeholders were from ACRRES, a research centre for renewable energy, the Skylark foundation who represent the farmers and finally Wim Steverink Techniques who is going to make the construction. A stakeholder workshop was held to evaluate and discuss the proposed requirements. When needed, some requirements were skipped, changed or even some other requirements were added to the BoR. After the stakeholder workshop the variable requirements were listed against each other and all the different aspects got a ranking as well. Together with the aspect ranking, a list of ordered requirements pops up.

7.2.1 Important Aspects

The requirements are all divided into different aspects. These aspects are: Economical, Technical and Social. The Economical aspect is dealing with the financial part of the whole system, so investment costs, electricity prices and yield reduction. The technical aspect is dealing with the design and usability of the movable solar panel system. So it is about the size, weight and the ease of use. The social aspect is about the design that has to fit into the landscape and the noise the system could produce.

In the BoR the aspects are also ranked to find the most important one. According to Table **7-1**, the Economical aspect has the highest weighting factor and the Social aspect the lowest. This weighting factor will be used for determining the most important requirements.

Table 7-1 Weighting factors of the aspects

Aspects	Weighting Factor
Economical	3
Social	1
Technical	2

7.2.2 Fixed Requirements

The design of the movable solar panel system has to face fourteen fixed requirements in total. Most of the requirements have to deal with the technical part. These requirements are dealing with folding, moving and connecting the system. Besides some usability requirements are set because it should be easy for the farmer to move the system in/out the field, without being time-consuming. Also theft security is an important issue, because replacing solar panels is expensive and undesirable. The economical part is about the before mentioned theft security and the energy yield reduction due to shade. There is last but not least one requirement which is dealing with the social aspect: the land use plan doesn't have to be changed. This is important because it causes costs and can require time before it can be implemented.

7.2.3 Variable Requirements

In Table 7-2 the ordered list of all the variable requirements is presented. The values for the requirements are based on assumptions and literature. The first requirement is that one that according to the other requirements is ranked as most important one. Therefore it gets the value 1. The one that has after all the second-high score get a 2 and so on. From the result of the ranking can be concluded that the economical part has the highest influence on the variable requirements. However the only economical part that has a low rank is the reduction of crop growth. This is because the project is about designing a movable solar panel system, not directly minimizing the crop yield reduction.

The only requirement, that is dealing with the social aspect, has the lowest rank. The reason is that this requirement is ranked lower than other requirements during the ranking. 50 dB of noise is not very high and if the noise is loud, it is also possible to wear earplugs to protect the ears, when working in the direct surrounding of the system.

The most important technical requirements are dealing with the design and usability of the system. Also the probability of the requirement to occur is taken into account. For example, the height of the system is more important than the length of the system, therefore the height has a higher rank than the length.

Table 7-2 List of variable requirements

Requirement	Aspect	Rank
The return of investment is at maximum 15 years (Rijksdienst voor Ondernemend Nederland, 2016b)	Economical	1
The investment costs are lower or equal to 2.0 €/Wp (Zonnepanelenkennis, 2016)	Economical	2
The price of the electricity should be at least 0.04 €/kWh (Spruijt and Terbijhe, 2016)	Economical	3
The system after folding together may not be higher than 4 m (Minister of TPWWM, 2016)	Technical	4
The system resists strong wind with a speed of at least 10 Beaufort (Geurts, 2004)	Technical	5
Installing the system takes less than 60 minutes per sub-system	Technical	5
The system after folding together may not be wider than 2.55 m (Minister of TPWWM, 2016)	Technical	7
The weight of the system is less than 2000 kg (Boels, 2016)	Technical	7
The reduction of crop growth is less than 50 % (Dupraz et al., 2011; Marrou et al., 2013)	Economical	9
The power cable between the sub-systems has a length of 100 m at maximum (Goodpal, 2013)	Technical	10
The system after folding together may not be longer than 12 m (Minister of TPWWM, 2016)	Technical	11
One sub-system exists of 20 Solar panels (Caplehorn, 2012)	Technical	11
The noise of the solar panel system is below 50 dB at one meter (Tech Environmental Inc., 2012)	Social	12

7.2.4 Desirability requirements

In the BoR are six requirements which are desirable. These requirements are wishes but not fixed or within a range. Some examples of these requirements are that the energetic yield of the solar panel system can be read out per sub-system, the system is remote controllable, that the systems can be replaced by one person and that the position of the panels can change when there is too much/less sunlight.

7.3 Key Functions

7.3.1 Function Matrix

To know how the system should look like, first it should be clear what the system is expected to do. One of the tools for that is to set up the functions that the system has to fulfil. One can check after the design phase if a certain design could fulfil the functions or not. These functions can be mechanical, but can also have to do with information streams for example. Here the functions of the system are listed according to three main objects the design team came up with. The result of this chapter can be seen in the function matrix below.

The matrix is built up with a few objects and a few verbs. The objects are: matter, animals/plants, natural enemies, energy and information. The verbs that have to do with these elements are transporting, transforming, accumulating and separating. Per object the design team thought about the possibilities within the subsystem and how to formulate these functions. The functions describe how something will [one of the verbs] [one of the objects].

In this function matrix below, Table 6-4, the result of this paragraph is shown. In the table all relevant defined functions of the system could be found. The most important objects are matter, energy and information. These objects have to be designed in an optimal way to have to good movable solar panel system. Matter is the used material/hardware and therefore mainly dealing with the constructional part of the system. However, natural matter like gasses and liquids for example are also placed under matter. Energy is mainly about the electronical part of the system, so how to produce and transport the energy coming from the solar panel. It could even be possible to store the energy and use it at a later moment. Energy is also needed for the crop to grow, so also some parts of the energy column are dealing with energy for the crop growth. All other functions that have to do with the crop but which cannot be directed to one of the other objects are placed in their own column animals/plant. This is because the main function of the neighbouring system soil has crop growth as main goal. Therefore the crop growth and functioning of the system within the crop growing system is another object. The information object is important to monitor the whole system. The information can be used for management of solar panel system on how to use the solar panel system in an optimal way to combine it with the crop cultivation.

The Natural Enemies object is about the diseases that could be present on the crop plant or which could be transported through the field to other crop plants. It cannot be designed, but can have an influence on how to execute the crop care. Finally, the object Animals/Plants is about the crop cultivation from seeding till harvesting and the transport from and off the field.

Almost all of the functions will take place in the operational phase of the system. Therefore, almost all functions have a ‘O’ in front. There is only one manufacturing phase (‘M’) and has to do with transforming all lose parts into a movable solar panel system.

Table 7-3 Function Matrix of the movable solar panel system, where "O" stand for Operational phase and "M" for manufacturing phase

	Matter	Animals/Plants	Natural Enemies	Energy	Information
Transport	▪ O: Solar panels can be transported into the field. ▪ O: Solar panels can be removed from the field. ▪ O: Cables can be transported for installation of the system.	▪ O: Seeds are transported to the field. ▪ O: Mature wheat is harvested and transported to the farm.	▪ O: Diseases could be transported by machinery such as tractors.	▪ O: Solar energy is transported by the cables from the solar panels to the grid connection	▪ O: Information of energy yield can be transported to the farmer (e.g. smartphone)
Transform	▪ M: Building materials and elements are transformed into a movable solar panel system ▪ O: Transform water and fertilizer into biomass. ▪ O: CO2 is transformed into O2 by the crop	▪ O: Transform seeded wheat into mature wheat during the season		▪ O: Solar energy is transformed into electrical energy. ▪ O: Solar energy is transformed heat ▪ O: Solar energy is transformed into crop growth by photosynthesis.	▪ O: Sensor measurements were transformed into useful data ▪ O: Data is transformed for the management.
Accumulate	▪ O: Solar panels are stored at the field	▪ O: Biomass (wheat) is stored at the field during the growing season.	▪ O: Diseases could accumulate at the crop	▪ O: Electrical energy could possibly stored at the farm to be more profitable by selling high value energy outside the energy producing peaks. ▪ O: Solar energy is accumulated in the crop.	▪ O: All sensor data of solar energy yield is collected and stored for further management. ▪ O: All data of crop yield is stored to see the long-term effect of the movable solar panel system on differences in crop growth.
Separate	▪ O: All different solar panel sub-systems can be separated. ▪ O: Cables for the connection can be separated from the whole system	▪ O: Mature wheat is separated from the field. ▪ O: weed is separated from the growing wheat.		▪ O: Solar energy will be separated into electrical energy, heat and crop growth.	▪ O: Management and sensor data will be separated into outputs for the actuators

7.3.2 Device Model in Goldfire

Like explained in the introduction part of the RIO section, the functions that were listed in the previous paragraph does have many relations, influences and dependencies with other elements within the system. To get an overview of the whole system according to the behaviour of the functions, a Device Analysis was executed with help of the design software IHS Goldfire. This analysis is a visual representation of the relations etc. within the total. The design analysis consists of two parts, the whole system (where the movable solar system is part of) and the second one is focused on only the movable solar panel system.

In the first layer (Figure 7-2), the super system (green boxes) are presented which has relations with each other and with components of the system (white boxes). The system also has some targets (yellow boxes) which also could have relations with other parts of the system. In the Device model, all the relations, both useful (blue) and harmful (orange), between the components, super systems and targets are given.

The five targets of this system are the CO_2 reduction, Social Acceptability, Crop Growth, Electricity and Profit.

To focus on the targets of the Device Analysis it has to be mentioned how the targets can be influenced, because both the components and the super systems affect the targets, but the design can only influence the components and thus not directly the targets of the system.

In Figure 7-3 an overview is given of the second layer, what is the system that has to be designed, the movable solar panel system. Also here all the relations are given. As can be seen, most of the components are in this part of the Device Analysis. The construction component is one of the most important ones in this analysis, because a lot of components and super systems have a relation with the construction as can be seen in the figure.

Based on all the functions out of the Device Analysis, together with the Device Analysis which shows the interaction of the different functions within the system, the most important key functions of the potential designs can be derived, which are needed later on in the design process. These key functions are mentioned and explained in the next paragraph.

