Department of Mechanical and Aerospace Engineering

Solar Charged Electric Farming Tractors

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A thesis submitted in partial fulfilment for the requirement of degree in
Master of Science in Advanced Mechanical Engineering
2015

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Signed: *Konstantinos Michail Akritidis* Date: 30/8/2015

Acknowledgements

I would like to thank my wife, Natalie, for being supportive in this tough year, without her nothing would be possible, my family for all these years of devotion and support and of course Dr. Paul Tuohy for all his guidance and cooperation.

I would like to extend my thanks to my classmates and colleagues for making this year more enjoyable.

This thesis is devoted to my new-born son Nicolas.

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Nomenclature

m: *meters*

cm: *centimeters*

N: *Newton*

Nm: *Newton meters (torque)*

W: *Watt*

W/m^2: *Watt per square meter*

kW: *kilo Watt*

Wh: *Watt hour*

Wh/m^2: *Watt hours per square meter*

kWh: *kilo Watt hour*

rpm: *revolutions per minute*

V: *Voltage*

Amps: *Amperes*

Ah: *Amperes hour*

EUR: *euro currency*

GDB: *British pounds currency*

AC: *Alternative current*

DC: *Direct current*

DOD: *Depth of Discharge*

DR: *Days Required*

HR: *Hours Required*

ABC: *Available Battery Capacity*

PC: *Percentage Capacity*

PV: *Photovoltaic*

PTO: *Power Take-Off*

Acres: *1000 m^2*

CO_2: *Carbon dioxide*

CO_2 eq.: *Carbon dioxide equivalents*

CAPEX: *Capital expenditure*

OPEX: *Operational expenditure*

IRR: *Internal Rate of Return*

EPC: *Engineering Procurement Construction*

GHG: *Green House Gasses*

FiT: *Feed in Tariff*

EU: *European Union*

UN: *United Nations*

FAO: *Food and Agriculture Organization*

ASAE: *American Society of Associate Executives*

NASA: *National Aeronautics and Space Administration*

IEA: *International Energy Agency*

AFOLU: *Agriculture, Forestry and Other Land Use*

EV ARC: *Electric Vehicle Autonomous Renewable Centers*

IR *losses:* *Losses attributed to the current and resistor*

Abstract

The last century the earth experienced a huge booming of its population. The rate of this growth is the biggest ever and all major predictions estimate that it will continue. Goods are becoming more and more valuable, thus their management requires precise and accurate decisions.

After the huge industrial revolution, the next huge step from mankind was to invent new ways of transforming the energy from the sun, into useful energy for all kinds of activities. Practically, sun will not expire before the end of earth's life, this fact drives to the assumption that these types of energy sources are considered renewable. Apart from energy, another major good that is fundamental for all societies is food. Agriculture, is the science that circulates all activities related to food production. It seems that the future of both goods will find them bonded and especially food production will be directly dependable to the energy. Adding to this, the demand for food production industry will increase and require more energy, hence it will add to the environmental depletion, by releasing CO_2 to the atmosphere.

The aim of this study is to present, a potential alternative solution regarding the covering of energy needs, required for farming activities related to the arable lands. As the car industry, gradually heads to the electric engines and electric vehicles, the farming tractor industry will not fall behind with traditional diesel engines. Assuming that it is possible to manufacture electric farming tractors, this paper is studying the energy balance between solar energy generation and the demands of the farming activities in the field. The main parts of this concept are, the solar array scheme, the electric motor of the tractor and of course the battery that will store the energy from panels and produce it to farming tractor, while operating in the field.

Except from evaluating the technical and financial feasibility of this project, this paper aims to enforce the combination of two fields into one; Agriculture and Sustainable Engineering to Sustainable Agriculture Practises.

Key words: solar energy, renewable, food, Agriculture, CO2, farming activities, electric engines, farming tractor, batteries, Thessaloniki, climate, wheat, cotton

1. Introduction

The attempt of this study is to examine if an electric tractor can fulfil all the farming activities in equal quality and efficiency as the classic farming tractors. Currently there is no specific model of an electric farming tractor in commercial size production. Hence for the needs of this study the electric tractor will be assumed to be a classic farming tractor with electric motor and no technical design details of any particular model will be discussed. The traditional fossil fuel, which is diesel, will be replaced from electricity from solar PV panels and the fuel tank will be the battery.

Key words: Farming tractors, agricultural mechanisation index, PTO, solar radiation, solar energy, batteries, electric motor

1.1. Farming Tractors

Since the dawn of the human civilization there were efforts from humanity to master the land and its utilization regarding the farming and generally the food production. It is widely known that the introduction of the first farming tractors altered the farming activities and food production as nothing else did before. The dramatic increase of the global population that occurred at the ending of the 19^{th} century is partly related to the industrialisation of agriculture (farm mechanisation). The core of the industrialisation of farming is the farming tractors; they maximized the efficiency of the farming activities by removing human and animal labour from the field, thus minimizing the ratio human labour/land area. Apart from the ease that farm mechanisation offered to humanity, it is the cause of connecting the food production with the energy demands.

1.1.1 Farming tractors and agricultural mechanisation index

The term agriculture mechanisation (farm mechanisation) is relatively well obvious, but it is difficult to be defined quantitatively. Agricultural mechanisation index is a quantitative value that defines the level of mechanisation in farming in every country (Tsatsarelis K., 2006). The basic unit of this index is the ratio of middle ranged power output farming tractors per arable land area. Although this index has got major drawbacks, it is a fundamental factor when it comes to food products and markets, regarding the comparative advantage.

The drawbacks are mentioned thoroughly in next paragraph.

The term “middle ranged” is not clearly defined due to different economies and technological progress of countries around the world, for example in Greece a 60 kW power output tractor is considered to be a middle ranged while in USA a 60 kW is considered relatively smaller. The size and type of tractor are not well defined. By the book very small tractors that are widely used in fields, are excluded. Another flaw of the agricultural mechanisation index is that all vehicles that can perform farming activities but are not farming tractors are excluded (electrical vehicles, harvesting machines, automatic fertilizer sprinklers etc.). All the electric motors that are installed in the fields, for example pumps and dryers, are not included. A very important factor that is still not included is the farming equipment (e.g. plow), it is important to say that the farming equipment is crucial because a farming tractor alone cannot operate any activity in the field. Last but not least an important gap lies in the actual meaning of the ratio tractor / arable land and that is to say that either for 50 acres or 300 acres one tractor is enough but the ratio is different (Tsatsarelis K., 2006). Although the index as a simple metric can be proven flawed, it is valued when it comes to factors which are used to define the level farming business in a country.

Country	**Tractors**	**Tractors per 1000 acres**	**Arable land in million acres**	**Acres per tractor**
Austria	500,000	**8,8**	57,0	114,0
France	1,264,000	**6,5**	195,8	154,9
Greece	249,900	**6,5**	38,5	154,1
Japan	2,028,000	**42,3**	47,9	23,6
USA	4,800,000	**2,7**	1772,6	369,3
India	1,525,000	**0,9**	1699	1114,1

Table 1. Number of farming tractors and agricultural mechanisation index from Faostat, 2005(Tsatsarelis K., 2006)

Commenting on the table (Table 1), it is interesting to compare the indexes of USA and India as although they are close they are not matching exactly the gap between the progresses of the farming business between the two countries. The size of the millions of acres of arable land is close but obviously the larger installed capacity of the middle tractor in USA is considered high than in India, this allows the US faming business to operate on more efficient levels, thus being stronger that the India's one. Going back in 1980 where FAO published some data the installed capacity per capita (kW/capita population) for US was 0.74 while in developing countries was 0.2, it is easy to understand why the agricultural mechanisation index is useful when it is combined with other indexes rather than being used alone (Tsatsarelis K., 2006). Concluding it is righteous to say that it is useful only for a country itself, not for comparing with other counties.

1.1.2 Power output of Tractors and PTO

There is a great range of farming tractors regarding their power output. The four main categories are:

- Low ranged power from 1-20 kW
- Middle ranged power from 20-50 kW
- High ranged power from 50-100 kW
- Super high ranged power >100 kW

(Tsatsarelis K., 2006)

There is a difference between farming tractors and the rest vehicles when it comes to defining the desired power output. Usually apart from defining the power output of the engine of the tractor, there is also the PTO power output which needs to be defined. PTO stands for Power Take-Off and is a shaft which connects the engine of the tractor with the farming equipment which requires kinetic energy to operate, such as pumps, rotary harrow etc. The main aspect of the PTO is that the rotary speed is usually stable and equal to the rpm of the engine (540 or 1000 rpm). Thus the PTO is not connected with the gearbox. The next pictures (Figure 1, Figure 2) demonstrate the shaft (PTO) which is usually located at the back side (modern tractors have both in front and back) of the tractor and a rotary harrow which is the predominant farming tool that is used connected with the PTO of the tractor.

Figure 1.PTO shaft output of a tractor, source: http://www.fronthitch.com

Figure 2.Rotary harrow connected with PTO, source: http://www.alibaba.com

1.2. Solar radiation

The sun, a huge fusion power plant which burns hydrogen, provides the earth with energy. It is the fundamental source of energy directly and indirectly, that energy can be extracted from the solar radiation as heat and electricity. It is measured from NASA that the solar radiation that reaches the atmosphere is equal to 1357 W/m^2 (Labourent & Villoz, 2009, 2010) and the amount of solar radiation that reaches the earth's surface is approximately equal to 1000 W/m^2 (David JC MacKay, 2009). Thus the sunlight can either be used to cover heat of electricity demands. In the next diagram (Figure 3) the basic exploitation of the sunlight is demonstrated.

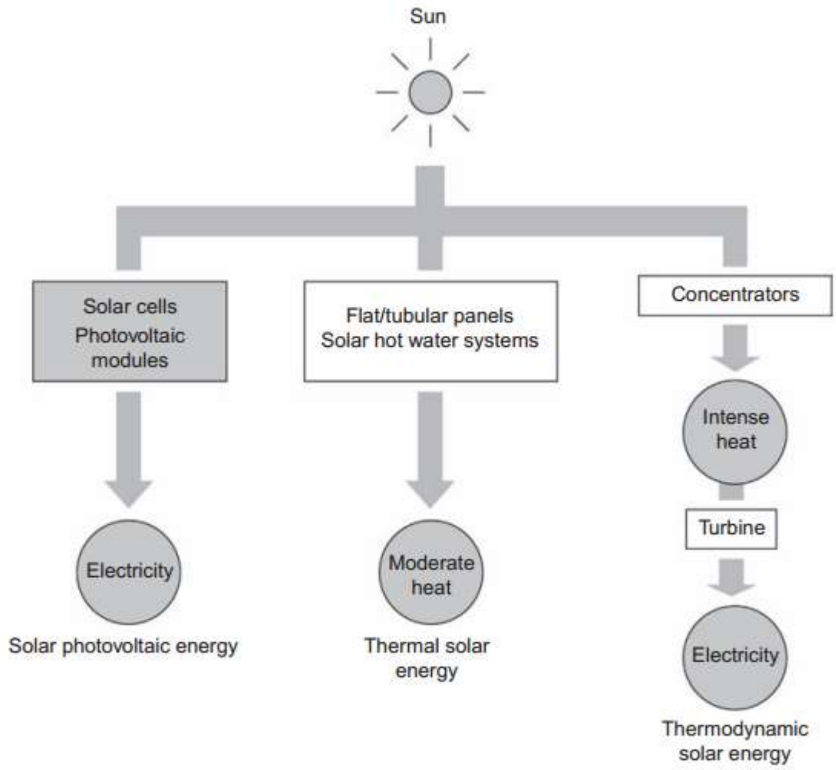


Figure 3.Types of energy from solar radiation (Labourent & Villoz 2009, 2010)

In locations such as Greece, Cyprus, and Israel solar collectors are widely used to collect heat from solar radiation and usually heat circulated water or other special liquid in order to transfer the energy.

Another very impressive method of exploiting energy from the sun is with concentrators, one of the most popular examples is the PS10 Solar Power Plant in southern Spain. Movable mirrors are gathering the solar radiation to a specific point (water tank) of a tower that is located opposite the mirrors, water is heated and a steam turbine produces electricity.

Apart from the heat, solar radiation can be exploited in order to generate electricity. In this case, solar photovoltaic panels are used, to convert the sun light into electricity. Solar photovoltaic panels are consisted from photovoltaic cells which are connected together to form modules and arrays. In order to avoid a common fault, it is important to mention that photovoltaic cells can generate electricity from any light source, but the sun light is the predominant.

For the needs of this study, only the solar photovoltaic panels will be analysed and covered, the rest are out of the scope of this study.

In all cases there is one major issue that limits the amount of energy that can be used throughout the day and that is that the sun shines only during the daytime hours.

1.2.1. The Photovoltaic effect

The photovoltaic effect was at first observed by a French physicist A.E. Becquerel in 1839. According to the Handbook of Photovoltaic Science and Engineering (Antonio Luque & Stevens Hegedus, 2011), the effect can be simply described as, incident solar or light photons which pumping the valence electrons of the negative semiconductor up to higher energy conduction band, by breaking their bonds. These electrons are releasing their energy by doing work, for example lighting a light bulb. The complete analysis of this effect is clearly out of the limits of this study, thus no further details are discussed in this paper.