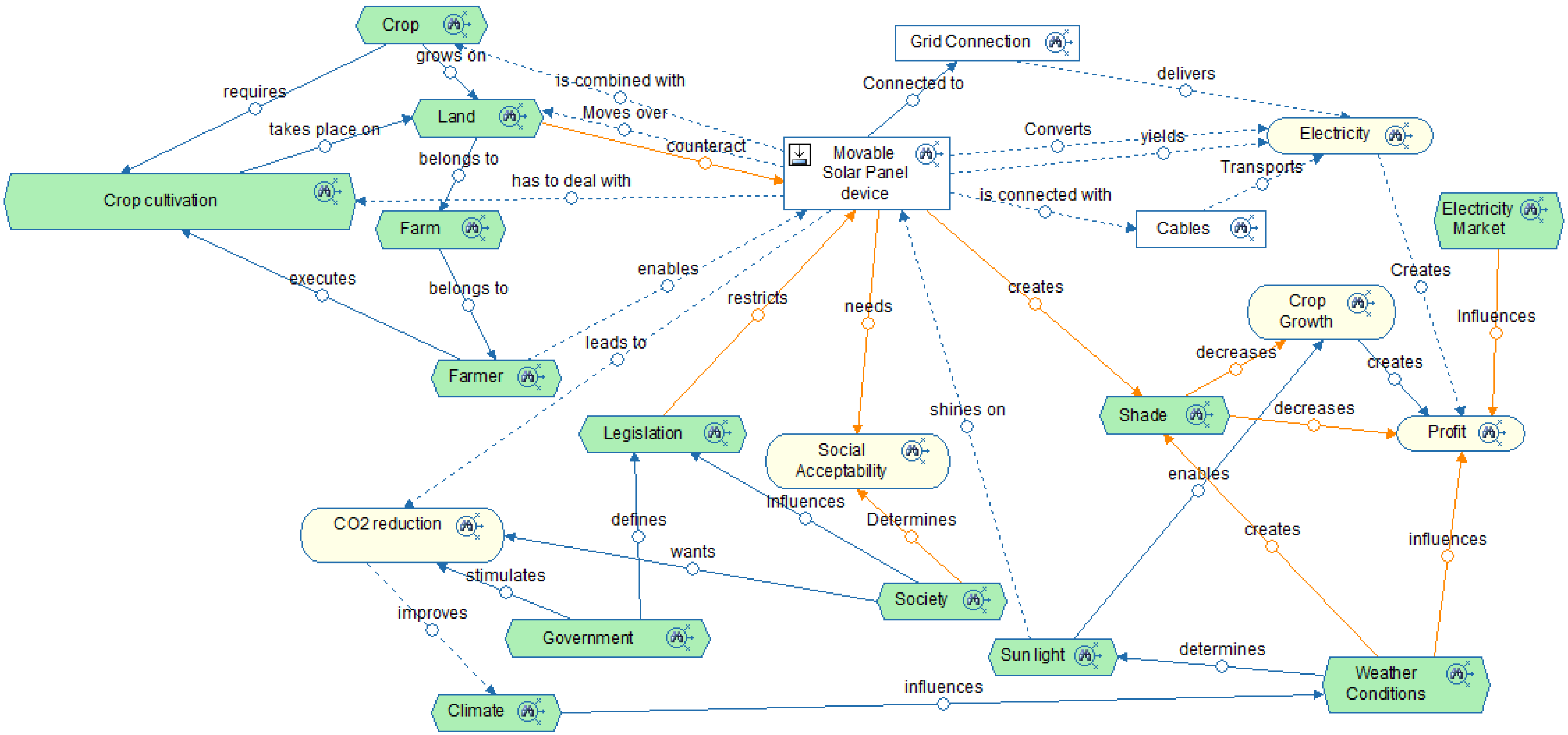


Figure 7-2 First layer of the Device Analysis of the model in Goldfire

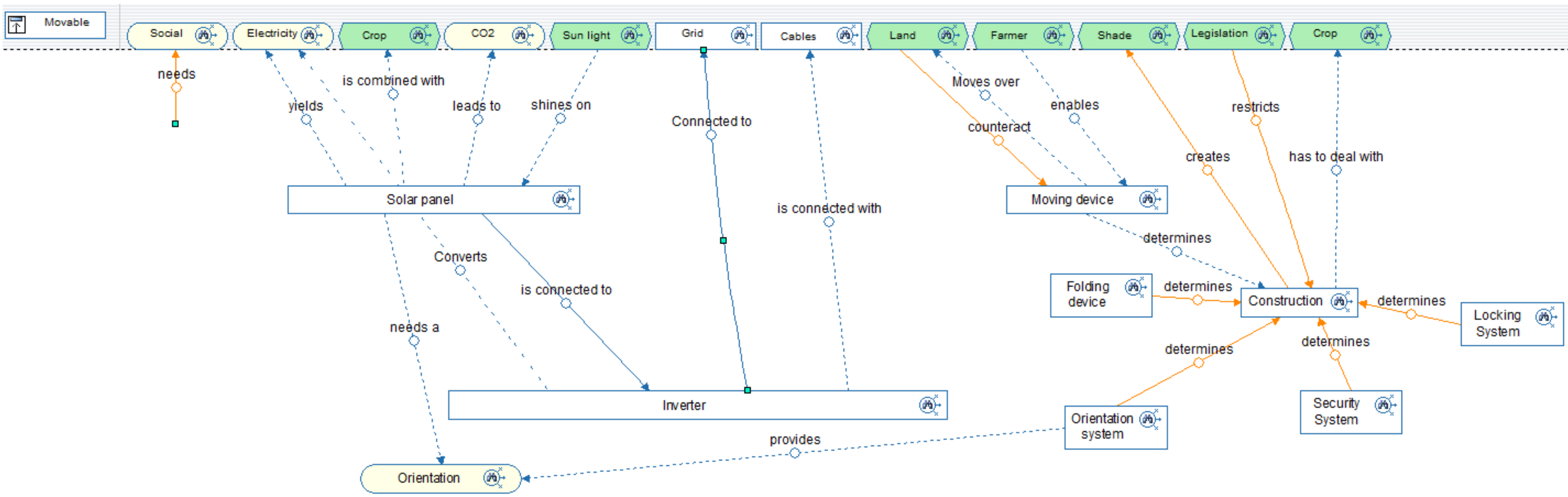


Figure 7-3 Second layer of the Device Analysis, the Movable Solar Panel Device

7.3.3 The Key functions

Based on the outcomes of the Device Analysis and the function matrix, the most important Key functions are determined. The Key functions are dealing with the main functions the system has to fulfil when it is in operation in the field.

The following eight functions are the key functions:

- Transport system transports the system
- Technics compresses unit size
- Solar panels optimizing solar yield
- The system is secured for theft
- Panel type mounted on the construction
- Construction supports the system elements
- Inverter inverts from DC to AC (current of the grid)
- Cables connecting system to grid

The first function has to be designed because the system must have the opportunity to be placed on different fields during some years. To make the transportation work easy, it is recommended to compromise the system into manageable components. To increase the yield of the system, it is important to orientate the system towards the sun, therefore an orientation system could be a solution. To catch the sunlight, solar panels are needed. Currently, there are a lot of different kind of solar panels available with different efficiencies in yield and also in transparency. When the product is ready, a security system is needed to secure the system against theft. To build the whole system, it is very important to think about the construction materials and how to build the whole construction. This has an influence on the weight of the construction and costs.

Also the converter has an influence on the yield of the system. Some inverters are for example able to deal with shade. To transport the energy from the sun to the grid, a connection has to be made between these two elements. There are multiple options possible, all with (dis)advantages.

In the next design step, these functions are the central functions the system has to fulfil. For every function a couple of possible solutions will be presented after looking into existing patents.

7.4 Morphologic Function Diagram

7.4.1 Patents related to the system

Before diving into the problem solving, already existing patents will be analysed in the design field. When looking and later on using solutions, one helpful tool is to take already developed solutions into account. This is important for two reasons. 1) If someone else patented a certain invention which could solve your problem, one has to be careful in implementing a solution, because someone has a patent that may not be copied or used in the way that is described. 2) Furthermore, it is useless to design the wheel again. Therefore, looking in already existing patents could be inspiring and motivating. One can learn of previous done work to implement that into their own design.

This paragraph will have a quick focus on the patents that exists on the field wherein the design process takes place. The patents that can form constraints for the process are mentioned to prevent plagiarism of existing systems that are patented. Next to that, some patents that can inspire the design process are mentioned in this paragraph.

The first patents are dealing with solar energy systems that can be moved in sense of location. Different types of carts, trailers and wheel platforms are described here.

WO2012170988 (A1) Portable, self-sustained solar deployment (Curran, 2012)

A portable solar system mounted on wheels with at least one solar panel array. The system is able to retract or deploy the panels to or from the main support frame, as shown in Figure 7-4.

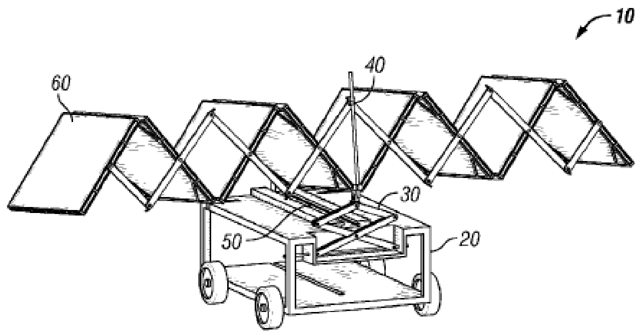


Figure 7-4 Portable, self-sustained solar deployment

US0062011811 (B1) Portable solar module cart (Azzam, 2001)

A simple foldable system with one solar panel mounted on a frame with wheels attached to it (Figure 7-5).

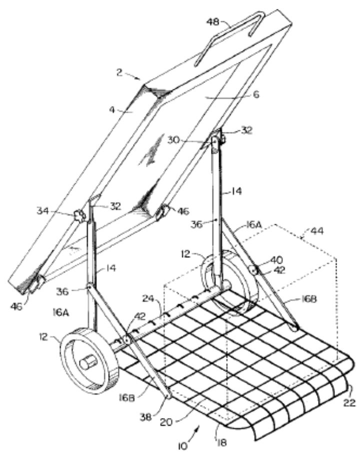


Figure 7-5 Portable solar module cart

US4261329 (A) Multi-transport modular solar energy system (Walsh, 1981)

A trailer with solar panels mounted on it. The system is self-containing and multi-functional to be able to work with different types of solar energy modules. The trailer itself is the transportation unit of the system (Figure 7-6).

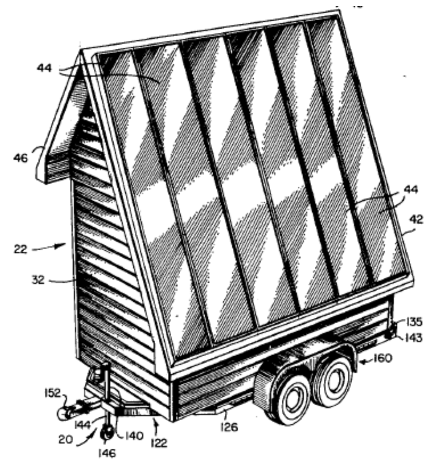


Figure 7-6 Multi-transport modular solar energy system

KR101615747 (B1) MPPT An efficient improvement method for maximum power point tracking of the solar inverter in case of partial shading

In case of partial shading the efficiency of the solar panel system will decrease rapidly. To minimize the reduction of the effect of shading on the solar yield, one has developed an efficient improvement method for maximum power point tracking of solar inverter in case of partial shading.

The second part of patents are dealing with movements around a fixed frame of unit. Some of these patents are moving in a way the crop will benefit from it.

US8492645 (B1) Transportable solar power system (Strahm, 2013)

A battery containing system that can deploy and retract itself in or out a base frame. Within this frame the energy system is still working but protected for transportation. In deployed state, the system is able to track the sun to optimize the solar yield with knowledge of a sun chart of the GPS location. Energy will be party saved in an included battery to make the system able to unfold after a period of darkness.

US20160073591 (A1) Reconfigurable solar array and method of managing crop yield using the same (Surany, 2016)

This patent is about the concept of combining crop growing and solar yield, with a special focus on optimizing crop care. The system is reconfigurable in order to deal with the most optimal shading levels for differ types of crops. Another advantage of the system is the protection that it can provide to the crop against damage due to hail and wind.

The next patents all have to do with optimizing the efficiency of the solar energy system in different ways.

US20160139235 (A1) Method for tracking a solar generator to the sun, control for a solar plant (Bruno, 2016)

This system tracks the sun in a way that the output quantity of at least a part of the solar energy system is controlled in a way to equal a value that is wanted and given at forehand as can be seen in Figure 7-7.

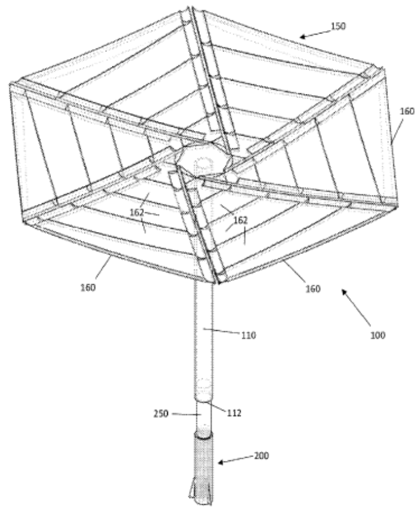


Figure 7-7 Method for tracking a solar generator to the sun

Here some other patents are mentioned that have to deal with the design project.

US009328942 (B1) Solar panel racking system (Kristian, 2016)

A racking system for solar panels that greatly reduces material and labour and with that time and money. A more efficient way to mount solar panels on a roof, field or other construction compared to the common systems (Figure 7-8).

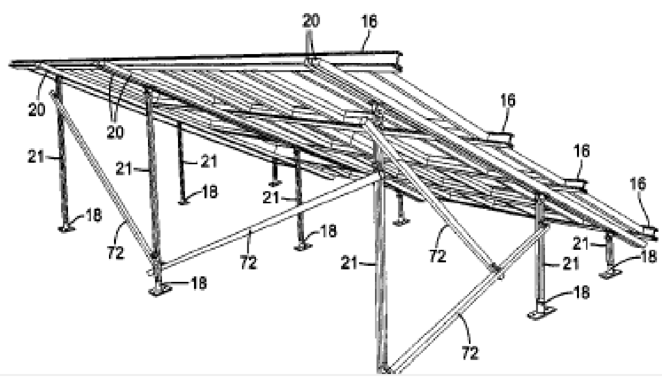


Figure 7-8 Solar panel racking system

KR20160020696 (A) Transparent conductive film where multi-layer thin film is coated

This patent is about a transparent conductive film with a high photo transmission. Due to the transparency this type of solar panel is highly suitable to implement within the solar panel system in combination with growing crops, because less shading on the crop will occur compared to normal solar panel systems.

KR20160001086 (A) Grid connected system for photovoltaic generation using energy storage system

A system with adaptations to the peak loads on the grid. By controlling the micro invertors, the batteries and the energy from the grid, a well operating power demand system is developed.