1.2.2. Solar Photovoltaic panels

The solar photovoltaic panels are one of the major and oldest main role players in electricity generation and they are being developed for over a half century (1954 Bell Laboratories), they generate DC electrical power from the sun light when semiconductors are illuminated by photons (D). One of their first applications occurred in space technology, where they proved their effectiveness.

There are three types of PV regarding the form of the silicon. The monocrystalline cells, the polycrystalline cells and the one so called “thin film” with the amorphous cells. PV panels are commonly used for many years and have proved their reliability. No moving parts are involved, no CO_2 emissions are released and no sound is created during their operation. Additionally a little maintenance is required. The main drawback is that they convert a very small amount of the solar energy into electricity. Although many manufactures claim to achieve high efficiencies, the current market is moving on rates of 12-17% due to various reasons, such as reliable technology, high costs, losses etc.

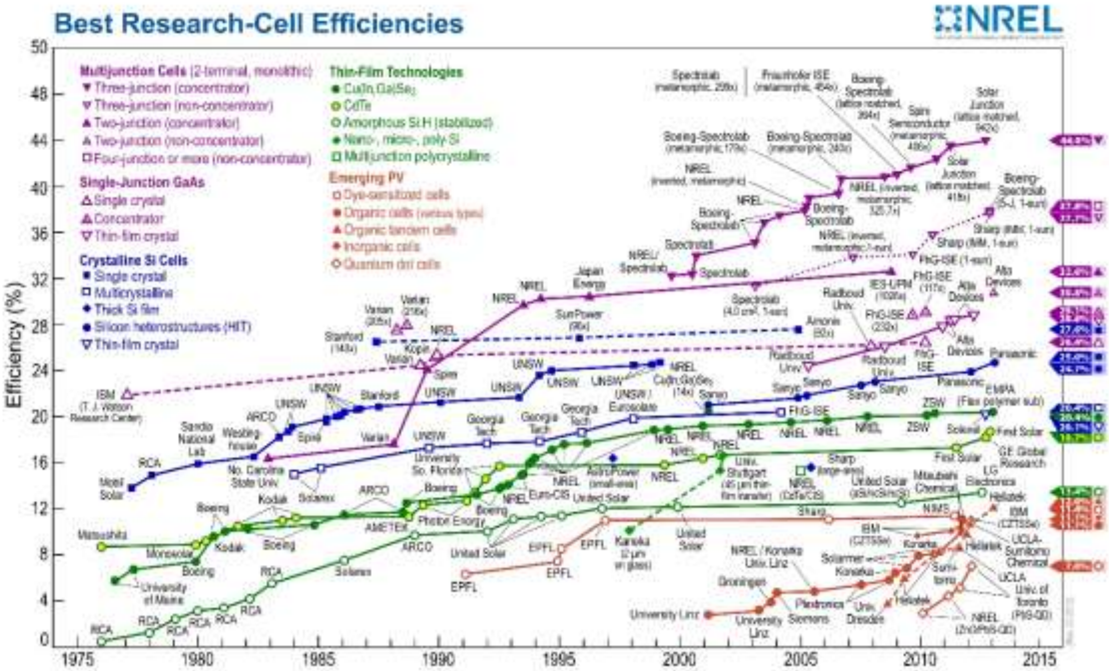


Figure 4. NREL Cell efficiencies source: http://www.nrel.org

1.3. Energy Storage

As mentioned before, the main obstacle with the solar energy is that it is available only in daytime hours, thus to match the demand needs during the 24 hours, the energy must be stored. In order to increase the usage of generated solar energy, which is non-despatchable, energy storage devices are necessary. Batteries and fuel cells are the most durable and widely used energy storage devices. However, these two technologies are still not very reliable, expensive and low capacity. Other types of storage are liquid air tanks and fly wheels.

For the needs of this study, only batteries are going to be used and analysed, thus some of the fundamentals of batteries are going to be covered. It is possible in the future that other innovative energy storage devices will be developed for the same need, but the current trend on electric vehicles is utilizing only batteries, that is why this study is concentrating it this particular technology.

1.3.1. Batteries

Batteries are storing electrical energy by transforming it into chemical and vice versa when they are releasing it. Batteries and solar panels share a very crucial attribute and that is the DC current of the electrical power. Although battery technology is very old (1738 B. Franklin and 1800 Alessandro Volta) and widely spread, it is still quite unreliable and low efficient. Various problems are still puzzling scientists, such as the depletion of the battery potential, charge and discharge cycles and the overall wear out of the battery through lifetime.

Batteries are consisted of three parts the anode which is the negative terminal, the cathode which is the positive terminal and the electrolytes which permit the movement of the electrons, thus the electric current generation.

Batteries are commonly known for two main attributes, their weight and their dirty. It is important to mention these aspects in the start of this project and that is because the heavy weight of the batteries can be considered as an advantage because farming tractors require heavy loads to achieve adequate friction when operating in the field.

1.3.2. Battery performance and degradation facts

All kinds of different technologies are improving continuously with amazing speed. Gordon Moore, the cofounder of Intel, has released an empirical law (Moore's Law) which claims that computers are doubling their processing ability every two years, this happens due to the size of electrons compared with the size of chips. Unfortunately this law does not even come close to describe the development in batteries. Batteries require huge chemical elements. So while most technologies are moving on, including the renewable energy field, batteries' performance does not seem to follow at the same rates.

A lot of different factors are responsible for the performance of the batteries. Performance is a term strongly related to the degradation (performance through lifetime). It is important to mention for literature reasons these factors. Further and deeper analysis of the level of effect of these factors to this project is out of the limits of this study and that is because of:

- Different manufacturers design same models of batteries with different material land different qualities
- Regarding this project, batteries are exposed to climate conditions 365 days a year
- No previous data of similar projects
- The analysis will require comparison of different battery materials, conditions, costs, cell designs etc. thus rendering the part of the analysis very large.

The factors affecting the performance are:

- Voltage level and different references to the type of voltage (e.g. open-circuit, theoretical, closed-circuit, midpoint etc.)
- Current drain of discharge (IR losses and polarization effects)
- Mode of discharge (constant current, constant load, constant power)
- Temperature of batteries during discharge
- Service life
- Type of discharge (continuous, intermittent)
- Duty cycles (intermittent and pulse discharges)
- Voltage regulation
- Charging voltage
- Effects of cell and battery design
    1. Electrode design
    2. Hybrid designs
    3. Shape and configuration
    4. Volumetric efficiency versus energy density
    5. Effect of capacity size
- Battery age and storage conditions
- Effect of battery design (cell configuration)

If it is of someone's interest to go deeper and search for many details, he or she is advised to review the references used for this study (David Linden & Thomas B. Reddy, 2002).

Finally for the needs of this project it is assumed that the electric tractors are following the technologies occurring in EV's industry. The battery that is used in this study, is assumed to share all the characteristics of the 85kWh battery. (http://www.teslamotors.com, 2015)

1.4. Electric Motors

Electric motors (DC & AC) use the electromagnetic features of electric current to produce kinetic energy. The major two categories of are synchronous and induction motors. Electric motors are widely used from a simple drill to a huge power plant. Theoretically the same machine that consumes electrical energy to produce kinetic energy can operate vice versa as generator. There is a huge range of motors regarding their power output. One of the most important attributes is that the larger the motor the higher the efficiency. The induction motors are known as AC motors and they are currently used in electrical vehicles.

1.5. Important notifications

From now on solar photovoltaic panels will be also mentioned as PV panels, solar panels or even just panels. The electric farming tractors may be mentioned as tractors and the lithium-ion battery as simply battery.

The term system includes the tractor (AC motor), the PV panels and the battery, as a unity.

2. Methodology of the project

In order to get all the, mentioned, pieces of the puzzle together, a proper methodology is required. To achieve a scientific approach to this concept, certain steps must be followed to reveal the overall feasibility of the study, while discover all the disadvantages that may occur.

Key words: Methodology, flow chart, Background, energy analysis method, financial, environmental issues, conclusion

2.1. Methodology flow chart

As this concept is a special case of solar energy exploitation in farming field, the steps that were followed, are demonstrated with the help of a flow chart.

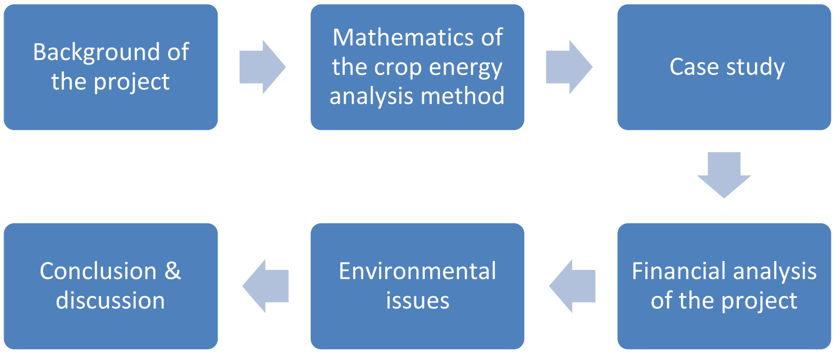


Figure 5. Methodology flow chart

The first step is to gather all existing data and information that will be the basic tools for establishing this study. This includes climate data, software and existing technologies.

The next step is to present the method that is used in order to calculate the energy demand for the crops. This is a specific method, which starts from the farming activities and applications required for each crop and ends up with the minimum energy power capacity which the farming tractor must have.

Moving on to the study, two base case studies are applied to the method and are described by their energy requirements. Finishing with the energy demands, the battery capacity and the solar generation are analysed.

For every case study-crop a financial analysis of the proposed system is necessary. The financial analysis is simple and aims to unveil the basic economic value that a venture like this holds in the current market with the current electric power and crop prices respectively. This specific project-concept is not available in commercial scale, thus the financial analysis demonstrates the requirements in terms of funding and subsidy if this idea is going to attract stakeholders in the future.

Last but not least it is important to mention and comment the environmental issues arising of this study.

2.2. Background

All information and data that were required for this project, are described in the Chapter 3. Inputs such as climate data base, software tools and existing technology are analysed, aiming to create a clear boarder line around the project. This chapter aims to help the reader of this study to understand what this project is about by explaining the basic parts that were used. This part of the study is very important as the project may be considered as an innovative one, without any similar predecessors, thus it is important to set the guidelines and the borderlines of this project.

2.3. Mathematics of the crop energy analysis method

All activities around farming practise require energy. Around the world farming practises differ in a great extend e.g. developing countries still using animals for ploughing, so it is very crucial to analyse which method is used to approach the energy needs of this particular project. Also it is important to separate the energy requirements from the power installation capacity, which is the engine output. Chapter 4, is covering all the above by introducing the reader into an energy approach of farming practises for this project.

2.4. Case study

After finishing with the explanation of the method the implementation of this is next. A realistic case study is presented and evaluated in order to unveil all pros and cons. In this chapter, Chapter 5, the energy yield of the solar PV panels is calculated, taken into consideration the climate data and technology for the desired location. Additionally an energy demand and generations is analysed, adjusted to the nature of the project, which is rather different from EV and building cases. The financial analysis of the project is separated from this part of the project.

2.5. Financial analysis

Whether this project is fitting the farming needs or not, it is necessary to present the economics occurring here. The analysis is based on the local market's conditions and is aiming to examine if this project is considered to be financially desirable or not and if not how it can be supported. Chapter 6. Includes all the above.

2.6. Environmental issues

This project belongs to the renewable energy sector and it has to be evaluated whether or not is complying with the goals that are set, worldwide, in order to move towards a more sustainable environment. Chapter 7 contains this aspect of the project.

2.7. Conclusion and discussion

The last chapter aims to gather all the important outcomes of this project and mention the overall advantages and disadvantages, while proposing possible alternatives. As mentioned before, this project could be considered as an "immature technology" regarding the real reliability because no information exists from relevant commercial scale concepts. Hence it is very important, at least theoretically, to demonstrate the potentials of this project to the reader

3. Back ground and Literature Review of the Project

As this project is about merging to different sectors together, agriculture and renewable energy sources, the literature review had to include sources from both sectors. Efforts were made to withdraw data and information that could rationally match together and produce a feasible result. Existing farming technologies, energy technologies, climate datasets, suitable software tools and economic policies were examined and opted to create the background of this project.

Key Words: Thessaloniki, GHI, US Department of energy, spreadsheet, Feed in Tariff, AC motors, torque, Lithium- ion, literature

3.1. Literature Review

As there are no previews reports or studies for this project, there was need to review different sources in order to find the desired information and data, to form the bare bones of this project. The literature review included:

- Books
- Manufacturer's brochures e.g. engines, motors, PV panels etc.
- Webpages
- Dealers from EV industry
- Previews studies
- Notes and academic material

All these sources were used in order to withdraw information regarding the existing technologies that could collaborate and create systems, climate data for the desired location, software tools required for the case study and of course any special policy that may exist. Briefly the fields that the literature review covers are:

- Climate data for the desired location
- Software tools
- Electric vehicle solar chargers
- PV cells
- Batteries
- Internal combustion engines
- Electric motors
- Policies

All data and information is referenced in order to allow the reader to check the viability of each aspect of the project.

3.1. Thessaloniki and solar data

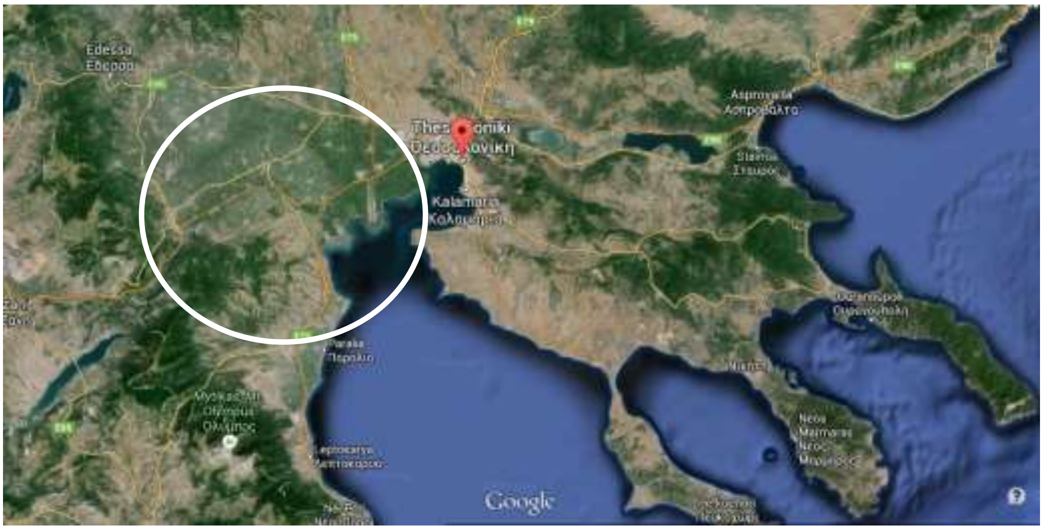


Figure 6. Google maps, Farming are of Thessaloniki, source: https://www.google.co.jp/maps/place/Thessaloniki,+Greece/@40.5738961,23.0985785,149305m/data=!3m1!1e3!4m2!3m1!1s0x14a838f41428e0ed:0x9bae715b8d574a9?hl=en, 2015

In this picture (Figure 6) the white cycle boarders the area that the most farming activity is taking place. In this area crops such as rice, wheat, cotton, and barley are grown. In this area there are also different varieties of high quality crops of grapes which are used from local vineyards that produce internationally approved high quality wines (http://www.wineroads.gr/).

The next table (Table 2) demonstrates the Global Horizontal Radiation for every first of the month from January to December at this location. The data were extracted from U.S. Department of Energy (http://apps1.eere.energy.gov/buildings/energyplus/) and plotted in order to get a first glance of the available energy (Wh/m^2) for the solar PV panels that could be installed. One factor that could cause confusion, but not very important as the weather data according to sun conditions do not change year to year, is that the data file uses different year dates. IWEC (International Weather for Energy Calculations) is a program that ASHRAE developed to create all these datasets, all files are derived from up to a 18 years of DATSVA3 hourly weather data originally archived at the U. S. National Climatic Data Centre. The weather data is supplemented by solar radiation estimated on an hourly basis from earth-sun geometry and hourly weather elements, particularly cloud amount information. (ASHRAE, 2001)

Direct	1984	1997	1992	1992	1990	1985	1990	1996	1989	1990	1994	1990
Wh/m2	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-June	1-July	1-Aug	1-Sep	1-Oct	1-Nov	1-Dec
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	0	0	0	0	0	0	0	0
5:00	0	0	0	0	0	0	0	0	0	0	0	0
6:00	0	0	0	0	5	16	17	3	0	0	0	0
7:00	0	0	0	12	85	129	127	51	28	8	0	0
8:00	0	4	22	86	273	317	312	196	178	106	15	3
9:00	40	88	162	200	477	520	514	373	378	290	113	44
10:00	174	250	343	293	622	703	695	549	566	469	252	117
11:00	301	390	501	342	647	845	835	698	710	608	387	178
12:00	387	487	607	520	684	907	926	782	803	692	482	264
13:00	417	527	642	646	666	871	959	814	834	711	518	317
14:00	388	508	598	692	599	734	931	789	800	665	484	319
15:00	304	431	496	567	531	593	843	701	713	557	379	231
16:00	178	304	346	402	428	422	706	569	564	398	233	123
17:00	44	146	179	226	299	252	525	405	371	211	78	24
18:00	0	20	47	94	197	148	323	229	169	46	4	0
19:00	0	0	1	11	57	56	135	79	24	0	0	0
20:00	0	0	0	0	2	6	19	7	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
0:00	0	0	0	0	0	0	0	0	0	0	0	0

Table 2. Global Horizontal Radiation Wh/m2 for every 1st of the month from Jan-Dec for Thessaloniki, source: U.S. Department of Energy

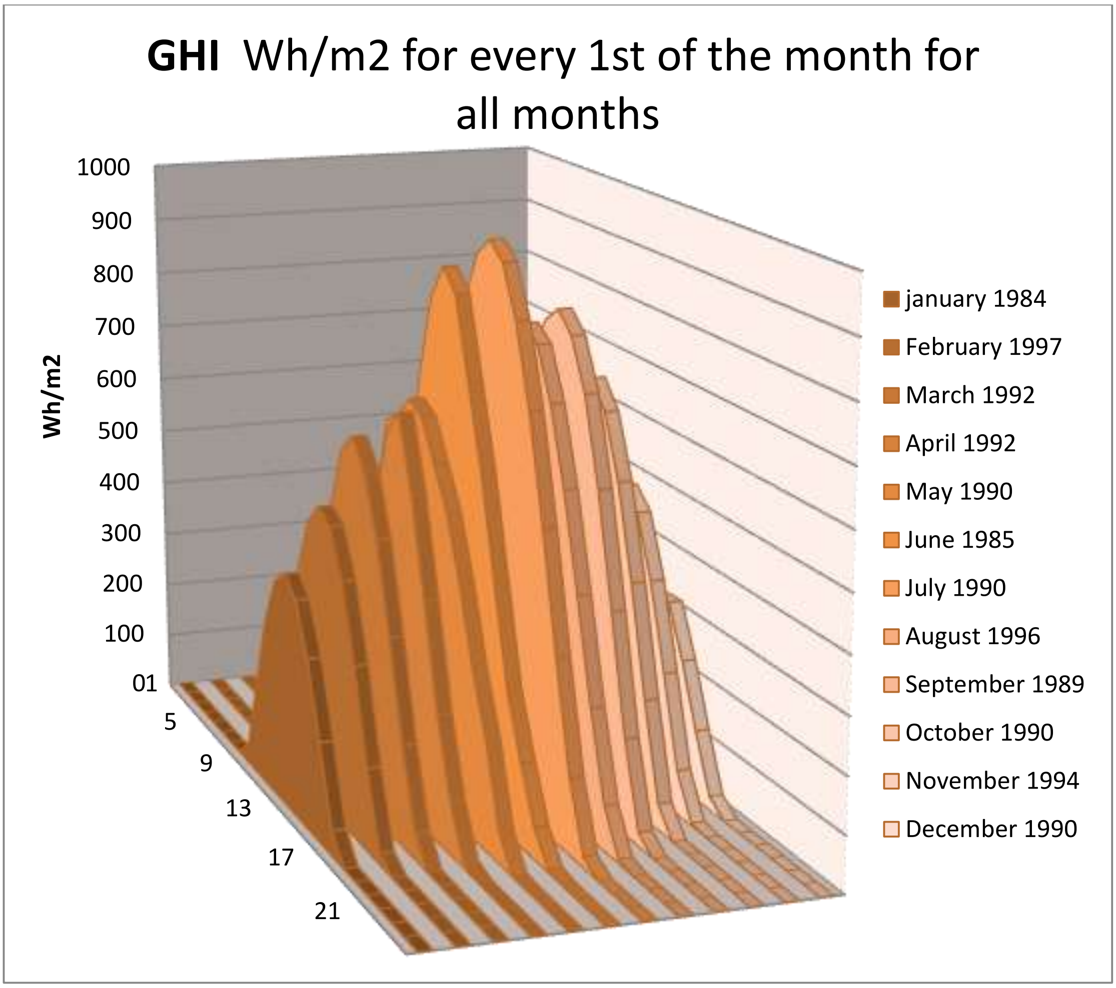


Figure 7. Global Horizontal Radiation Wh/m2 for every 1st of the month from Jan-Dec for Thessaloniki, source: U.S. Department of Energy

The chart (Figure 7) demonstrates the same information as the table but in a schematic format. The area that is enclosed between the curve and the x-axis (00:00-23:00) is the available energy from the sunlight that a PV panel can exploit to produce electric power. This chart is available for any stakeholder who desires to make comparison with other locations.

In order to get an indicative power output, related to Thessaloniki's climate, simple unprocessed calculation is apposed:

Let us assume a 3kW power capacity solar system with $5m^2$ cell surface is set up accordingly. The efficiency of the module is 15% (Sunmodule SW 250 Mono, 2015)

For January (1/1/1984) the sum of all the Wh/m^2 energy measurements is:

40+174+301+387+417+388+304+178+44 = 2233 Wh/m^2, which is approximately $2kWh/m^2$.

Then, 2kWh/m^2 * 5 m^2 * 15% =1.5kWh is the energy that is produced.

For the same system on July (1/1/1990) the system produces: 7.867kWh/m^2 * 5 m^2 * 15% = 5.898 kWh.

3.2. Software Review

After gathering all the data, a search for the most appropriate software tool took place. The three candidate software tools were, the Homer Pro, the Ret Screen, Merit and the PVsyst. All of them, are widely used for renewable energy projects. Additionally there were a fourth option including a spreadsheet that was developed based on spreadsheet that was provided from professor Nick Kelly, who was the supervisor of the Jenny Maclean, Muhip Tuna Meti, Bartosz Nowak and Konstantinos Michail Akritidis for the project: "Assessing the Feasibility of Integrated PV and Wind Farms". This spreadsheet specifically calculates the energy yield for a given climate database and a given solar array.

3.2.1. Homer Pro

The first software tool that was evaluated for its suitability for the needs of the project was Homer Pro tool. As the developers support this tool is accordingly developed for design and analysis of different microgrids. It allows the user to select from a large library of generation and storage systems and match them with the desired demands profiles. There are two main advantages of Homer Pro, the first one is that it enables the user to select the climate data from a map, by just selecting a location in the map, all data are downloaded from NASA's database. The other advantage is that when the user designs the project, the software allows the user to enter all the data that occur the cost analysis. After running many simulations, Homer produces results from the different scenarios that took into consideration and repots which are functional. Apart from technical details, it also provides an economic analysis for each different case. (http://www.homerenergy.com)

3.2.2. Ret Screen

The Ret Screen is developed and supported from the Natural Resources of Canada (Ministry) and it can be consider as competitor of Homer Pro tool. Yet again it is a design tool, that is using the Microsoft Excel interface and it is a very friendly user program. When the data entrance procedure ends Ret Screen produces the results of the project. Apart from the technical results, it produces a very analytical and comprehensive financial analysis over the lifetime of the project. (http://www.retscreen.net)

3.2.3. Merit

Developed in the University of Strathclyde, Merit has got various weather databases installed while it is possible to load others from external sources. Additionally it has got a very informed library of ready solutions regarding the energy generation and storage. Apart from allowing the user to design specific energy generation schemes to meet certain demands, it can go over all possible scenarios, that the user designed, and generate matching rates, which indicate the user which one to select. This tool focuses on the matching of demand and supply energy profiles. (http://www.esru.strath.ac.uk/Programs/Merit.htm)

3.2.4. PVsyst

This program is developed from two individuals the Andre Mermoud and Michel Villoz. This tool focuses only on photovoltaics and especially on the technical aspect of a project. It includes various simulations for PV efficiency generation and especially the shading effect and its impact on power generation. (http://www.pvsyst.com)

3.2.5. The Spreadsheet

All tools were assessed equally, regarding the time and detail level, but were rejected because they did not fit the simple but exact requirements of this project. It is clearly out of the scope of this paper to analyse and compare all the mathematics and functions that these tools are using, however it is worth mentioning that all programs produce, in a reasonably and scientifically acceptable level, the same results regarding the transformation of the solar power to electric. So there was no such a reason to compare and then reject any of these tools. The reason that the author of this project opted for a costumed designed tool (spreadsheet) is that this concept required the energy production of the designed solar system, in Hourly and Annually time scale for a given climate database. Then the next step was to match the hourly production with the capacity of the battery for different time periods of the year, to define whether or not it is feasible to charge the battery in the desired time period. The rest energy is considered to be exported into the grid and it is used in the financial analysis. The financial analysis is then developed into a different spreadsheet which is analysed in the chapter: 6. Financial Analysis.

3.3. Basic schematic representation of the proposed system

Nowadays many different companies have made a great progress regarding the electric vehicles. Obviously this is a new part of industry and everyone tries to compete by introducing its own design. Considering the background of the literature review and the technological achievements there is a basic structure of the system that supports the electric vehicles.

- Electric motor, usually AC induction motor
- AC/DC converter due to the AC motor
- Lithium – ion batteries
- Charging controller
- More recently regenerative braking system

A farming tractor is considered to be a vehicle and the hypothetical one that it is used for this study shares these basic parts. The only difference is that most electric vehicles charge from special locations connected to grid, in this case the only source is solar PV panels. Other renewable sources could be small scale wind turbines, or electricity that is generated from biofuels, or even hybrid systems, but officially there is no literature describing these ways.

The next picture (Figure 8) demonstrates a typical connection of solar panels, charger control and batteries.