7.5 Morphologic Function Diagram

The Morphologic Chart (MC) is a visualisation of the selected key functions with possible solutions for these. For the filled in chart, see Figure 13-3 in Appendix 13.7.The MC is made with use of the eight key functions that were generated in an earlier stage in the design process, see paragraph 7.3.3. For the functions, possible solutions were found by using different methods. From literature research, for each function different techniques were found that are used or researched nowadays. The technics that can be a solution, which can be used within the key functions are mentioned in the MC. Furthermore, common solutions to a function are also mentioned.

In the previous chapter, some patents were found that could inspire the design. The most supporting patents are used within the MC. For each of this patents the level of protection for the movable solar panel system will be explained.

US4261329 (A) Multi-transport modular solar energy system

This patent is used to fulfil the function of transport of the solar systems. A solution for this objective could be that the system itself is able to be moved around by being pushed or pulled. This patent is about solar panels mounted on a trailer. The content of the patent is so general that no problems in the design with this patent are expected. For this US (United States) patent, the A means that the patent is granted within the mentioned region (US).

WO2012170988 (A1) Portable, self-sustained solar

A technic to compress size of a system is to fold a system together. This solution is commonly used in agriculture. For example, most big cultivators or seeding machines are in working mode wider than the allowed sizes during transportation on the road. Therefore, these machines can be (mostly) hydraulically fold together. For a solar panel system, a patent is found for a device that uses this technic. However, this technic is widely used, therefore the protection level of this patent is low because the patent is about the whole system with the panels mounted on a foldable frame with wheels mounted to it. If the patent is not about a detail of a system, the owner of the patent is not able to get no competitors, because a slightly different system will not fall under this patent. For this WO (World Intellectual Property Organization) Patent, the A1 means that the patent is an international application with search report.

US009328942 (B1) Solar panel racking system

A solution for the construction is described in this patent. It is an idea of a low weight construction which is therefore more easy to handle. The level of protection of the patent is also low, because this has to do with a specific combination of materials in a certain way. A suitable frame can be made with this solution in the mind. For this US patent, the B1 means that the patent is granted and published.

In the following text parts of the MC will be explained that will probably not speak for themselves when reading the MC in Figure 13-3 in Appendix 13.7. The text will not explain all solutions of the MC.

The first solution that needs more explanation is that in the transport function, the fourth mentioned solution has to do with rails. Here a link is possible with the Lasting Field project (Steverink Techniek, 2014). The movable solar project can potentially be integrated into this project because of the same initiators. Lasting Fields is a project where the transport between fields of one farm is mainly replaced by an autonomous rail system. If this system is implemented on farms, the solar panel system can move around using the rail system.

The second explanation comes up by the fact that in the technics to compress the size of the solar panel system, making the system rotating is a potential solution for compressing size. To explain this, one has to understand that with this solution nothing more is meant than the fact that some rotating parts of a system can be rotated in such a way that it supports compressing the total size of the solar panel system.

Another subject that is good to mention is about the last function. This function, cables connecting the system to grid, have to do with the connection on the field. So from the panel system to the grid. The grid itself is the responsibility of the grid management company, but the cables in between have to be placed somewhere between grid and system and for that some solutions to solve this problem are mentioned.

7.6 Generation & Evaluation of Solutions

In this paragraph the different scenarios of the developed systems are explained and visual presented with pictures and drawings. Choices made within the scenario will be made clear. For the design project four scenarios are produced to fulfil different types of focus on the system. Each of the scenarios has to fulfil all the functions that were mentioned in the previous paragraph. For every scenario, per function one or more solutions that fits the best to the scenario are chosen.

7.6.1 Solution A: Profit Optimisation

The first solution is focussing on the optimisation of the profit. This scenario focuses on the combination of wheat and solar power yield. In this scenario a system that can be folded and slide together to a more compressed size is placed on the field. More of these sub units can be placed on a trailer to move to another field or location. The mono crystal panels are mounted flat. This makes the system cheaper in comparison with rotating systems. Mounting the panels in a flat way is cheaper because less complex construction is needed. From the SunShade model, describe in paragraph 5.1, it is known that the extra solar yield of panels mounted under an angle is only 2%. Next to that, the flat panel system fits better into the landscape and cannot create shadow on the neighbouring solar panels. The sub-units will be placed on the field where will be less shade from trees or buildings. Therefore, a string inverter works perfectly with this system. The connection to the grid is done by a cable that is rolled out over the field. An overview of all the chosen solutions is given in Figure 7-9.

Figure 7-9 Solution A: Profit optimisation

7.6.2 Solution B: Environmental impact optimisation

The second system design is a design which is focussing on a low impact on the nature and landscape environment. Therefore, transport of this system will be done by a rails system, which can be an easy, silent and sustainable way to move the systems around, cause no fossil fuel is used here and therefore the CO_2 production is reduced. The mono crystal panels are placed in a way that they can track the sun.

This will be done by moving the panels on a double axis, this will improve their solar energy yield. There is chosen for mono crystal instead of poly crystal panels because of the higher efficiency of the mono crystal panels. With the higher efficiency more solar energy will be collected with the same amount of panels compared to poly crystal panels. The power inverter also optimises the solar yield, because it can deal with small shade spots. The system maximal yield is, with these power inverters, not reduced to the smallest yield of each sub-system. The more rotating parts, the more material is needed and the more energy went to rotating and controlling these parts. Therefore it has a lower environmental impact when minimizing the use of extra servo's or machinery. To do so, chosen is that the solar system will be demounted in smaller parts to compress size. The cables will be dig into the ground to maintain the landscape environment during the wheat growing season. In Figure 7-10 an overview is given of all the chosen solutions.

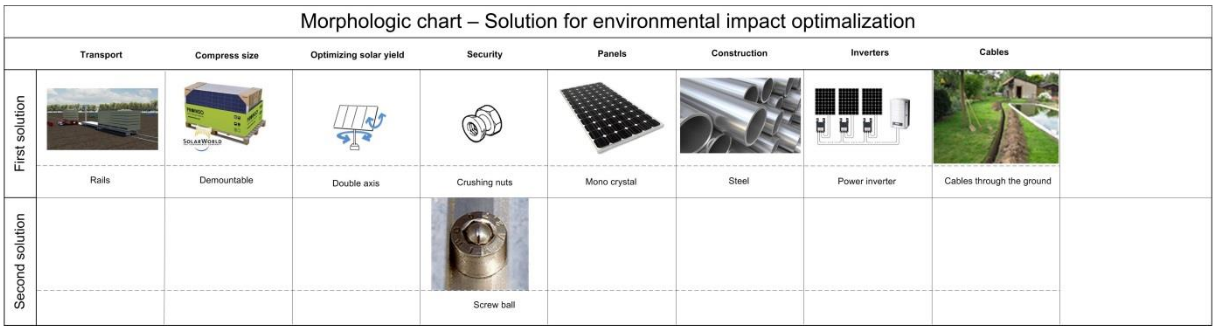


Figure 7-10 Solution B: Environmental impact optimisation

7.6.3 Solution C: Low Cost System

For the low cost system (Figure 7-11), the purpose speaks for itself. For every sub-solution, the solution with the lowest system costs is chosen to be implemented. Therefore, the system will also be demounted by hand and the different parts are transported on a trailer. The cheaper poly crystal fixed solar panels are mounted on a construction of steel, which is a cheap material because of the common use. The system cannot deal with shade spots since it makes use of a string inverter. The security is done with relative cheap solutions to make theft more difficult.

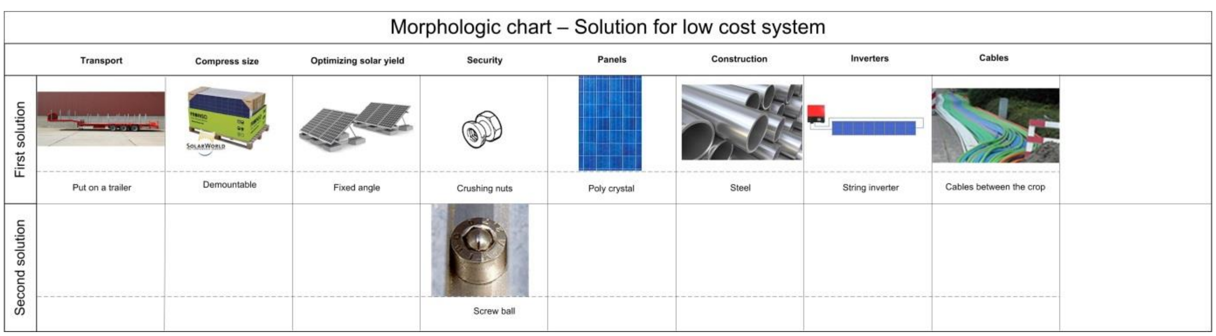


Figure 7-11 Solution C: Low cost system

7.6.4 Solution D: Future Ideal System

The future ideal system (Figure 7-12) is created with a focus on the future. New upcoming or even non existing technologies or methods are applied to create the theoretical most optimal system where wheat losses are minimised and at the same moment the solar yield will be as much as possible. Within the choices of this system, the price of parts or principles was not taken into account. Therefore, the system will contain for every problem the best solution, which is probably not financially feasible within the coming ten years. But technologies are developing very fast and products gets cheaper . Especially within the solar panel business, prices are decreasing rapidly (Mearian, 2015).

This system has Liquid Solar Arrays (LSA) that can be moved on two axes. The system will track the sun and monitor his own solar energy efficiency and the crop growth. If the efficiency is getting lower and the crop has a lack of solar energy, the LSA's can be turned in such a way that the crop gets more attention than the solar panels. The panels can be turned around, so they can cool down. A big advantage of the LSA in comparison with the common panel systems is that they need less solar sensors, because they are using a lens in each component to merge the solar energy together to one certain point. Next to that advantage, the sun that is not captured within the solar lens, is not adsorbed or reflected, but can go through the plastic lens to get to the crop.

If the system is not needed on the field anymore, the system can be fold, turned and slide together before it will autonomously move to another location.

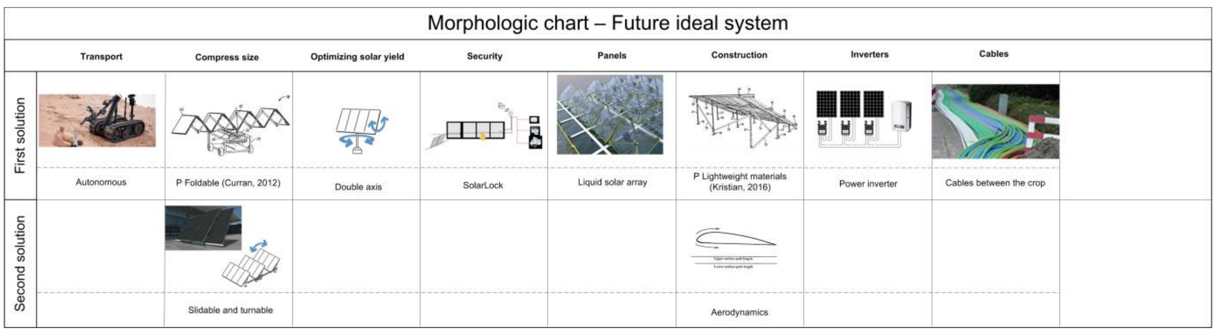


Figure 7-12 Solution D: Future ideal system

7.7 Assessment of Solutions

Out of the Morphologic Chart four different design concepts were created like seen in the previous paragraph. These four different design concepts were focussed on "Profit optimisation", "Environmental impact optimisation", "Low cost system" and finally the "Future ideal system". Comparing and ranking these four different designs is necessary to evaluate them. For ranking the systems, the Kesselring Evaluation and the Radar Plot are used, which will be described in the following paragraphs.

7.7.1 Kesselring Evaluation

In the Kesselring evaluation, all evaluations of the designs are plotted in a graph with 2 aspects on the X- and Y-axis. The most ideal point is where both aspects scores 100%. In Figure 7-13 the ideal point is represented in the upper right corner with the red dot. The closer the distance to the ideal point, the better this design will be for these 2 aspects. As can be seen in Figure 7-13, the most optimal design is focussed on profit optimisation. This design scores 80% on economics and 84% on the technical aspect. The future ideal situation scores better on the technical aspects since this design is more advanced. However, a disadvantage of this design are the high costs, which declare the low scoring on the economical aspect. The other two systems all have lower percentages on both scales and therefore are less suitable than the future ideal and profit optimisation systems on these two aspects.