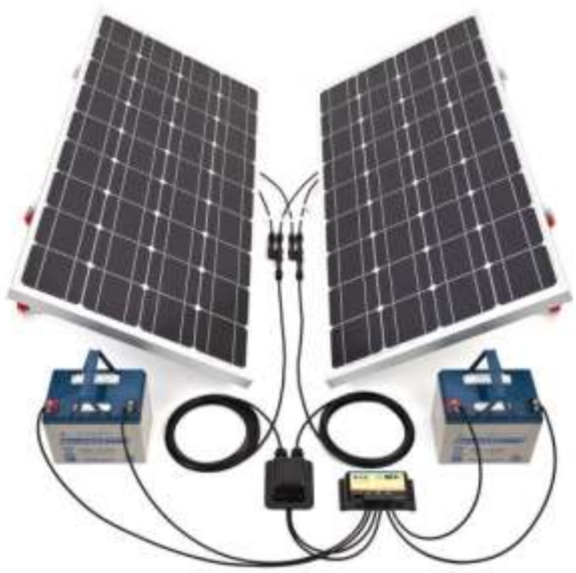


Figure 8. Typical connection for PV panels, control charger and batteries, source: http://www.bestecoshop.com/

When the desired battery pack is fully charged it disconnects from the charging system and connects to the electric motor. Although DC motors are widely used, recently industry shifted to AC induction motors for many reasons; hence the DC current from batteries must be altered to AC in order to allow the motor to produce work.

Next picture (Figure 9) demonstrates the basic connection of a battery, converter and AC electric motor.

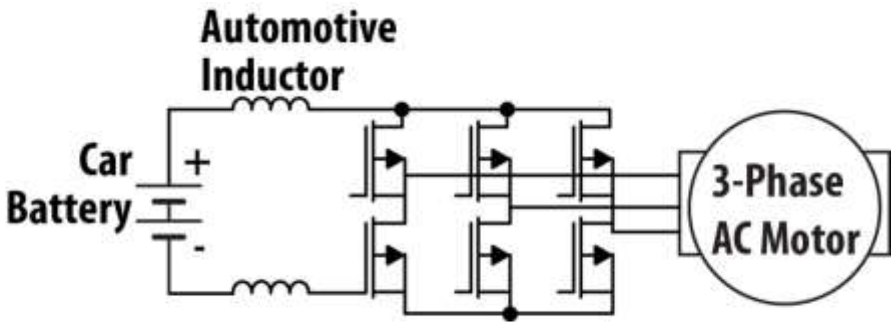


Figure 9. Battery, AC/DC converter, AC electric motor, source: http://johndayautomotivelectronics.com/

3.4. Existing Solar chargers for EV

The idea of electric vehicles to be totally depended on solar energy, thus off the grid, is very attractive to developers who seek these energy trends. There are some solar charging points, in airports, supermarket's parking spaces and generally parking spaces. These solar charging points are mainly for supplementary energy source for electric vehicles. Some developers such as Ford motors and Sun power are trying to upgrade this concept to the next level by installing PV panels in the sky of a Ford C-max (http://www.ford.com).

One typical example is the EV ARC (Electric Vehicle Autonomous Renewable Charger) solar charging pole in San Francisco where, 3.3kW panel array charges a lithium battery of 22kWh, which battery in turn charges the EV. The brochure that is released by the company Envision Solar contains all the details of the EV ARC (http://envisionsolar.com/pdf/EVARC.pdf), but the most important are:

- 2.5 or 3.3 kW DC (capacity)
- 3.800-7.000 kWh/year
- Solar Tracking system
- 22 kWh battery, lithium – ion
- No grid connection
- No foundation is required

Figure 10. EV ARC, source: http://envisionsolar.com/pdf/EVARC.pdf

Other examples are demonstrated in the book "Designing with Solar Power", located in US, Spain, Japan etc.

3.4.1. Solar PV cell types

There are three predominant technologies in the current market regarding the solar cells of a photovoltaic panel:

- Mono-crystalline or Single-crystalline
- Poly-crystalline
- Thin film

According to International Energy Agency (IEA, 2010) the efficiencies of these three technologies are demonstrated in the next matrix:

Crystalline silicon technologies	2010 - 2015	2015 - 2020	2020 - 2030 / 2050
Efficiency targets (commercial modules)	• Single-crystalline: 21% • Multi-crystalline: 17%	• Single-crystalline: 23% • Multi-crystalline: 19%	• Single-crystalline: 25% • Multi-crystalline: 21%
Industry manufacturing aspects	• Silicon (Si) consumption < 5 grams / watt (g/w)	• Si consumption < 3 g/W	• Si consumption < 2 g/W
R&D aspects	• New silicon materials and processing • Cell contacts, emitters and passivation	• Improved device structures • Productivity and cost optimisation in production	• Wafer equivalent technologies • New device structures with novel concepts
Thin film technologies	**2010 - 2015**	**2015 - 2020**	**2020 - 2030**
Efficiency targets (commercial modules)	• Thin film Si: 10% • Copper-indium/gallium (CIGS): 14% • Cadmium-telluride (CdTe): 12%	• Thin film Si: 12% • CIGS: 15% • CdTe: 14%	• Thin film Si: 15% • CIGS: 18% • CdTe: 15%
Industry manufacturing aspects	• High rate deposition • Roll-to-roll manufacturing • Packaging	• Simplified production processes • Low cost packaging	• Large high-efficiency production units
R&D aspects	• Large area deposition processes • Improved substrates and transparent conductive oxides	• Improved cell structures • Improved deposition techniques	• Advanced materials and concepts

Figure 11. IEA estimations about the Photovoltaic cells efficiency, source: https://www.iea.org

By retrospection to the existing solar charging points or poles, it is observed that usually mono and polycrystalline technologies are installed, due to their efficiencies. The thin film is usually used when aesthetics is major target of the developer. The main differences between mono and poly crystalline solar PV panels are briefly summarised in the next categories:

- **Price**: For the same capacity (W) single-crystalline are more expensive then poly-crystalline
- **W/m^2 capacity**: For the same are mono-crystalline have larger capacity than single-crystalline
- **Efficiency**: Mono-crystalline have bigger efficiency than poly-crystalline (Figure 11)
- **Life duration**: As a technology mono-crystalline panels are more matured and it is believed that its life time is prolonged, compared to the poly-crystalline, but in reality developers provide approximately for both technologies that same warranty, which ranges from 20-25 years.

The project that is analysed in this paper is very immature, thus the main factor which affects the feasibility of it, is the cost. Currently the prices of the panels are minimized significantly but when it comes to the full design of a photovoltaic array the calculations of the cost must be breakdown to all the factors, such as metal supporting constructions, installation costs, charger controller etc. This part of the concept will be analysed on the economic analysis later on.

3.4.2. Solar Generation Capacity and Feed in Tariff

In many countries there is a feed in tariff policy, from power supply companies, for private owners of solar panels who export electric power to the grid. This study predominantly refers to Greece where its policy has recently changed and affected all projects, this will be explained later. As all projects up to 10kW capacity are subject to this policy, the rest days of the year when the farmer is not using the tractor there is surplus that can be exported and render the whole investment more feasible.

3.5. Basics of Electric and Diesel Motors

As mentioned before, technical details considering the design of an electric tractor are out of the scope of this study, however there are important elements that must be mentioned and analysed when it comes to the election of the proper electric engine.

Apart from the type of energy source that is utilized for the engine, there is another crucial difference between electric and internal combustion engines and that is the torque. The torque is the figure that demonstrates the traction force of a vehicle and it is measured for different revolutions per minute (rpm). The unit of torque is the Nm and for vehicles that are used for traction purposes and not high speed travelling, it is a very important attribute of the engine's capability.

Traditional internal combustion engines (gas, diesel) tend to reach their pick torque at certain rpm. For example a typical car diesel engine tend to reach its pick torque at the 2500 rpm, which is the point that the constructor of the car advise the driver to change gears in order to optimise the use of engine.

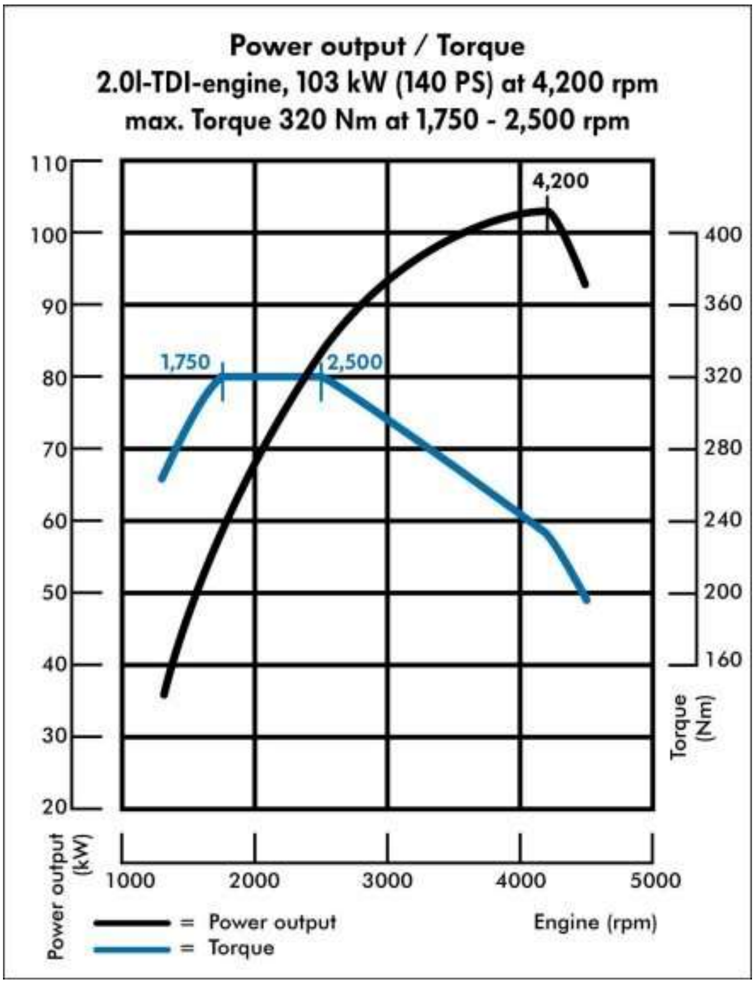


Figure 12. Torque vs rpm for 2.0 TDI VW engine, source: http://www.vw.com

At the specific example that is demonstrated at chart 3, the engine reaches it maximum torque from 1750-2500 rpm, which is 320 Nm.

An electric engine usually produces its maximum output from very low rpm. Many race drivers that are testing new electric cars admit that the sense of the pull from electric engines is very intensive. That is why electric motors are widely used in cranes and lifters. By providing high torques in low rpm the electric motors can be useful for farming tractors where high torques are required in low speeds e.g. ploughing average speed 7 km/h.

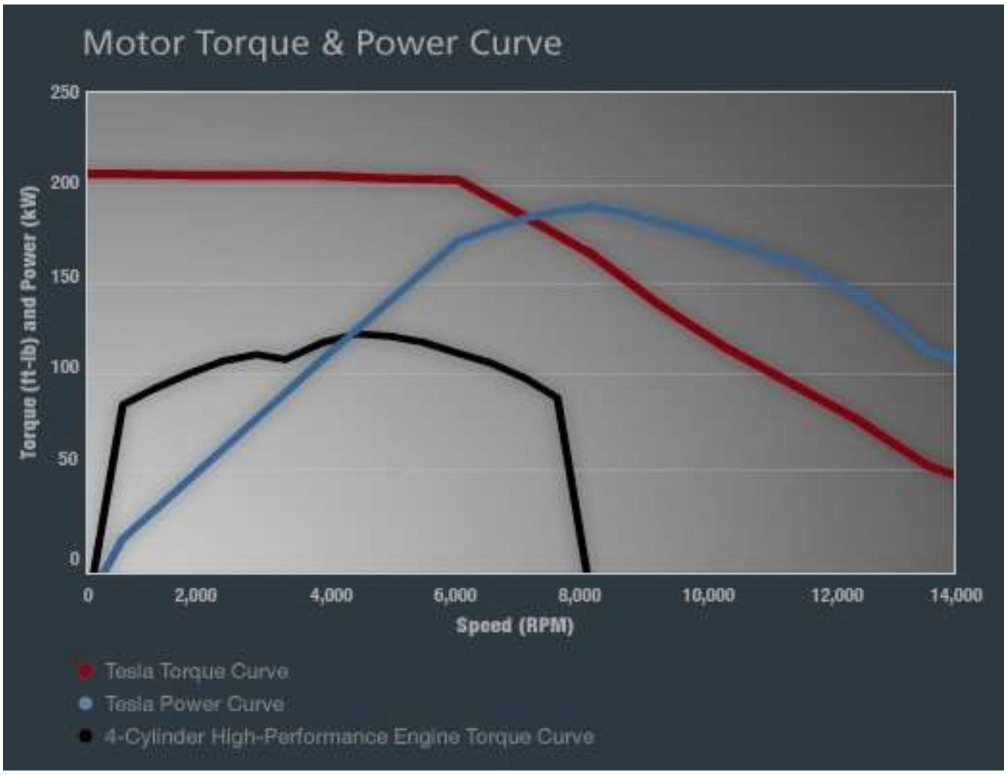


Figure 13. Motor Torque & Power Curve for a Tesla engine, source: http://www.teslamotors.com

Note that 1 ft-lb = 1.355 Nm. At the graph above it is clear that the engine produces its maximum torque from very low kW power and low rpm. Thus an electric engine requires low kW power to produce the desired torque.

The factor that defines the torque of an electric engine is the current I (A). From the equation that relates the current with the power, it is clear that for a default voltage high current can affect the torque of a motor. Another important element that is demonstrated to this chart is that the power requirements for low rpm is relatively low.

Hence comparing the two engines, the diesel one produces 270 Nm with power output of 70 kW and the electric (200 x 1.355 =271 Nm) 270 Nm from the approximately 2 kW power output. Although this comparison requires many other aspects to be mentioned, it intends to demonstrate the different natures of the two motors.

3.6. Lithium Ion Batteries

The technology of lithium – ion batteries took off with the boom of smartphones and generally portable electronic devises. Even when the global market experienced the crisis in the year 2009 the number of the mobile phones increased at a rate of 20% and it is estimated that the demand for more durable devices is will increase, thus the demand for Lithium-ion batteries will also increase. (Yuping Wu, 2015)

The lithium ion batteries is the technology that most EV manufacturers (Tesla, Nissan etc.) are implementing in their cars. These batteries share advantages such as tolerance to high voltages for supercharging and larger charge/discharge limits. Tesla is using packs from 60 to 85 kWh while Nissan (Nissan Leaf, 2015) is using 24kWh. Currently this technology is taking up due to the huge impact on the car industry that Tesla did.

For the needs of this study, after the energy demands calculations, the battery package that is going to be selected will be one of the existing in the market but providing the assumption that it can be constructed to match a farming tractor hood. The price and warranty of the battery pack will be taken from the developers brochures and utilised in the economic analysis.

Further research regarding the battery pack that is suitable for this study can be done in the future, but now it is out of the limits for various reason, especially time and level of research constraints reasons.

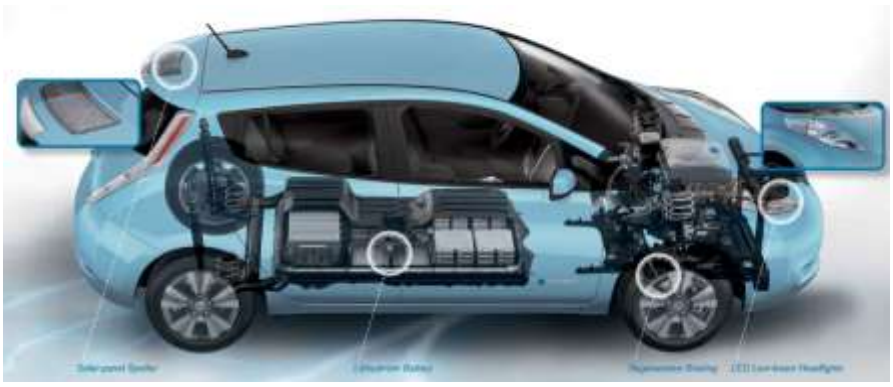


Figure 14. Size and shape of the 24 kWh battery, Nissan Leaf, source: Nissan Leaf's official brochure Size and shape of the 24 kWh battery, Nissan Leaf, source: Nissan Leaf's official brochure

Usually the capacity of batteries is demonstrated with the Ah unit, however a very useful unit is the kW, which is the product of the multiplication of the Voltage times the Amperes.

$$P\ (kW) = V\ (Volts) * I\ (Amps)$$

If for example a battery capacity is 30 kW then, theoretically, the energy than it can release in one hour is 30kWh.

3.7. Environmental Reports and Policies

Apart from all the above, a very significant factor of the overall project's background, is the environmental standards that do exist. It is important to examine the reports and their outcomes, from large and reliable organisation and countries' energy departments (e.g. USA). The project has to comply with the environmental standards, which do and will exist in order to maintain its green character.

4. Crop Energy Analysis Method

In this chapter the definition of the energy demand, which is the corner brick element of the feasibility of this project, will be discussed. Different crops require different farming activities, thus energy demands. Nowadays agriculture is shifting gears and focuses in planning, designing and managing crops more accurately than ever. For this project the method that is used is analysed and discussed.

Key Words: ASAE table and equation, calendar of farming activities, total energy of pulling farming tools

4.1. Mathematics, Functions and Indicative Examples

The first efforts for proper management and planning of the farming activities were conducted in order to minimize the cost, especially the operation cost. Later on more sophisticated methods were applied in order to include the indirect cost that is related to the activities that were usually postponed and were adding to cost. This method is called the method of the best and not the lowest cost. Although these methods were introduced to decrease the extra cost, they can provide valuable information regarding the energy demands of the activities. In Greece a very huge problem was that farmers were doing business for decades without consulting agriculturalists for the management and planning of the farming activities. Subsidies and funding from EU were covering the cost that was created, but after the financial crisis of 2008 subsidies and funding were decreased and farmers had to turn into these methods in order to have a better approach in their business. Apart from the financial issues, all these years amount of CO_2 emissions were released to environment due to inappropriate farming practises, adding to the depletion of the environment.

The overall energy demands include the:

- Energy needs for farming activities in the field
- Energy needs for transportation and transfers

The definition of the annual energy demands will indicate the desired power output of the tractor (kW). The next equation demonstrates the relationship between the power and energy

$$P = E/t \quad \text{(W or kW)} \quad (1)$$

Where,

- P : is the power of the tractor
- E : is the energy required for all the activities
- t : is the annual usage

The energy demands, for pulling reasons only, for each farming equipment or tool are calculated individually from the force that is needed for traction, the speed that is used, for example for ploughing the average speed is 7 km/h, and the efficiency of the tools in the field.

The next table is sourced from ASAE Standard D497 (ASAE, 1995):

Farming tool	Speed (km/h)	Efficiency	Length unit W	Farming tool's parameters			Soil parameters		
				A	B	C	F1	F2	F3
							heavy	medium	light
plough	7	0.85	m	652	0	5.1	1	0.7	0.45
subsoiler	8	0.95	ploughshare	226	0	1.8	1	0.7	0.45
chisel plough	8	0.85	ploughshare	294	0	2.4	1	0.85	0.65
disk harrow	10	0.8	m	309	16	0	1	0.88	0.78
cultivators	10	0.85	m	46	2.8	0	1	0.85	0.65
small cultivators	8	0.8	line	260	13	0	1	0.85	0.65
tillage	11	0.85	m	2000	0	0	1	1	1
roller packer	10	0.85	m	600	0	0	1	1	1
fertilizers	9	0.65	line	900	0	0	1	1	1

Table 3. ASAE Standard D497 parameters of farming tools

In order to calculate the exact force that is required for every tool, ASAE Standard produced an empirical equation that implements the parameters from table 1.

$$D = Fi * [A + B * S + C * S^2] * W * T \quad (N) \qquad (2)\ (ASAE, 1995)$$

Where,

- D: Pulling force (N)
- F: parameter for type of soil
- i =1, 2, 3 (1=heavy soil, 2=medium soil, 3=light soil)
- A, B, C parameters of the farming tool taken from table 1
- S: average required speed for every farming tool (km/h)

- W: length unit (m) or number of lines or ploughshares
- T: the depth that the farming tool enters the soil (cm), for fertilizing this is equal to 1 cm

For example a plough with three ploughshares, with length of each ploughshare at 35cm, the depth that the tool enters the soil (medium soil F2) is 25 cm and the ploughing speed is 7 km/h, requires 16572 N.

Figure 15. Triple ploughshare plough source: http://www.viarural.com.uy

[F2=0.7, A=652, B=0, C=5.1, S=7, W=3*0.35=1.05m, T=25cm]

Thus, $D=0.7*[652+5.1*7^2]*1.05*25=16572$ N

As we observe there is no force loss factor involved in the equation and that is because this equation is offered for a theoretical approach to the pulling force problem. In reality a lot of problems can occur, such as loss of friction of tractor, incline surface, muddy soil, etc. For the needs of this study the theoretical approach is adequate and that is because every case is different and needs to be analysed differently.

Coming back to the previous example with the triple ploughshare plough, by using the equation (3) the power equals to:

$$P = \frac{D*S}{1000} \; (kW) \quad (3)$$

$$P = 16572 * \frac{7000}{3600} * \frac{1}{1000} = 32.3 \; kW$$

And continuing to the calculations for energy with implementation of the equation (1) the result is:

$$E = P * t\ (kWh)\ \ (4)$$

From the previous equation (4), the time that is required for an acre to be ploughed is calculated from the next equation (5),

$$C_E = W * S * Ef\ \ (5)$$

Where,

- C_E: acre/ hour, hence 1/C_E hour/acre
- W: length unit (m) or number of lines or ploughshares
- S: average required speed for every farming tool (km/h)
- Ef: efficiency of each tool from Table 1

By applying the figures for every factor in equation (5) we have,

$$C_E = 1.05 * 7 * 0.8 = 5.88\frac{acres}{hour}$$

Or,

$$\frac{1}{5.88} = 0.17\ \text{hours/acre}$$

Which is the time that will be used if equation (4) in order to calculate the required energy for ploughing, hence:

$$E = 0.17\ \left(\frac{hours}{acre}\right) * 32.3\ (kW) = 5.49\ \left(\frac{kWh}{acre}\right)\quad (5)$$

The energy that is required for ploughing is, 5.49 kWh / acre the same series of calculations can be applied for all the farming tools that are needed for the farming activities.

4.1.1. Calendar of planned farming activities

Creating a proper calendar of planned farming activities can aid the farmer to calculate the overall energy needs that a specific crop requires. This action is crucial because it sums all the activities in one table.

The next table (Table 4) is an example of a typical schedule of activities for three different crops, wheat, cotton and corn. The activities are considered to be per acre, for example one fertilizing per acre, this enables the farmer to calculate the work in an area unit. This table is not advised to be used as a guide because every crop is located in different location, additionally all varieties of the same crop may need different fertilizers and fertilizing technics and of course the type of soil can vary the activities especially when a soil is problematic (e.g. salted soil)

Farming activites	number of interventions in the field					
	crops			acres		
	wheat	cotton	corn	50	100	70
ploughing	1	1	1	50	100	70
disk harrow	1	1	2	50	100	140
cultivator	0	3	2	0	300	140
fertilizing	1	1	1	50	100	70
seeding and fertilizing	1	1	1	50	100	70
light cultivators	0	2	2	0	200	140
sprinklers and medicines	1	4	2	50	400	140
harvesting	0	1	1	0	100	70
balls of hay	1	0	0	50	0	0
irrigations	0	5	5	0	500	350
transportations	9	30	20			
transfers	1	10	1			

Table 4. Schedule of farming activities for wheat, cotton, corn (Tsatsarelis K. 2006)

At this point there are three important notes that need to be mentioned:

1. Most of the time all irrigation activities are completed from autonomous pumps which either have diesel engines or electric which are connected to the grid, but sometimes in isolated area, farming tractors can move the irrigation pumps with the PTO. For this study pumps are out of the energy analysis.
2. Even if the tractor is parked onsite a great number of transfers are taking place and must be included into the study.
3. Tractors are responsible for all the transfers regarding the harvested crops.

In order to calculate the power that is required for transfer and transportation the total weight of the tractor or the tractor and a platform must be calculated, also the friction factor for the wheels must be taken into consideration (according to ASAE Standards it is equal to 0.07), thus for a weigh of 3500 kg, speed of 20 km/h which is an acceptable speed for a tractor in a road, the force that is required to move the load is, 245kg = 2450 N, 2.45kN.

$$P = \frac{2450 * \frac{20000}{3600}}{1000} = 13.61\ kW \quad (6)$$

A convenient way of estimating the energy that the tractor will consume for transfer is to calculate it based on distance.

$$E = 13.61\ (kW) * 0.05(\frac{h}{km}) = 0.689\ kWh/km$$

Regarding the transportation the only change that is necessary to be applied is to sum the tractor weight and the platform (loaded) weight. For example for a summarized weight (tractor and platform) of 10 tons the resulted energy is equal to:

By using equation 6, $E = 7(kN) * 20\frac{\left(\frac{km}{h}\right)}{3.6} * \ 0.05\ \left(\frac{h}{km}\right) = 1.95\ kWh/km$

Hence, because this study focuses on replacing fossil fuels with electrical energy this amount of energy per km, is the equal term of consumption (e.g. miles per gallon UK)

Having the tools to calculate the power (kW) and the energy (kWh/acre) for all the farming activities another table can be created. This table includes all the farming activities translated into energy demands. The total energy, regarding the pulling of tools, will affect the power output of the tractor that is required.

This table will be presented in the next chapter where the exact identification of the demands are demonstrated regarding specific case studies.

According to K.Tsatsarelis the equation which calculates the required power output of the diesel engine of the tractor is:

$$P = \sqrt{\frac{E*l}{CF*q}} \quad (7)$$

Where,

- E: Total Energy of the farming activities, traction reasons
- l: cost of labour of the operator of the framing tractor €/h

CF: Cost factor, annual operational cost per purchasing price of the tractor which is considered to be 0.11

- q: purchasing price € per kW of PTO €

This equation (7) is provided after a series of calculations that are out of the limits of this study, further information can be found in the book of Tsatsarelis K. Management of Farming Equipment. At this study this equation is used only to serve the purpose of defining the power output of the electric motor of the tractor.