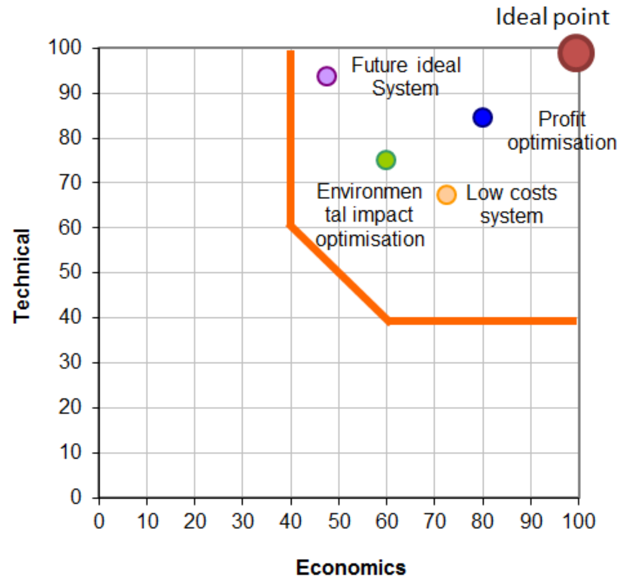


Figure 7-13 Kesselring evaluation with the technical and economic aspects plotted against each other

For the other two Kesselring graphs the social aspect is included, but this social aspect consists of only two parameters, see Figure 13-4 and Figure 13-5 in paragraph 13.9. The first one, a fixed requirement is about changing the destination plan, which for all systems is not necessary, so they scored the same. The second parameter, the variable requirement, is about noise production, where the future ideal design scores the best. This highest scoring for the future ideal design is caused by the more advanced system which produces as less noise as possible. For the profit optimisation only the economic aspects are important, and therefore the more advanced systems which produces less noise will not be seen as best design due to a lower score. Therefore, only this variable requirement is not reliable enough to rank the four different designs.

7.7.2 Radar plot

In this paragraph the four different designs were ranked with the Radar plot. Therefore, all percentages that the designs obtained within the Kesselring were converted into scores varying from 0 till 5. So if an aspect scores between 0 and 20%, the score will be equal to 1. The remaining 80% is equally divided over the other 4 scores.

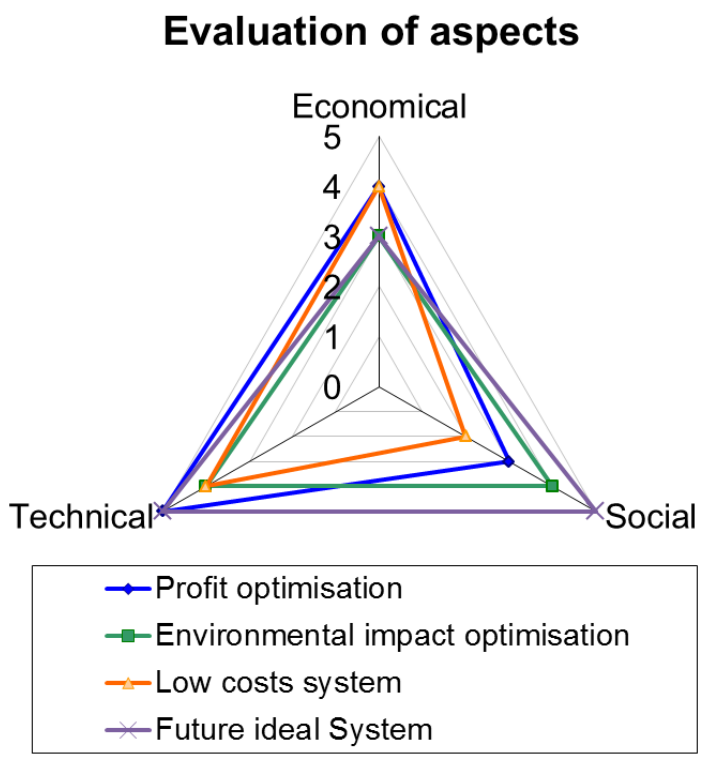


Figure 7-14 Scoring the four different designs with a radar graph. For the three different aspects, the percentages were converted into scoring number from 0 until 5. The better the design, the bigger the distance from the centre.

As can be seen in Figure 7-14 the profit optimisation design scores best on the economic aspect even like the low cost system. However, the low cost system scores the worst on the social and technical aspects. Therefore, the profit optimisation is, according to this scoring, overall more suitable to name the best design.

For the technical aspect the score of the profit optimisation design is equal to the future ideal situation. At the other hand, the future ideal situation scores lower on the economic aspect due to the high costs. The future ideal situation scores best on the social aspect, but this aspect is not very reliable, as described in the previous paragraph. Therefore, here the same can be said. The profit optimisation scores better overall than the future ideal vision.

So if the social aspect is ranked as less important, the environmental impact optimisation scores the lowest of all the scenario’s. The bottleneck such as the high investment costs for the future ideal design will make this design still not usable. Finally, the best design is the one focussed on profit optimisation.