Apart from equation (2) all others are sourced from the (Tsatsarelis K., 2006)

4.1.2. Further energy analysis for each crop

After finishing with the definition of the power output of the motor, a more thoroughly and detailed energy analysis needs to be done regarding the exact timescale of the farming activities. Different crops require different planning. It is necessary to calculate the energy demands throughout the time periods when farming activities occur and of course examine the daily demands at the pick periods. The target is to provide the best solar power generation to cover the energy crop needs at the periods when the sun light is not adequate.

5. Case Studies

In order to move on, case studies must be analysed, based on the proposed methodology. Two types of crops that are common in the selected location, were chosen. The target of this chapter is to examine what happens when it comes to apply this project.

Key Words: farming tools, kW, kWh, traction energy requirement, engine matching, torque, battery duration, series, parallel, 3, 5 and 10 kW, installed capacity and used capacity, cloudy days, daily matching, flexible matching

5.1. Types of crops and number of acres

The two case studies include one of 50 acres of wheat and 70 acres of cotton. The hypothesis here is that different farmers own these two crops. The number of acres might seem small but these are the typical land areas which are cultivated in Greece. Cotton and wheat are quite common crops in the farming area of Macedonia in Northern Greece (Figure 6).

5.2. Farming tools specifications and diesel engine power requirement

In this part, the method which was analysed on the previous chapter, is applied. The final goal of this method is to find the desired, diesel, energy power output that is required for the crops.

For these two case studies of wheat and cotton crops the next farming tools are necessary:

- Ploughing with 1,4 m width and three ploughs
- Disk harrow with length of 2 m and cultivation depth of 15 cm
- Cultivator with length of 3 m and cultivation depth of 25 cm
- Fertilizer with length of 3 m
- Seeding and fertilizer combined with length of 3 m
- Light cultivator with length of 3m and cultivation depth of 15
- Pharmaceutical sprinklers of 2m length
- Harvester (cotton) 2m length
- Hay ball machine 2m length

These farming tools, pulled from tractor, could be analysed technically, but this is out of the scope of this study.

The next table (Table 5) illustrates the number of applications in field, the force, the power and the energy per acre, which every tool requires in order to be effectively pulled from the tractor. Thus no confusion of traction energy and electric energy for the motor, should be done.

The figures completing the table are either calculated from the ASAE table or taken form the case studies that Tsatsarelis K. is analysing in his study (Tsatsarelis K., 2006). As always useful to be mentioned these figures are subject to change under different circumstances. Thus this approach is only for the location described in this project.

Farming activites	number of interventions in the field				Pulling Force (N)	Power (kW)	hours/acre	kWh / acre
	crops		acres					
	wheat	cotton	wheat	cotton				
ploughing	1	1	50	70	22096.6	43	0,2	**7.3**
disk harrow	1	1	50	70	12381,6	34,4	0,1	**2,1**
cultivator	0	2	0	210	3774,0	10,5	0,1	**0,6**
fertilizing	1	1	50	70	1800,0	4,5	0,1	**0,4**
seeding and fertilizing	1	1	50	70	4464,0	11,2	0,1	**1,0**
light cultivator	0	2	0	140	1744,2	3,9	0,07	**0,3**
sprinklers and medicines	1	4	50	280	828,0	2,3	0,8	**0,4**
harvesting	0	1	0	70	4950,0	11,0	0,2	**1,7**
balls of hay	1	0	50	0	14175,0	31,5	0,2	**6,1**

Table 5. Detailed energy and power analysis of the farming activities and tools

This matrix enables the farmer to understand the energy, only for traction, that is related to every farming activity for every acre of his or her land. For example the total traction energy needs for ploughing, which is the most basic activity, is equal to 7.3 kWh/acre times the number of acres. The energy requirements for the two cases is 365.4kWh and 511.5kWh for 50 and 70 acres respectively. The same process is followed for all activities. The next step is to calculate the total traction energy that each crop requires.

Another two farming activities that require traction energy analysis are the transfers and transportations that are required. These two are calculated separately because they are reduced to km, instead of acre.

By retrospection to chapter (4. Crop Energy Analysis Method) for a farming tractor that weights 3500kg and moves with the speed of 20km/h, the energy that is required is 0.689 kWh/km, thus this is the energy for transfers. The energy of transportation is calculated form the tons of cotton or wheat that is produced and harvested at the end of the farming year. The average production rates for wheat and cotton are assumed to be 400 kg/acre and 120 kg/acre respectively thus the tractor must pull loads of 20 tons and 8.4 respectively. These numbers can vary for numerous reasons which are out of the scope of this study. By assumption the tractor pulls a platform that can hold a max load of 6 tons. The overall weight is 6+3.5= 9.5 tons or 9500 kg or 6.65kN, hence:

By using equation 6, $E = 6.65\ (kN) * \frac{20}{3.6}\left(\frac{km}{h}\right) * 0.05\ \left(\frac{h}{km}\right) = 1.84\ kWh/km$

Concluding there will be 4 transportations for the wheat crop and 2 for the cotton crop. By assumption the delivery point of the two crops is 3 km away from the arable land, hence:

- Wheat: $1.84\ \left(\frac{kWh}{km}\right) * 4 * 3(km) = 22.08\ kWh$, and

$$\frac{22.08(kWh)}{50(acres)} = 0.44\ kWh/acre$$

- Cotton: $1.84\ \left(\frac{kWh}{km}\right) * 2 * 3(km) = 11.04\ kWh$, and

$$\frac{11.04(kWh)}{70(acres)} = 0.15\ kWh/acre$$

Also by assumption there the transfers are 30 per year for each crop, hence:

- $0.689\ \left(\frac{kWh}{km}\right) * 3(km) * 30 = 62.01\ kWh,$ and

$$\frac{62.01(kWh)}{50\ (acres)} = 1.24\ kWh/acre$$

$$\frac{62.01(kWh)}{70\ (acres)} = 0.88\ kWh/acre$$

For wheat and cotton respectively.

The next table (Table 6) show the overall energy needs for each activity in the bolded columns, they are resulted by multiplying the kWh/acre column with the acres.

Farming activites	**number of interventions in the field**				kWh / acre	**Total Energy kWh Wheat**	**Total Energy kWh Cotton**
	crops		**acres**				
	wheat	**cotton**	**wheat**	**cotton**			
ploughing	1	1	50	70	7,3	**365.4**	**511.5**
disk harrow	1	1	50	70	2,1	**107,5**	**150,5**
cultivator	0	2	0	210	0,6	**0,0**	**129,5**
fertilizing	1	1	50	70	0,4	**19,2**	**26,9**
seeding and fertilizing	1	1	50	70	1,0	**47,7**	**66,8**

light cultivator	0	2	0	140	0,3	**0,0**	**39,9**
sprinklers and medicines	1	4	50	280	0,4	**17,5**	**98,0**
harvesting	0	1	0	70	1,7	**0,0**	**120,4**
balls of hay	1	0	50	0	6,1	**303,0**	**0,0**

Table 6. Total energy demands for each activity per crop (kWh)

The total traction energy requirements are 768.9 kWh and 1015.6 kWh for wheat and cotton crops respectively. Also the traction energy needs from the transfers and transportations are:

- Wheat: $50(acres) * \left[0.44\left(\frac{kWh}{acre}\right) + 1.24\left(\frac{kWh}{acre}\right)\right] = 84\ kWh$

- Cotton: $70(acres) * \left[0.15\left(\frac{kWh}{acre}\right) + 0.88\left(\frac{kWh}{acre}\right)\right] = 72.1\ kWh$

Including to the previous calculations the energy demands from the transfers and transportations the results are:

➢ **Wheat : $\mathbf{860.3 + 84 = 944.3\ kWh}$**

➢ **Cotton: $\mathbf{1143.5 + 72.1 = 1215.8\ kWh}$**

The next step is to calculate the desired power output of the tractor in order to meet these demands. The equation (7) from chapter (4. Crop Energy Analysis Method), provides the result.

$$P = \sqrt{\frac{E*l}{CF*q}} \quad (7)$$

By assumption and based to the current market rates of Thessaloniki, the l factor, which stands for the salary per hour of the operator of the tractor, is equal to 4,5 €/h. The q factor is equal to 750 € and the CF is equal to 0.11.

By replacing the energy needs for the two crops, the results are:

▪ **Wheat: $\mathbf{P = \sqrt{\frac{944.3*4.5}{0.11*750}} = 7.17kW}$**

- **Cotton:** $\boldsymbol{P = \sqrt{\frac{1215.8*4.5}{0.11*750}} = 8.14kW}$

Note that these two figures of power output are only related to the pulling force of the tractor, thus the engine must produce more than that. According to Tsatsarelis K., in order to include the losses from the friction from the wheels, the transmission and the pulling action these two results must be increased by 55% in order to calculate the power output of the engine.

Hence, for the two crops the **diesel engines** must produce **11.11 kW** and **12.67 kW** for the wheat and cotton crops respectively. These two figures are rounded up to **11** and **13 kW** respectively.

Concluding the demand calculations it is fundamentally important to mention that these power outputs are occurring **diesel** and not electric motors. The next part of this chapter deals with these correlation of the diesel and electric motor power outputs and torques, based on the theory that was previously discussed (3.5. Basics of Electric and Diesel Motors).

5.3. The engine matching

The key point regarding the engine selection is the torque. The previous analysis is based on diesel engines and in one fundamental attribute, the relationship between rpm and maximum torque. Most of the diesel engines produce their maximum torque between 1500-2500 rpm and with the aid of special gearboxes, that are used only in farming tractors, they allow tractors to move with low speed (7 km/h) in order to operate in farming lands.

As mentioned before, the selection of the engine is going to be done after an investigation on the existing variety of engines that are used in farming tractors. One of the top manufactures of these engines is Yanmar (http://www.yanmartractor.com). In the next three charts (Figure 16), three engines are demonstrated in order to examine the maximum torque and its relationship with the power output. The first engine produces 13.5 kW, the second 16.4 kW and the last one 26.2 kW. For the needs of the two crops it is obvious that the first engine is suitable for both crops (13.5 kW for 11 and 13 kW).

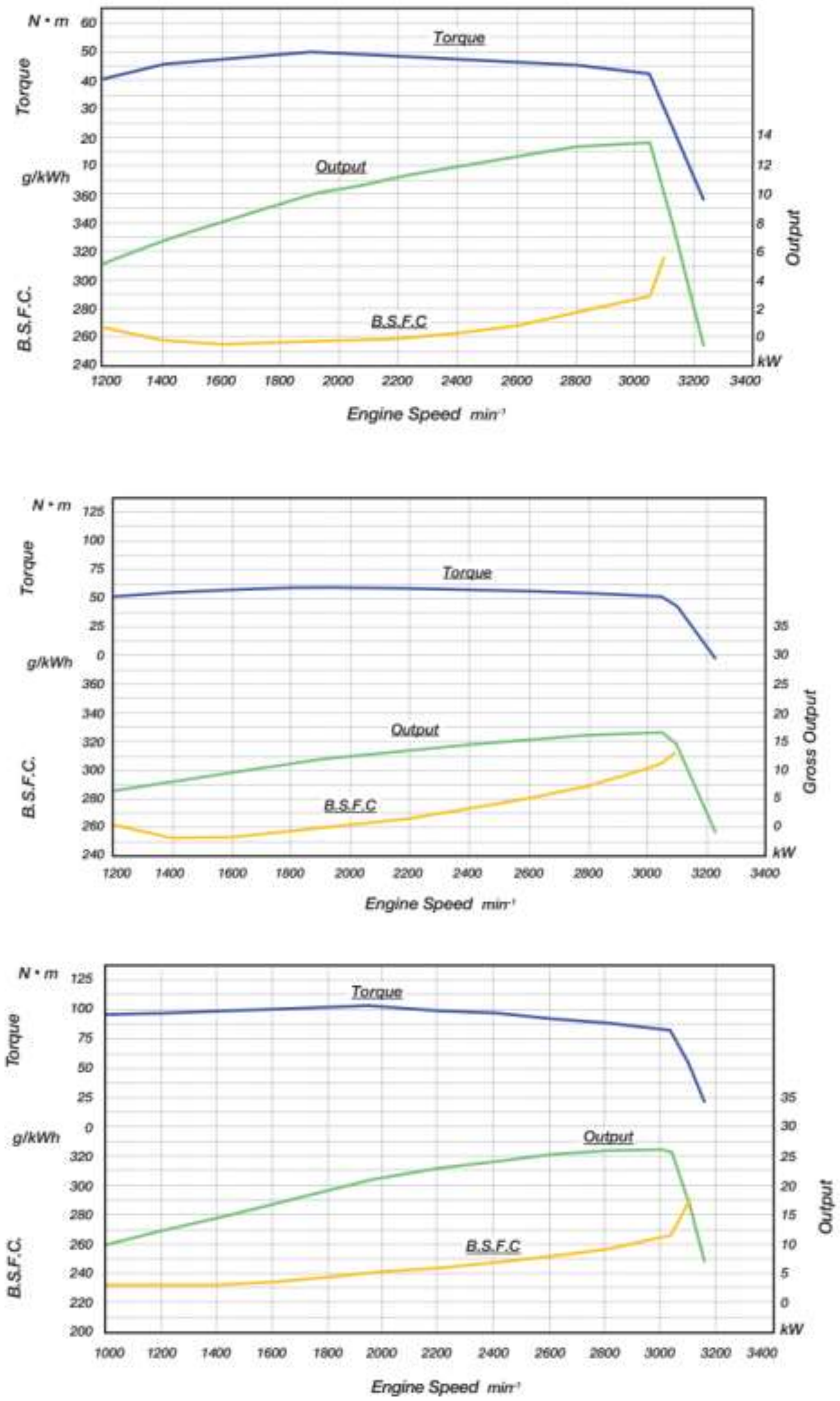


Figure 16. Yanmar engine torque & power charts (Yanmar 2014)

The first engine of 13.5kW reaches the maximum torque of 50 Nm at 1900 rpm. The goal is to find an electric motor that matches the torque of the previous diesel engine. The Yanmar charts show the rpm-torque relationship only after the 1200 rpm while the torque remains approximately stable up to 3000 rpm. Thus the maximum torque of a diesel engine must match exactly the torque of the electric engine.

Going into further detail, the electric motor must operate either at 540 rpm or 1000 rpm. These two speed occur the PTO. The AC motor must provide the desirable torque at least at 540 rpm.

After contacting a dealer in USA (http://www.hpevs.com) who provide the US market with AC motor kits and spear parts for EV upgrades (golf cars, EVs, baggage carriers for airports etc.) some AC motors were proposed for suitable replacements. Although in diesel engines different capacities provide different power outputs in AC motors the same model can provide different power output and torque. This is happening due to different voltages and amps. In the next charts some examples are demonstrated. The three models are the AC-9, AC-12 and AC-15.

model	voltage	current	HP(540 rpm)	kW(540 rpm)	Ft lbs(1000 rpm)	Nm (1000 rpm)
AC-9	48 V	650 Amps	6.7	5	68.15	92.3
AC-12	48 V	450 Amps	6.7	5	69.92	94.7
AC-12	48 V	650 Amps	9.5	7.1	93.52	126.8
AC-15	72 V	650 Amps	10	7.5	74	100.3

Figure 17. AC motor's specifications (used capacity)

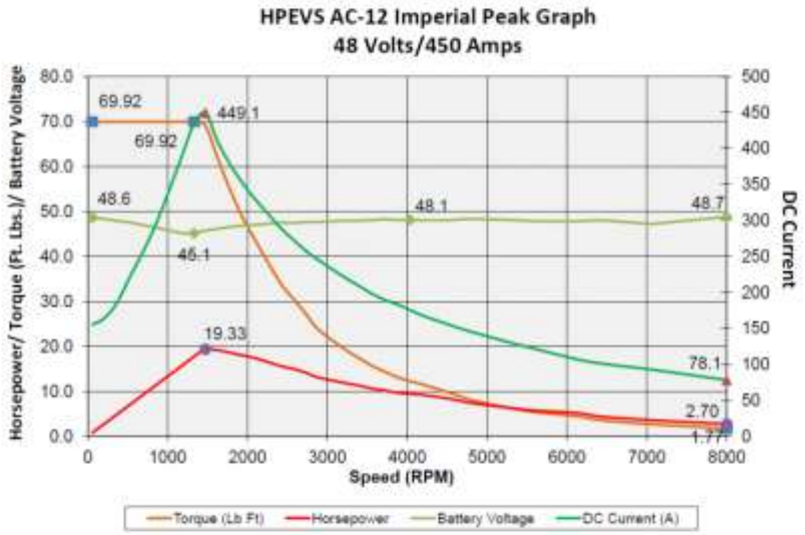


Figure 18. AC-12 motor 48V/450Amps torque & power curves

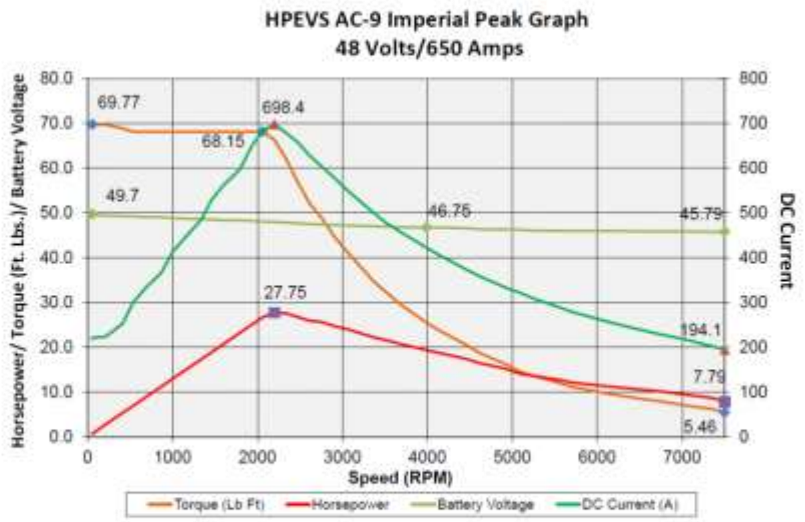


Figure 19.AC-9 motor 48V/650Amps torque & power curves

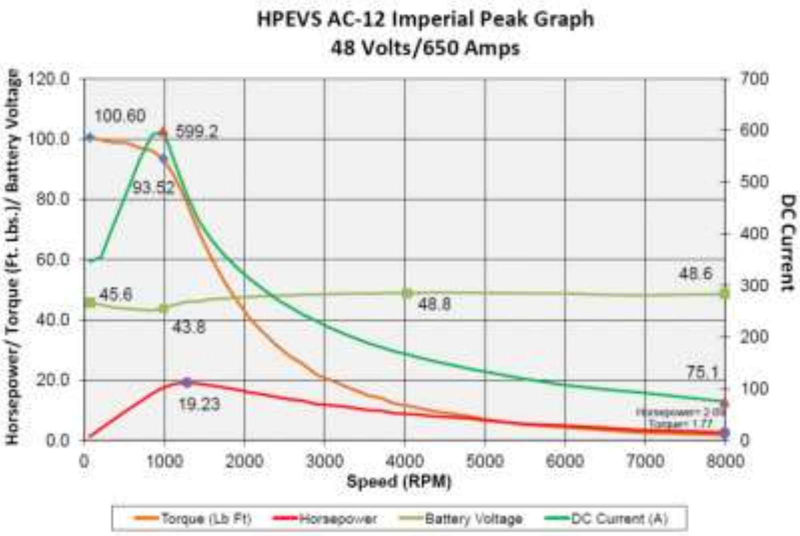


Figure 20. AC-12 motor 48V/650V Amps torque & power curves

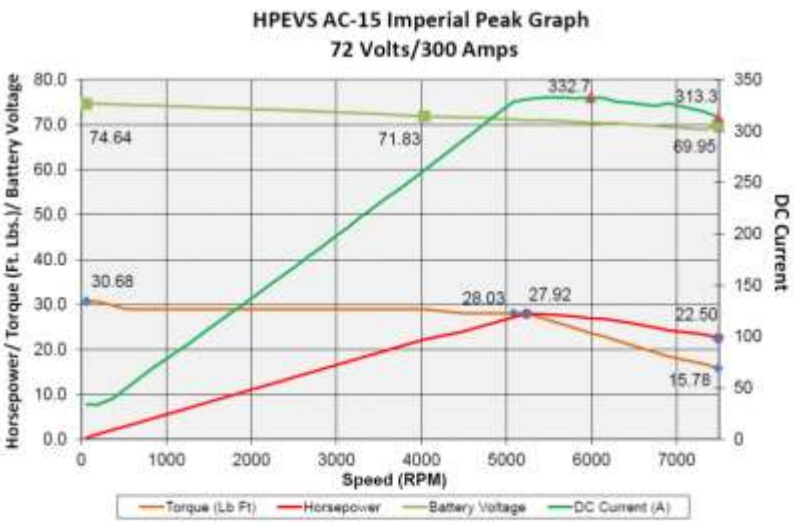


Figure 21. AC-15 motor 72V/300Amps torque & power curves

The model AC-9 48V/650 Amps is chosen with a torque that is much higher than the desired (92.3 Nm compared to 50 Nm).

5.4. The energy capacity and size of the battery

The main constrain in battery capacity is the charging time from the solar array scheme. The basic farming activity is ploughing. Farmers tend to complete this task in three days maximum in order to preserve a homogeneity in the soil structure (Panayiotopoulos K., 2008). As mentioned before, apart from providing the required energy, the battery will provide the adequate weight which is necessary in order to maintain the friction between the tractor's wheel and the ground. Hence the battery must be large enough in order to provide long autonomy to farming activities. Two issues that are rising here is the cost of such a huge battery and the required charging time.

As mentioned in the introduction of this project, the battery is assumed to share the same characteristics from mainstream models, such as Nissan Leaf. One important attribute of lithium-ion batteries is the depth of discharge. For example Nissan's battery depth of discharge or DOD factor is approximately 70% of the batteries capacity (www.electricvehiclewiki.com 2015). If for example the nominal capacity is 25 kWh and the DOD factor is equal to 70% the actual capacity that is used form the motor is 17.5 kWh.

Concluding, for AC motor power requirements of 5 kW, for one hour of operation at steady speed, a 5kWh electric energy is required.

The battery unit that is used in this project is the CALB – CB180FI and With 3.2 V and 180 Ah which is equal to 0.576 kWh of energy capacity (www.hpevs.com 2015). The main reason that this particular cell is used, instead of a Nissan's or Tesla's battery cells, is because the cost of this cell is accessible open to anyone. The next matrix (Table 7) indicates the specifications of the battery unit.

Nominal Capacity Ah	180
Nominal Voltage V	3,2
Charging Upper Voltage V	3,65
Charging Cut-off Voltage V	2,5
Standard Charging Time h	4
Quick-acting Charging Time h	1
Battery Weight kg	5,7

Table 7. Battery module CALB – CB180FI specifications

All AC motors have different specifications, regarding the voltage and current. By implementation of the series and parallel connection between battery cells, it is feasible to meet the demands for these motors. The next step is to calculate the energy capacity of the battery in kWh. The next table (Table 8) demonstrates some combinations with both parallel and series connections.

			SERIES														
	n/n		**V**	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Ah	**3,2**	22,4	25,6	28,8	32	35,2	38,4	41,6	44,8	48	51,2	54,4	57,6	60,8	64
		180															
PARALLEL	1	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
	2	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
	3	540	540	540	540	540	540	540	540	540	540	540	540	540	540	540	540
	4	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720
	5	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
	6	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080

Table 8. Parallel & Series battery connections

The AC-9 motor requirements in voltage is 48 V, hence the less number of battery units that are connected in a series is 15. In terms of current, the requirements are up to 300 Amps (for 5 kW power output), however in order to achieve an adequate capacity (kWh) the number of battery units connected in parallel is 3 and the capacity is 540 Ah. The weight of this battery will be 45 x 5.7 = 256.7 kg. The nominal energy capacity of the battery will be 48 x 540 =25.9 kWh. Rounding up the nominal capacity of the proposed battery to 26 kWh and considering the DOD at 70%, the available energy capacity is **18.2 kWh**.

5.4.1. Battery degradation

All batteries are suffering degradation due a lot of reasons. The lifetime of the battery is usually counted in years or charge/discharge cycles. After reviewing the literature for batteries, it was assumed that the battery will be able to support the system for 8 years. This assumption is mainly based on the Nissan's and Tesla's 8 year warranty.

5.5. Solar Generation Schemes

Concluding this chapter of demands and supply, it is necessary to analyse the solar array that is suitable for this project. Starting with three different installed capacities, in Greece most domestic solar arrays are up to 10 kW and are usually installed on the roof of the residencies. The project can borrow this "roof embedded" solar array scheme. Note that in Greece all solar schemes up to 10 kW are subjected to Feed in Tariff policy. This can be key element in the financial analysis of this project on its own or combined with the farmer's revenue from the crops.

Figure 22. Typical domestic solar array, Greece

Fitting this concept in to farming, this solar array can be installed on the roof of the storage of farming equipment or as it is (house roof) when farmer has his residence near the land.

The tool that is used for calculating the output of the solar arrays is a spreadsheet that was developed from Bartosz Nowak, Muhip Tune Meti, Jenny MacLean and Konstantinos Michail Akritidis for the needs of a group project for the University of Strathclyde (http://www.esru.strath.ac.uk/EandE/Web_sites/14-15/PV_Wind/index.html), this tool was based on a spreadsheet that was provided from Dr Nick Kelly, who was the academic supervisor of the mentioned project. The modules that were used (polycrystalline) are of capacity of 200W and electric efficiency of 0.123. Every panel has a surface of 1.63 m^2 (Solar Cell Hellas Group 2015). The spreadsheet calculates the solar energy per meters squared and then the electric efficiency is applied in order to extract the electric energy yield.

$$Solar\ energy\ (kWh) * electric\ efficiency\ = electric\ energy\ (kWh)$$

If for example the user desires to calculate the energy yield from a solar scheme with 1 kW installed capacity, then the total surface of the panels is 5 times the surface of each panel (1.63 m^2), that is to say 8.15 m^2. Next, the program calculates the solar energy from radiation per m^2 from the climate data (3.1. Literature Review) and then converts it to electrical. In the same example if the solar radiation energy from 13:00 to 14:00 is 0.8 kWh/m^2 then the electric energy is equal to the total surface of panels times the efficiency times the solar radiation energy.

$$8.15(m^2) * 0.8 \left(\frac{kWh}{m^2}\right) * 0.123 = 0.801 \ (kWh)$$

In this case the energy yield from panels is for the time between 13:00 and 14:00. The user is allowed to create time periods from all hours of all days of the year as the climate data are available for all the hours and days of the year. One common tactic is to calculate the average hourly energy yield of a typical day for every month. In this project only three months are out of the interest, December, January and May and that is because no farming activity is planned during these months. Three installed capacities were examined to investigate the level of matching to the proposed ac motor-battery system, these are 3kW, 5kW and 10kW.