7.8 Design Concepts

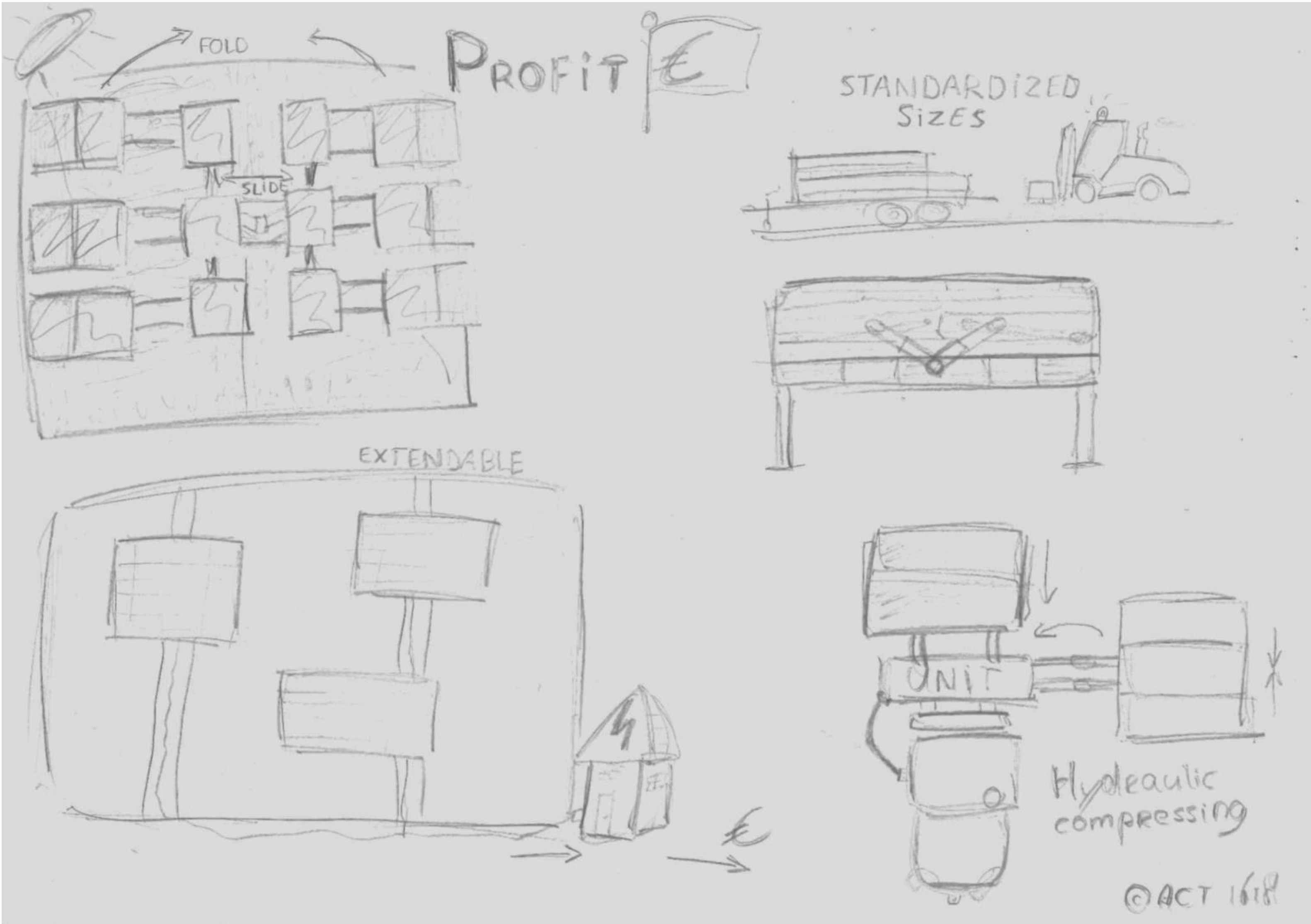


Figure 7-15 Visualisation of the design Profit Optimisation

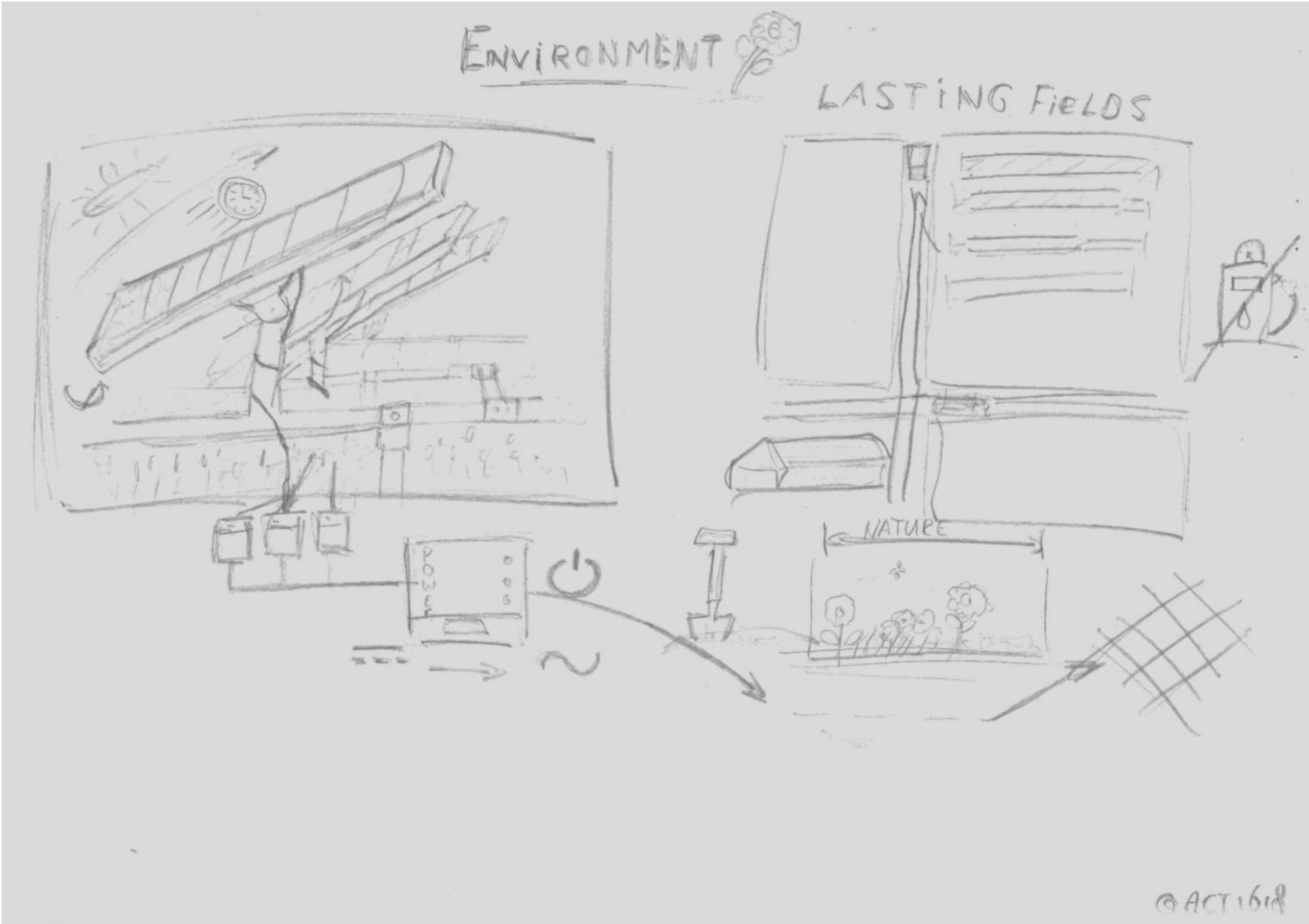


Figure 7-16 Visualisation of the design Environmental Impact

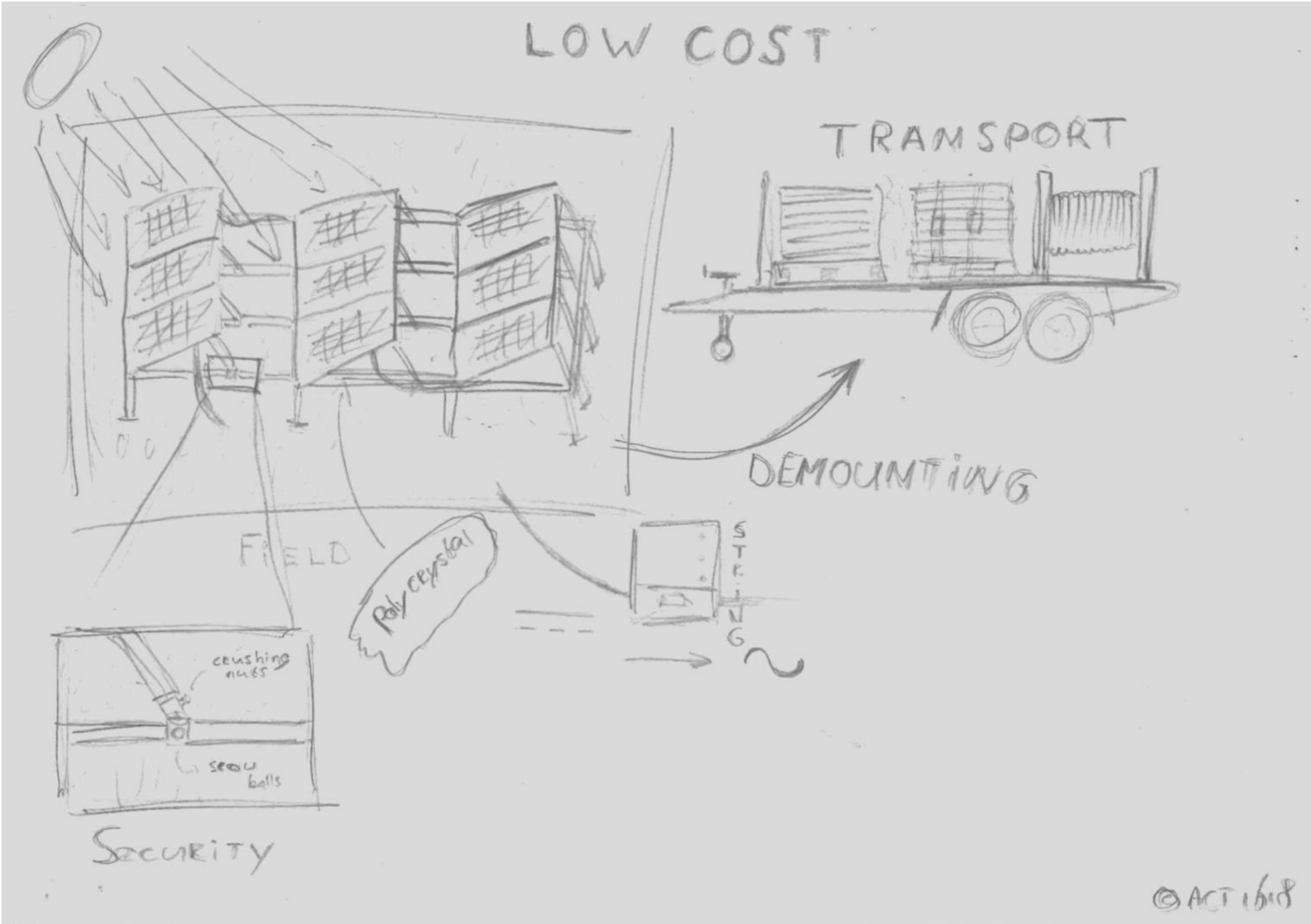


Figure 7-17 Visualisation of the design Low Cost System

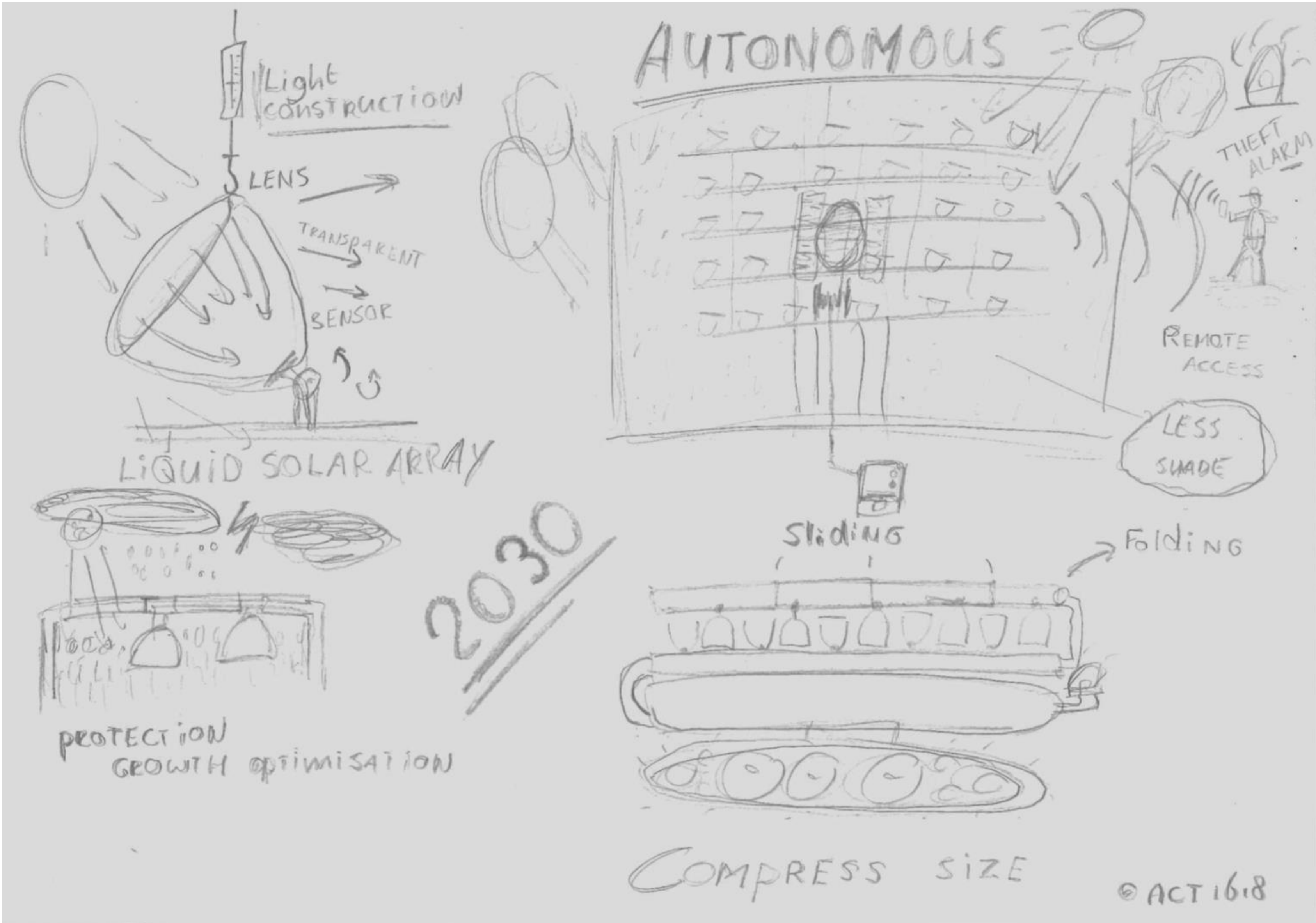


Figure 7-18 Visualisation of the design Ideal Future System.

8 Bottleneck Analysis

Creating a system to produce solar energy and crop simultaneously is a challenge. In this report four possible solution for this problem are mentioned, but these designs have to deal with several bottlenecks. The bottlenecks which will be mentioned in the next paragraphs should be solved or taken into consideration when developing and implementing the real project.

The first bottlenecks come from the design itself. In the design process four designs were produced, but during this design process the total amount of construction is not taken into account. Therefore the total weight of the system is not calculated. If this weight is too high or the construction cannot deal with the weight it has to carry, the design does not satisfy. If the construction has to carry a large amount of panels, the construction can also become too complicated to build or to implement on the yield.

Another bottleneck according to the design is the installation time. This installation time can be more than expected and could therefore deter possible customers/farmers to invest in this system. If the installation time is too long according to the farmers, they will not buy the system because the disadvantages of extra work are more than the advantages of extra revenue from solar energy. The installation time becomes even more important if the system has to be removed for spraying and fertilizing. If the system remains in the field during spraying and cultivation, these objects will influence the performance of both crop cultivation activities. This could also be a bottleneck when the fertilizer or chemicals are not equally distributed over the field due to the solar panel systems in the field.

The second part of the bottlenecks has to do with the cultivation of crop beneath the solar panels. If a crop grows beneath the solar panel construction, the crop, e.g. wheat, will receive less solar energy while this energy is captured by the solar panels. This shade can lead to a possible bottleneck namely the quality of the wheat product. If the product beneath the panels will not ripen well, the wheat could not be harvested. If the solar panels are removed and the whole field will be harvested by a combine, it will be unpractical to harvest only the ripe wheat. If the ripening problems will occur in reality is still not clear, because no clear information in literature was available about this problem. Another possible bottleneck of the combination of crop with these solar panel system is the installation and the elimination of the system. When these activities have to be done, the crop around the solar panel system will be damaged by machinery or walking people. This damaged crop is a bottleneck when the wheat is ready to harvest, this will reduce the crop yield.

The third part of this bottleneck analysis has to do with the legislation. A new designed system has to deal with legislation such as the building law. If the construction is lower than 5 meter high, the building law does not apply. If the construction is higher, which will presumably not be the case, this building law becomes a bottleneck.

Another part of the legislation is the usage plan of the land. The system has to fit into this plan, otherwise there will be no permission to apply the system. These two laws are important and could become a bottleneck as described before.

The fourth part is about the finance of the whole system. The investment costs are still high compared to the revenue. So till now, most of the times subsidy is needed to make these systems profitable. This high investment is therefore a bottleneck if there is no possibility to get subsidy.

Before the system can be installed, a connection to the grid is necessary. If there is no connection to the grid available, for example on an external field, the installation costs of such a connection will be €50,000. This high investment is also depending on the distance between the grid and the solar panel system. These high additional costs should be considered and could become a bottleneck as well.

After the installation solar energy will be sold to the electricity company. Logically, the price paid for this solar energy has to be more than the Levelized Cost Of Electricity (LCOE), or in other words the average total costs of producing solar energy. In addition, these systems will be purchased for a period of 25 years, which is equal to the average lifetime of a solar panel. For this relative long period, also the inflation and loss of yields over the lifetime have to be considered in the LCOE. These aspects are important possible bottlenecks for the financial part of the system.

Finally some bottlenecks will be described for the social acceptability. These bottlenecks have to be considered while the neighbourhood has to accept these systems, otherwise this plan is not feasible. A possible reaction could be the “Not in my backyard” reaction. Another important bottleneck caused by social acceptability can be the mistrust towards the preparatory and decision-making process of the project. If this bottleneck will occur, the project has to deal with these problems.

More information about the above mentioned bottlenecks can be find in the relevant section. These possible bottlenecks have to be considered before the pilot project could start.

9 Discussion

In this chapter the results found in the previous chapters will be discussed.

The social acceptability is based on the available literature about social resistances found by recent projects on renewable energy, both solar and wind energy, in developed countries. In the literature a lot of different factors were listed about the social resistance against solar panel systems, there were even some discrepancies between some papers. In this report therefore only the most important and corresponding points where mentioned. Therefore, it can be possible that some aspects were not mentioned because other authors found it not that important but maybe they are.

The overall chance of getting a permission is positive due to the energy policy of the Netherlands, but when the system exceeds the production of 500 kW, a special permission is needed. Therefore, it is important to take this into account. Besides the willingness to give a permission can be different from place to place due to different environmental circumstances. This makes it hard to predict if the local government will give the permission to use land for harvesting solar energy with solar panels next to crop cultivation. Also the subsidy the government can give to the solar investment can be limited, which means that it can be less attractive to invest in the movable solar panel system.

Determining the crop production was really hard. In the literature there was a lot of information available but not in the content that was needed. Therefore, some rough estimations were made, which has a big influence on the correctness of the model output. The estimations were based on a lot of different variables that are described in different ways in articles from all over the world. The estimation of the production is based on assumptions of the shade beneath the system. This is a rough estimation, it is hard to determine the exact shade on the plant, because it is depending on a lot of different factors. The water and temperature household is also different compared to normal crop cultivation. Therefore, it is hard to determine the real crop production underneath the solar panel system.

In the solar irradiation model real input data could be used. But because the calculations were made with a constant electricity price, this data was simplified to a yearly radiation sum. When dealing with a fluctuating electricity price it is important to use hourly data instead of yearly data.

In the model also the influence of placing the solar panels on an angle of 0° and 20° was calculated. Based on the result of the model placing the solar panels on an angle of 20° resulted in an additional yield of only 2%, which is rather low, because almost all solar panels will be installed on an angle. It can be possible that in that specific year there was a lot of diffuse light, which has on both angles the same influence on the yield.

In the financial calculations some assumptions were made because there was no or incorrect information available. As a consequence, it is possible that not all used values are a good representation of the reality. Even if there was correct data available, it is doubtful if it is the same for the coming 10 till 20 years. It is likely that prices will changes due to different reasons. Also there is a possibility that not all costs are included, like some very small parts of the construction. This can have an influence on the calculations and can lead to a too positive revenue than it will be in practice.

The business model which are presented in this report are narrowed down to applied PV projects in the Netherlands, since they have faced similar environmental, social, legislative, economic conditions. These conditions can be different for other countries in Europe.

In the design process, the requirements for movable solar panel system had to be defined. This was done by the ACT Group 1618. Determining the requirements for the system by only three persons with the same background is bit subjective. As a consequence, the scope of each person can be the same and some important issues could be missed or some could be excessive. By doing a stakeholder workshop, it was tried to undermine this and listen to people who have a different kind of view.

The same is the case when the designs had to be ranked. This is also very subjective, because it is hard to determine which design scores the best at one requirement and how good scores it at a range of 0 to 4. At the end, making combinations of solutions of every function is also very subjective. What would be the best to combine and which fits good together and what totally not. Based on common sense some good design where made.

The last design concept was the Future Ideal system. This design may be too complex and too expensive for the moment, but later, when prices are changing and more developments are made, it is possible that this solution can be profitable. Therefore, it may not be excluded as a solution. In this design some patents were also present. When implementing this patent, it is important to do a research on which parts/concepts may be used and which one not. It is possible that you may not use a part because it is protected by the patent.

In the design part, some actions were taken to prevent the solar panels to be stolen. This is hard and basically it is impossible to have a theft prevention of 100%. By using some theft prevention solutions, it is tried to prevent theft as best as possible.

10 Conclusion

The design process pointed out that the best design possible is the one that optimize the profit, based on the technical and economical requirements used to assess the designs (see paragraph 7.7). So the profit optimization is the final objective of the required movable solar system.

This movable solar system can be composed either by polycrystalline or monocrystalline solar panels. The first technology has a lower cost, while on the other hand the monocrystalline ones have an efficiency level slightly higher. It has been observed during the literature research that the most commonly applied are the polycrystalline solar panels. Another option could be represented by thin-film solar panels. Those have a low efficiency, around 13%, and a lower efficiency per square meter, therefore a solar system composed of thin-film solar panels requires a higher surface compared to the others mentioned above. For this reason is can be noticed that their application on roofs is limited, since this area is limited and has strong space constraints.

From the Solar Irradiation Model it has been obtained the optimal angle that a solar panel should have in order to produce the maximum amount of energy, which is 20 degrees. However it must be taken into account that with a high density of solar panels, they will create shade on each other. This it can be prevented installing the panels horizontally. From the model data is has been observed that the extra solar energy obtained with the optimal slope is only 2% more compared to the horizontal placed solar panels. So it can be concluded that for systems with a high density of solar panels the best choice is to place them horizontal, since an additional advantage is the simpler construction, which leads to lower investing costs for the system. The total solar energy the model gives is 3304 MJ per square meter per year, which means 5452 MJ per panel per year.

From the Crop Yield Model has been calculated that the production of wheat will be reduced of around 50% underneath the panels. Since it can be assumed that the panels are not covering the whole field, the overall decrease in crop production will be less. Even if the loss of yield is high, however in financial terms this is not a real issue since the revenue obtained per additional solar panel is higher than the revenue obtained by crop harvest from the same surface.

A financial calculation of the Levelized Cost of Electricity (LCOE) has been done. The LCOE obtained is between 14 to 16 cents. Since this result is lower than the consumer price for electricity, business models which includes own usage of electricity are recommended. In order to obtain a better economic result Chinese panels are recommended for their lower cost. In the opposite, polycrystalline panels are cheaper but the total LCOE obtained with monocrystalline panels is higher, due to its higher efficiency. A relevant variable for the project is the connection to the grid, since it can raise the investment cost by more than €50,000. Another financial aspect studied is the Net Present Value (NPV) of the investment. This is resulting negative, even if positive cash flows are expected along the lifetime of the system. This means that a positive cash flow doesn't imply a positive final NPV. Also the Internal rate of Return (IRR) is -10 %. This means that a loss is made when the electricity is sold to the grid applying this project. Surely a subsidy would make the outcome more attractive and profitable.

At this regard, is has been noticed a general positive attitude from the Dutch government toward the renewable solar energy. In particular the focus is on promoting cooperation between solar energy producers and consumers. At the moment a subsidy program called SDE+ is existing for solar energy, however to apply for this subsidy with a system bigger than 500 kW, an environmental license and a feasibility study is required. Another constraint imposed to systems used within a field, is the environmental license. According to this, the complete system should be no bigger than 5 meters, to not conflict with the building law, and it should fit into the usage plan of the involved land fraction (mainly agricultural). This local usage plan is set up by the local governmental institution, and its changes are depending on their good will.

Common for solar energy projects is to face social resistances. In order to prevent them, the project has to take into account and involve the local population. This means sharing with them the benefits coming from the project (this can either mean direct financial compensations, local co-ownership within the project, or benefits in kind, as direct local improvements). Local involvement in the decision phases of the project is determinant. The project should include since the design phase a stakeholder workshop, to increase its openness, inclusiveness, responsiveness, accountability and flexibility. Additional actions are providing more complete knowledge about the technology installed to the population in the targeted area, in order to give the stakeholders the right expectations. And finally there is evidence that if the location of the planned PV installation is not directly visible for the public the social resistances will decrease.

11 Recommendations

This chapter will deal with recommendation for the project. The reader will get an overview of how the outcome of the project can be improved. He/ she will find ideas of how to overcome certain limitations of the solutions presented in this report.

For more realistic energy revenue, when someone has a high solar yield, the hourly production should be combined with the fluctuating energy price. Furthermore Investigation for more direct opportunities to use the electricity should be considered. The goal is to become independent of the grid prices and have a sustainable cooperation solution for it. Addition to this recommendation, a battery could be financial rewarding when you have to deal with fluctuating energy prices. The reasoning is the possibility to sell the energy only at high prices. However this needs to be investigated.

From the technical point of view, further research should be at on folding and transporting mechanisms. Since, there is not a complete market overview about the possibilities. For a lesser environmental impact, it should be considered to combine the system with the Lasting Fields project. The transportation on rails could be a promising system. Also more research is needed about the influence of the panel system on crop growth, how to harvest and how other crops are dealing with the system. Nevertheless placing the panel system one full year on a resting field might be also a good solution. At the end Intercropping could be used to maintain the opinion of the society at your side.

For the shading model approximations were made. However with some experiments in wheat fields in the Netherlands it should be analysed which realistic parameters could be obtain within this system. Therefore someone should put shade on different spots in a field and look how the yield changes.

Overall most of the literature used is always referring to fixed traditional solar panels. It is been assumed that the main problematic points presented can be an issue also for movable systems, however there is still no empirical evidence for that. To observe the problems experienced by a pilot project of movable solar panels will make the conclusions more consistent. It is recommend to evaluate before starting the application phase of a project: the level of experience accumulated in previous years by involved local population about similar PV projects, the local policy attitude towards renewable energy technologies, and the local level of trust in political institutions.

In order to have a successful realization of a project, someone should work together at early stages with the local government in order to ensure that the project fulfills the requirements the government sets before giving permission. Further investigation about the local usage plan for the specific location where a project will be placed needs to be done.

The business model is a tool that every business activity should measure upon its own interests, objectives and possibilities. The conclusions from the report should be considered as a starting point, and further implemented within a given environment by the producing company. In this previous phase of the study it is not possible to define yet the best business model. Since it depends on the purpose of the business (social oriented, profit oriented) and contract conditions with the local energy company. Therefore the presented general overview will help to make an evaluation of the best business model a company can further develop and apply. So far Business modules, which include self-consumption of electricity, are more preferable then selling to the grid.

However the conclusions are based only upon Dutch projects experience. This research might not be applicable if extended worldwide.

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13 Appendix

13.1 3 Circle Chart

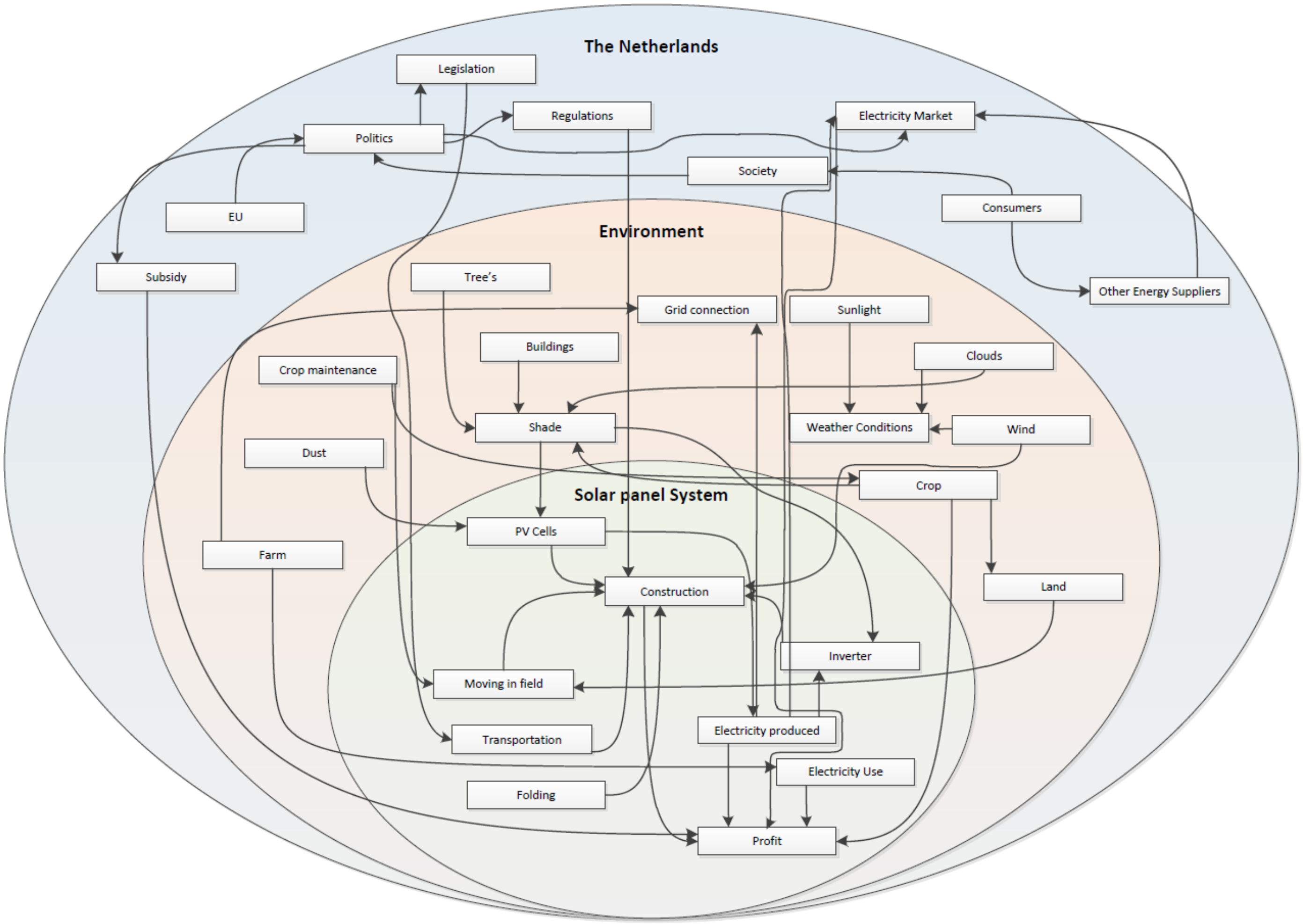

Figure 13-1 3 Circle chart of the solar panel system

13.2 Objective Tree

To know where the design process will result in and how the end design would look like, some future views of the desired system are made by making the objective tree. Within this tree of objectives, the ideal system is described by defining all (sub) objectives of the system. The first main goal is to combine growing low revenue crops with the production of solar energy at the field. In this case this equals to a short description of the project goal: movable solar panels combined with growing low-revenue crops. At the second row, the tree of objectives is set up by listing all the important sub objectives. Then relative weights were given to the related different sub objectives from the same main objective. These weights are used in order to get a calculated tree of objectives. The more important a sub objective is, the higher the weight that is given to it. The total weight of a level underneath one main objective has to equal 1. After the calculations, that was done by the program called Microsoft Visio, two major objectives were obtained. The weights for the second level are in a range starting from 0.12 up to 0.2. For the third level the range is lower compared to the second range and varies between 0.036 and 0.12.

The objective that is ranked as highest is selling the solar energy (with a value of 0.12 at the right side of Figure 13-2). This is because the profit of the farm will increase by the earnings obtained by the solar panel system. Therefore, for the farmers who are going to implement the system, this is the major motivation. Next to that, it is also part of the main goal of the project: to increase the profit with the implementation of a solar panel system within the production of low-revenue crops. The objective 'Own energy' scores also high with a weight of 0.1. This is due to the fact that in the solar energy business reducing own energy costs is relative more profitable than selling the rest energy to the grid. Because of the fact that the own consumption is a small amount of energy relative to the total amount of the energy that will be produced, this objective has a smaller weight than the 'Energy sells' of the system.

In the planet objective, in order to get a higher efficiency of sources, the reduction of CO_2 is seen as an important objective. Therefore, this objective scores the second highest in the total tree. The solar energy system will produce green energy and therefore, the usage of fossil energy will decrease. Next to that the reduction of CO_2 is a hot topic within the (inter)national politics nowadays. For example the Kyoto pact (United Nations, 1998) is an agreement between countries were they have made appointments for the reduction of CO_2 emissions up to 2020. Therefore, the planet, the politics and with that the entrepreneur will have CO_2 reduction as a major objective to contribute to a better planet.

Notable in the tree is the objective 'Combined production', which gets the lowest weight. The combined production can be seen at the second left column of the Tree of objectives. This low scoring can be seen as strange due to the fact that the whole project is dealing with this innovative combination. Therefore, it has to be mentioned that this objective belongs to the sustainable system objective of the society. According to the design team, the society doesn't care much about the fact that a combined system is used in order to have a sustainable system. The society is much more interested in the knowing that they can consume energy that is produced in a sustainable way. People in the neighbourhood can use the sustainable energy in order to be self-sufficient in energy.

The combination of both the solar and crop system gets important in the profit part of the tree. The objective 'Reduced land costs' is the main outcome of the shared purpose of the field. Two production systems are placed on the same field and therefore the field costs are shared between the production of low revenue crops and the production of solar energy.

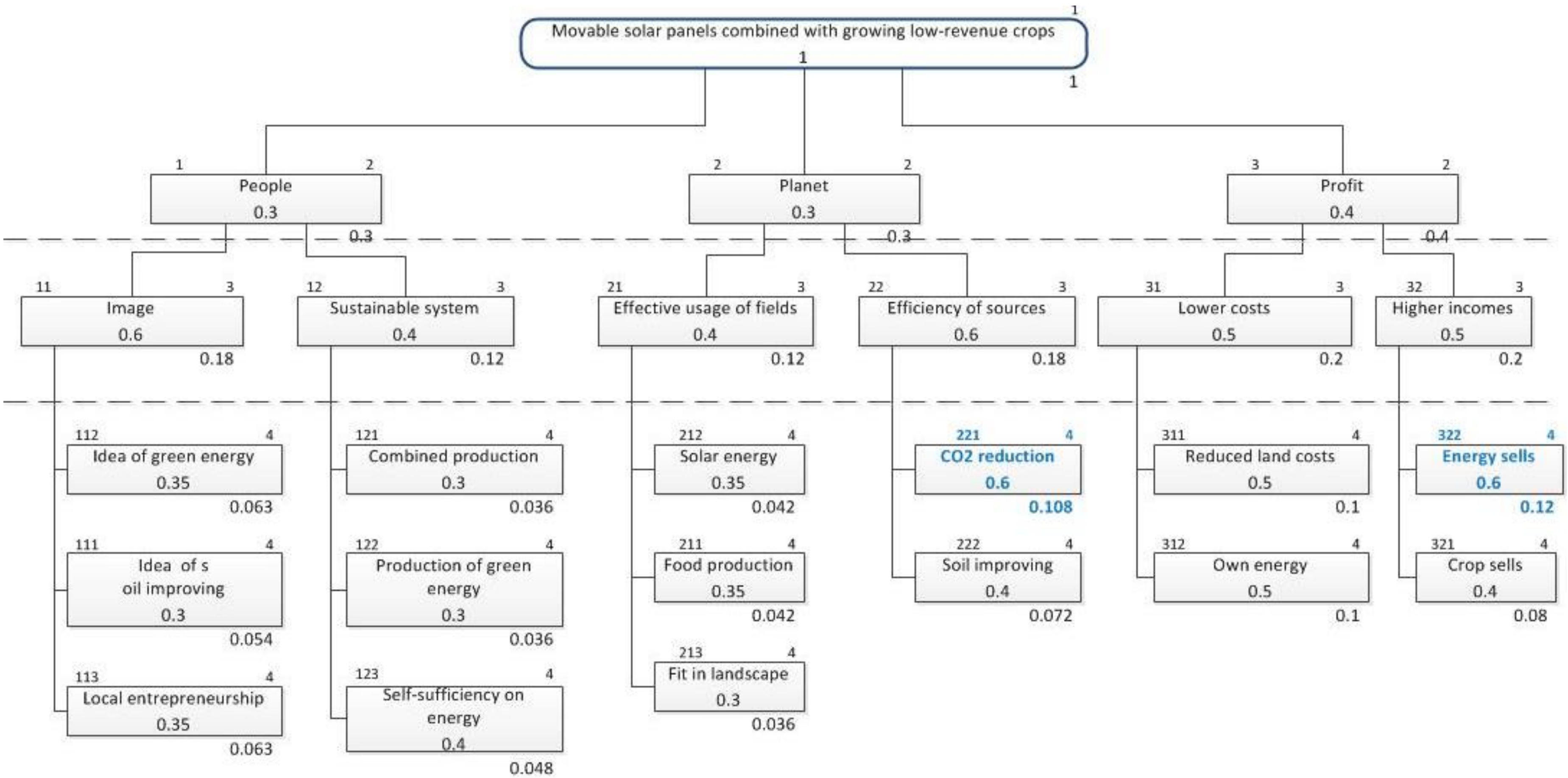

Figure 13-2 Tree of Objectives

13.3 Business models' bottlenecks and advantages

Table 13-1 Business models' bottlenecks and advantages

Customer-Owned	Solar Shares	Third Party
STRENGTHS		
ownership - especially suitable for those customers willing to have as much independence and self-management as possible	the number of farms that potentially can be involved is higher, since the requirement of financial investment possibilities disappear	the number of farms that potentially can be involved is higher, since the requirement of financial investment possibilities disappear
the business company can offer a strong management and organization of the services to the customer	increased probability of social acceptability of the solar panel systems from the local community	customer binding
	Cost oriented	the leasing contract ensure large participation without facing the net metering law boundary
WEAKNESSES		
Access to a bank loan can be required, otherwise an high farm liquidity	absence of legislative regulation in the Netherlands for off-site or virtual net metering	complexity of the arrangements that the organization must find between investors and end users
cost efficiency will be more difficult to be applied without lower the customer satisfaction if customized service will be provided		Profit oriented
ADVICES		
the movable solar company should address targeted customer segment as farms with crop rotation cultivation system to which it is possible to combine the proposed movable panels. This is a new market niche created by the innovative design of this project.		
The targeted customer segment for this business model is a farm with possibilities of initial great investment outflows (likely a medium-large size farm)	centralized coordination is needed to guarantee against information gaps and technological risks	
highly appreciated a customized service: The best way to give personalized advice is when suppliers meet with customers individually to check their farm and provide customized recommendations		

13.4 Input variables economic aspect

Table 13-2 The input variables for the economic calculations

Input variable	Value	Source
Expected lifetime	25 years	(Frauenhofer, 2016)
Inflation	3%	Assumption
Inverter	€0.10/Wp	(Frauenhofer, 2016)
Movable construction	€150/Wp	Assumption
Cables	€100-500/100m	(Solaranlage-ratgeber, 2016)
Grid connection	€42,553.89	(Stedin.net, 2016)
Insurance	0.3-0.8% of total investment cost	(Photovoltaiksolarstrom, 2016)
Maintenance& operations cost	6.6%	Assumption
Crop loss	50% of crop profit	Crop growth model
Monocrystalline panel	Power 320Wp, Efficiency 19.7%, Surface 1.66m^2	(Solar, 2016)
Polycrystalline panel	Power 260Wp, Efficiency 16.3%, Surface 1.62m^2	(Solar, 2016)
Yearly insolation	1154kW/m^2	
Monocrystalline panel price	European €0.66, Chinese €0.56	(Solarwirtschaft, 2016)
Polycrystalline panel price	European €0.65, Chinese €0.54	(Solarwirtschaft, 2016)

13.5 Stakeholder Analysis

Table 13-3 Stakeholder Analysis

	Stakeholder-background	Name Stakeholder	Type of Relation to improvement of sustainability of the current topic	Stakeholder - typology	Position	Motivation for stakeholder typology
1	Primary producer	Skylark Farmer	Growing crops and earning money with the solar panel system at the same time.	7. Definitive Stakeholder	Neutral	Additional Income for the farmer
2	Knowledge Institute	ACCRES-WUR	Supporting the pilot project with knowledge	3. Demanding Stakeholder	Supporting	Gives important information to make the project a success
3	Societal representative	Skylark Foundation	Represent the wishes of the Skylark Foundation	4. Dominant Stakeholder	Supporting	Supports the farmers who participate to the Skylark Foundation program.
4	Consumer		Has to pay for the Green Energy	3. Demanding Stakeholder	Supporting	Needs electricity at home
5	Neighbours		Have to face the solar panel system for a long period	5. Dangerous Stakeholder	Supporting to Limiting	Suffer from some advantages
6	Funder		Supporting the financial aspect of the farm	4. Dominant Stakeholder	Supporting	Gives money to invest in the solar panel system
7	Employee		Has to move/transport the solar panel system	6. Dependant Stakeholder	Supporting	Needs to work
8	Grid Operator	Stedin	Has to deliver a connection for the solar panel system to the grid	5. Dangerous Stakeholder	Supporting to Limiting	Has to provide a connection at the point where the solar panels are located
9	Energy Supplier	Eneco	Has to receive the electricity and pay the farmer for it	5. Dangerous Stakeholder	Supporting to Limiting	Has to accept the supplied energy

10	Constructor of Equipment and Machinery	Wim Steverink	Has to build the first movable solar panel systems	3. Demanding Stakeholder	Supporting	Should be feasible to build the design system
11	Knowledge Institute	ACT Consultancy Group 1618	Provides information for the feasibility of the project and provides some design suggestions	2.Discretionary Stakeholder	Supporting	Gives advices to make the project a success
12	Feedstuff supplier		Supplies cables, PV cells, inverter and etc.	3. Demanding Stakeholder	Supporting	Needed to make the solar panel system
13	Public representative and policymaker	Government	Makes regulations and laws for the system and gives subsidy	5. Dangerous Stakeholder	Limiting	Can be important for the feasibility of the project

13.6 Brief of Requirements

Table 13-4 Sorted Brief of Requirements

Brief of requirements (Sorted) for Project: Movable Solar Panel System							Quantify requirements			
Index	**Aspect**	**Requirement description**	**Fixed Req.**	**Variable Req.**	**Desirability**	**Parameter**	**Min. value**	**Max value**	**Target**	**Unit**
1	Economical	The investment costs are lower or equal to 2.0 €/Wp		x		Investment costs		2	1.3	€/Wp
2	Economical	The return of investment is at maximum 15 years		x		Return of investment		15	10	year
3	Economical	The system can run without subsidy			x	Financial feasibility				
4	Economical	The reduction of crop growth is less than 50 %		x		Size of system		50	0	%
5	Economical	The system has to deal with shade	x			Efficiency				
6	Economical	The solar panels are locked to the frame to prefent theft	x			Security				
7	Economical	The price of the electricity should be at least 0.04 €/kWh		x		Financial feasibility	0.04		0.06	€/kWh
8	Social	The design of the system should fit into the landscape			x	Acceptability				
9	Social	The noise of the solar panel system is below 50 dB at one meter		x		Noise		50	30	dB
10	Social	The land use plan doesn't have to be changed	x			Regulation				
11	Technical	The system could be easily placed and removed in the field during/after the growing season	x			Usability				
12	Technical	The system can fold together	x			Size of system				
13	Technical	The system after folding together may not be wider than 2.55 m		x		Size of system		2.55	2.25	m
14	Technical	The system after folding together may not be higher than 4 m		x		Size of system		4	3	m

15	Technical	The system after folding together may not be longer than 12 m		x		Size of system		12	7	m
16	Technical	The system can be replaced by one person			x	Movability				
17	Technical	The system can connected to the grid with one connection	x			Production				
18	Technical	The system can be replaced with use of an agricultural vehicle	x			Movability				
19	Technical	The system resists strong wind with a speed of at least 10 Beaufort		x		Solidity	10		10	bft
20	Technical	The weight of the system is less than 2000 kg		x		Size of system		2000	1000	kg
21	Technical	One sub-system exists of 20 Solar panels		x		Size of system	10	30	20	# panels
22	Technical	The position of the solar panels changes when there is too less/much sunlight			x	Efficiency				
23	Technical	Spraying/fertilizing the field is possible	x			Usability				
24	Technical	The system can move over uneven soil	x			Robustness				
25	Technical	The connection between the solar panel system and the grid should be easily and quickly doable (plug and play)	x			Installation time				
26	Technical	Installing the system takes less than 60 minutes per sub-system		x		Installation time		60	30	Minutes/ sub-system
27	Technical	The yield per system can be read out	x			Usability				
28	Technical	The solar panels follow the sun (orientation)			x	Production				
29	Technical	The system is remote controllabe			x	Usability				
30	Technical	The power cable between the sub-systems has a length of 100 m at maximum		x		Connection		100	50	m
31	Technical	Crossing the road with the power cable is possible	x			Usability				
32	Technical	The power cable to the connection in the field can be collected	x			Connection				
33	Technical	The system is able to be adapted to security systems.	x			Security				

13.7 Morphologic Function Diagram

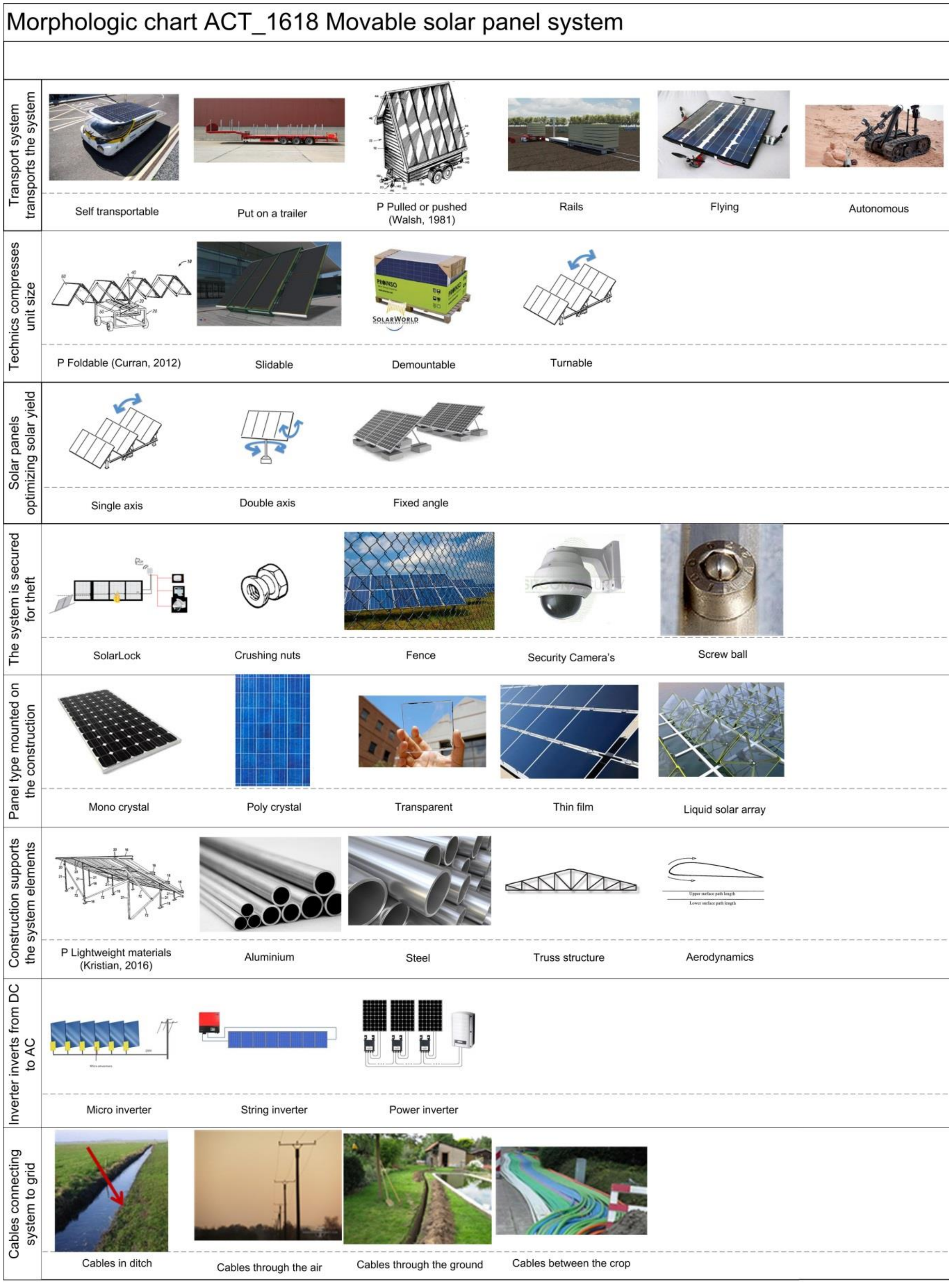

Figure 13-3 Morphologic Function Diagram of the movable panel system

13.8 Assessment tables

Table 13-5 Assessment table for the fixed requirements

		A	B	C	D	Ideal
		Profit optima lisation	**Environm ental impact optimalisa tion**	**Low costs system**	**Future ideal System**	
Criteria for Assessment (Fixed req).	Aspect	Ass.	Ass.	Ass.	Ass.	Ass.
The system has to deal with shade	Economical	0	1	0	1	1
The solar panels are locked to the frame to prefent theft	Economical	1	1	1	1	1
The land use plan doesn't have to be changed	Social	1	1	1	1	1
The system could be easily placed and removed in the field during/after the growing season	Technical	1	1	1	1	1
The system can fold together	Technical	1	0	0	1	1
The system can connected to the grid with one connection	Technical	1	1	1	1	1
The system can be replaced with use of an agricultural vehicle	Technical	1	1	1	1	1
Spraying/fertilizing the field is possible	Technical	1	1	1	1	1
The system can move over uneven soil	Technical	1	1	1	1	1
The connection between the solar panel system and the grid should be easily and quickly doable (plug and play)	Technical	1	1	1	1	1
The yield per system can be read out	Technical	1	1	0	1	1
Crossing the road with the power cable is possible	Technical	0	1	0	0	1
The power cable to the connection in the field can be collected	Technical	1	0	1	1	1
The system is able to be adapted to security systems.	Technical	0	0	0	1	1
Total Score:		11	11	9	13	14

Table 13-6 Assessment table for the variable requirements

			A		B		C		D		Ideal	
			Profit optimalisation		**Environmental impact optimalisation**		**Low costs system**		**Future ideal System**			
Criteria for Assessment (Variable req).	Aspect	Weighing factor	Ass	Score	Ass	Score	Ass	Score	Ass	Score	Ass	Score
The investment costs are lower or equal to 2.0 €/Wp	Economical	3	3	9	2	6	4	12	2	6	4	12
The return of investment is at maximum 15 year	Economical	3	3	9	2	6	3	9	1	3	4	12
The reduction of crop growth is less than 50 %	Economical	2	3	6	3	6	1	2	4	8	4	8
The price of the electricity should be at least 0.04 €/kWh	Economical	2	4	8	3	6	3	6	1	2	4	8
The noise of the solar panel system is below 50 dB at one meter	Social	1	2	2	3	3	1	1	4	4	4	4
The system after folding together may not be wider than 2.55 m	Technical	3	4	12	4	12	4	12	4	12	4	12
The system after folding together may not be higher than 4 m	Technical	2	4	8	4	8	4	8	4	8	4	8
The system after folding together may not be longer than 12 m	Technical	1	4	4	4	4	4	4	4	4	4	4
The system resist strong wind with a speed of at least 10 Beaufort	Technical	3	3	9	3	9	1	3	4	12	4	12
The weight of the system is less than 2000 kg	Technical	2	3	6	3	6	2	4	3	6	4	8
One sub-system exists of 20 Solar panels	Technical	1	3	3	3	3	3	3	3	3	4	4
Installing the system takes less than 60 minutes per sub-system	Technical	3	3	9	1	3	2	6	4	12	4	12
The power cable between the sub-systems have a length of 100 m at maximum	Technical	1	3	3	3	3	3	3	3	3	4	4
Total Score:				88		75		73		83		108
Relative Score (%):				81.5		69.4		67.6		76.9		100

13.9 Kesselring Method Graphs

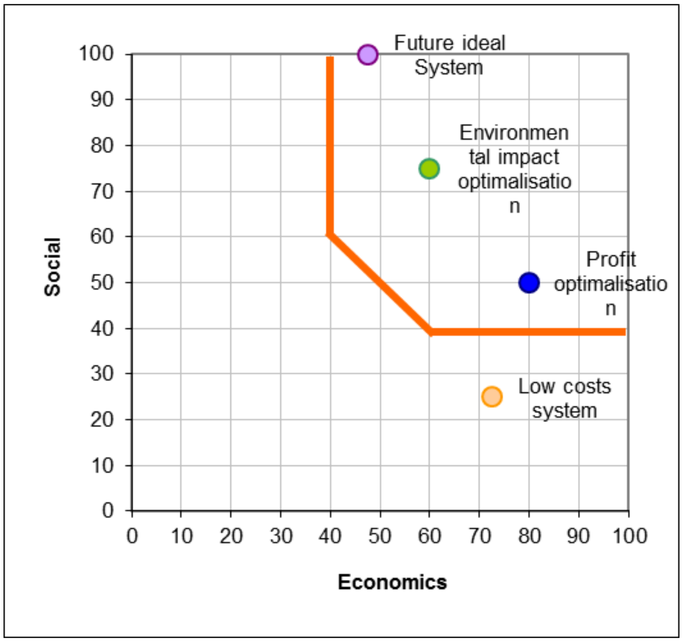

Figure 13-4 Kesselring Method with Social and Economic aspects

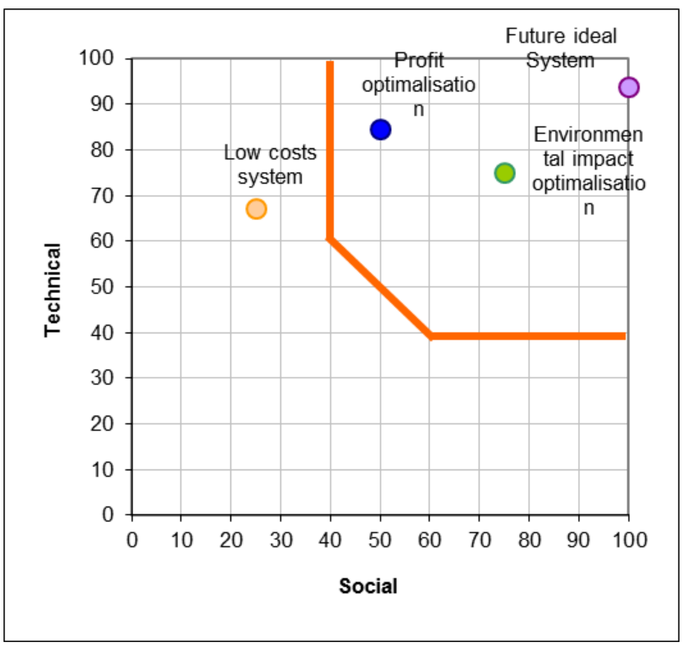

Figure 13-5 Kesselring Method with Social and Technical aspects