5.5.1. 3kW installed capacity

The total surface of the panels of this capacity is 15 times 1.63 m^2, which is 24.45 m^2. The next table demonstrates the average hourly energy yield for a typical day for each month. The annual total energy yield is 4988.62 kWh. The tilt is 39° and the orientation is southern.

Average Hourly Output (kWh) of each Month									
Hours	**February**	**March**	**April**	**June**	**July**	**August**	**September**	**October**	**November**
1:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6:00	0,00	0,00	0,00	0,06	0,03	0,01	0,00	0,00	0,00
7:00	0,00	0,01	0,09	0,30	0,24	0,13	0,05	0,01	0,00
8:00	0,03	0,15	0,37	0,74	0,67	0,52	0,33	0,14	0,03
9:00	0,34	0,57	0,81	1,28	1,22	1,09	0,83	0,49	0,24
10:00	0,86	1,07	1,27	1,84	1,76	1,68	1,37	0,91	0,58
11:00	1,32	1,49	1,65	2,30	2,20	2,18	1,84	1,27	0,91
12:00	1,64	1,79	1,94	2,58	2,56	2,53	2,17	1,55	1,16

13:00	1,76	1,90	2,07	2,66	2,73	2,68	2,30	1,66	1,26
14:00	1,67	1,80	2,01	2,53	2,69	2,60	2,21	1,59	1,20
15:00	1,46	1,58	1,82	2,33	2,49	2,34	1,96	1,39	0,99
16:00	1,09	1,20	1,44	1,94	2,09	1,90	1,52	0,99	0,64
17:00	0,60	0,70	0,95	1,41	1,54	1,30	0,93	0,46	0,15
18:00	0,12	0,23	0,44	0,86	0,90	0,66	0,33	0,05	0,00
19:00	0,00	0,02	0,07	0,34	0,34	0,17	0,03	0,00	0,00
20:00	0,00	0,00	0,00	0,04	0,04	0,01	0,00	0,00	0,00
21:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL kWh									
	10,89	12,49	14,95	21,20	21,50	19,82	15,85	10,52	7,16

Table 9. 3kW installed capacity, average hourly electric energy output for each month kWh

5.5.2. 5kW installed capacity

The total surface of the panels of this capacity is 25 times 1.63 m^2, which is 40.75 m^2. The next table demonstrates the average hourly energy yield for a typical day for each month. The annual total energy yield is 8314.37 kWh. The tilt is 39^o and the orientation is southern.

Average Hourly Output (kWh) of each Month									
Hours	**February**	**March**	**April**	**June**	**July**	**August**	**September**	**October**	**November**
1:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6:00	0,00	0,00	0,00	0,09	0,05	0,01	0,00	0,00	0,00
7:00	0,00	0,01	0,14	0,51	0,41	0,22	0,08	0,01	0,00
8:00	0,05	0,25	0,62	1,23	1,12	0,87	0,55	0,24	0,05
9:00	0,57	0,95	1,35	2,14	2,03	1,82	1,38	0,82	0,40
10:00	1,43	1,78	2,12	3,07	2,93	2,80	2,29	1,51	0,96
11:00	2,21	2,48	2,75	3,83	3,67	3,63	3,07	2,12	1,51
12:00	2,74	2,98	3,24	4,30	4,26	4,22	3,61	2,58	1,93
13:00	2,93	3,16	3,45	4,43	4,55	4,47	3,83	2,77	2,11
14:00	2,78	3,00	3,36	4,22	4,48	4,34	3,68	2,65	2,00

15:00	2,43	2,63	3,03	3,88	4,15	3,91	3,27	2,32	1,66
16:00	1,82	1,99	2,41	3,23	3,48	3,16	2,54	1,66	1,06
17:00	1,00	1,17	1,58	2,34	2,56	2,17	1,54	0,77	0,25
18:00	0,20	0,39	0,74	1,43	1,50	1,11	0,54	0,09	0,00
19:00	0,00	0,03	0,12	0,56	0,57	0,29	0,05	0,00	0,00
20:00	0,00	0,00	0,00	0,07	0,07	0,02	0,00	0,00	0,00
21:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL kWh									
	18,15	20,82	24,91	35,33	35,84	33,04	26,42	17,53	11,93

Table 10. 5kW installed capacity, hourly average electric energy output for each month kWh

5.5.3. 10 kW installed capacity

The total surface of the panels of this capacity is 50 times 1.63 m^2, which is 81.5 m^2. The next table demonstrates the average hourly energy yield for a typical day for each month. The annual total energy yield is 16628.74 kWh. The tilt is 39° and the orientation is southern.

Average Hourly Output (kWh) of each Month									
Hours	**February**	**March**	**April**	**June**	**July**	**August**	**September**	**October**	**November**
1:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6:00	0,00	0,00	0,01	0,19	0,10	0,02	0,00	0,00	0,00
7:00	0,00	0,03	0,28	1,01	0,81	0,45	0,15	0,03	0,00
8:00	0,09	0,50	1,24	2,46	2,24	1,75	1,09	0,48	0,10
9:00	1,14	1,89	2,71	4,28	4,06	3,64	2,77	1,64	0,79
10:00	2,86	3,56	4,24	6,13	5,87	5,61	4,57	3,02	1,92
11:00	4,41	4,95	5,50	7,66	7,34	7,26	6,13	4,23	3,02
12:00	5,48	5,96	6,48	8,60	8,53	8,44	7,22	5,16	3,87
13:00	5,85	6,33	6,91	8,85	9,09	8,93	7,66	5,54	4,21
14:00	5,56	5,99	6,71	8,43	8,96	8,68	7,36	5,30	4,01
15:00	4,87	5,27	6,05	7,77	8,30	7,82	6,55	4,64	3,31
16:00	3,64	3,99	4,81	6,46	6,96	6,32	5,08	3,31	2,12
17:00	2,00	2,34	3,17	4,69	5,12	4,34	3,08	1,54	0,49
18:00	0,39	0,78	1,48	2,86	3,00	2,22	1,08	0,17	0,01
19:00	0,00	0,06	0,24	1,12	1,15	0,58	0,09	0,00	0,00
20:00	0,00	0,00	0,00	0,14	0,14	0,03	0,00	0,00	0,00

21:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0:00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL kWh									
	36,30	**41,64**	**49,83**	**70,66**	**71,68**	**66,07**	**52,84**	**35,06**	**23,86**

Table 11. 10kW installed capacity, average hourly electric energy output for each month kWh

5.6. Daily demand and generation matching

In order to investigate the level of suitability of each solar capacities, a mismatch between the average daily generation (kWh) and the battery capacity (kWh) took place. The next table (Table 12) and figure (Figure 23) demonstrate the percentage of matching, on daily basis, for the three capacities for each month.

	3 kW	5 kW	10 kW
Feb	41,88%	69,80%	**139,61%**
Mar	48,04%	80,07%	**160,14%**
Apr	57,49%	95,82%	**191,64%**
Jun	81,53%	**135,89%**	**271,77%**
Jul	82,71%	**137,85%**	**275,69%**
Aug	76,24%	**127,06%**	**254,13%**
Sept	60,97%	**101,06%**	**203,24%**
Oct	40,45%	67,42%	**134,83%**
Nov	27,53%	45,88%	**91,76%**

Table 12. Matching percentages (average daily generation/battery capacity) (kWh)

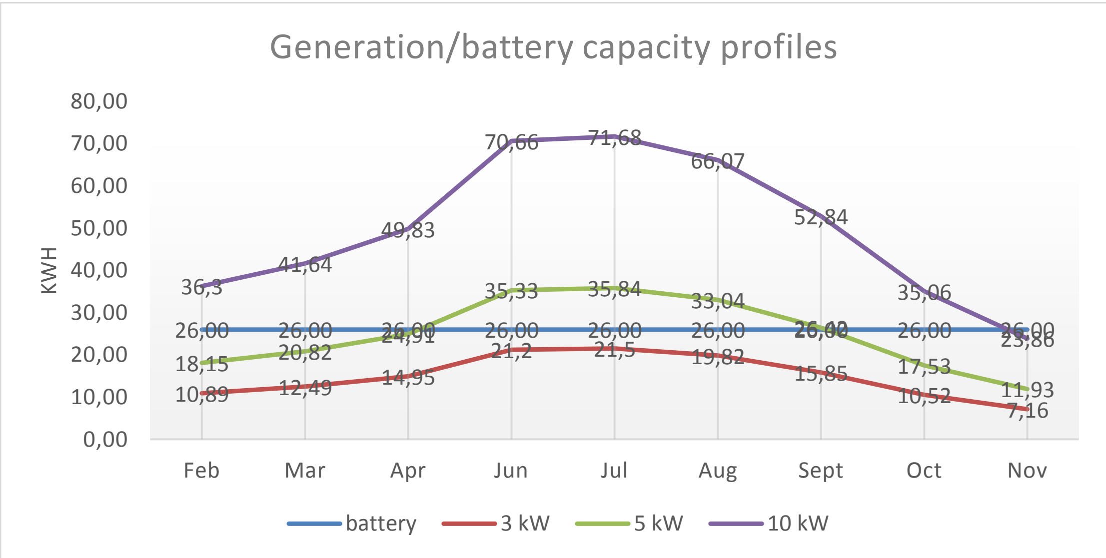


Figure 23. Generation vs Battery capacity profiles (kWh)

As it is demonstrated in the figure (Figure 23), the 3kW scheme is not able to fully cover the battery needs, as the profile is always lower than the battery capacity, even in summer months when weather conditions are in favour. The 5 kW scheme is able to cover the needs only from April to September and the 10 kW is always exceeding the battery needs, thus always exporting energy to the grid.

5.7. Flexible demand and generation matching

The previous matching process was based in daily charging conditions, unveiling all the cases when this did not occur. The next matching process is following a more flexible approach by enabling more than one days in charging.

The next two tables (Table 13, Table 14) are calendars of activities for the both crops. Not all crops are the same, thus not all activities occur exactly the same day and time, hence in order to match better the energy requirements, the activities are separated in large periods (months).

The next simple calculations result the required time for ploughing for both crops. The width of the plough is 1.4 m. thus with 7 km/h the tractor will plough an area of 9800 m^2/h or 9.8 acres/h. For the 50 acres crop, this means that the overall required time for ploughing is 50/9.8=5.1 hour. For the 70 acres crop, this means 7.14 hours. The same applies for other activities.

Farming activites	number	Months	km/h	acres	length m	acres/hour	hours of operation
ploughing	1	September	7	50	1,4	9,8	5,1
disk harrow	1	September	10	50	2	20	2,5
cultivator	0	September	8	50	3	24	2,1
seeding and fertilizing	1	October	7	50	**3**	21	2,4
light cultivator	0	October	10	50	**3**	30	1,7
fertilizing	1	February	9	50	3	27	1,9
sprinklers and medicines	1	April	10	50	2	20	2,5
balls of hay	1	June	10	50	2	20	2,5

Table 13. Calendar of activities for Wheat.

Farming activites	number	Months	km/h	acres	length m	acres/hour	hours of operation
ploughing	1	October	7	70	1,4	9,8	7,1
disk harrow	1	March	10	70	2	20	3,5
cultivator	2	March-April	8	70	3	24	2,9
seeding and fertilizing	1	April	7	70	**3**	21	3,3
light cultivator	1	October	10	70	**3**	30	2,3
fertilizing	2	November-March	9	70	3	27	2,6
sprinklers and medicines	4	June-July-August	10	70	2	20	3,5
harvesting	1	October	10	70	2	20	3,5

Table 14. Calendar of activities for Cotton

The battery DOD factor allows the motor to utilize 18.2 kWh per fully charged battery. Theoretically, the AC motor requires 5 kWh per hour of operation. In reality this might be subject to change, but for the needs of this project it will not change. By a simple division, a fully charged battery provides the tractor with autonomy of 3.64 hours of operation, this figure is rounded to **3.5 hours** and kept as a constant for the next calculations.

All farming activities must be completed as soon as possible. If there is need for more than one day to finish an activity, the farmer will operate the next day, after 19:00 for summer months and after 17:00 or 18:00 for the rest, when the battery is charged, because the contribution after the mentioned times to the charging process is small. This is not a problem because operating in evening hours, is a common tactic from farmers as most tractors have head and tail lights.

The next two tables indicate how many days are required for the farming activities to be completed for each crop.

WHEAT	hours required	days required
ploughing	5,1	1,5
disc harrow	2,5	0,7
cultivator	2,1	0,6
seeding & fertilizing	2,4	0,7
light cultivator	1,7	0,5
fertiliziing	1,9	0,5
sprinklers & medicines	2,5	0,7
balls of hay	2,5	0,7

Table 15. Wheat, days required for activities completion

COTTON	hours required	days required
ploughing	7,1	2,0
disc harrow	3,5	1,0
cultivator	2,9	0,8
seeding & fertilizing	3,3	0,9
light cultivator	2,3	0,7
fertiliziing	2,6	0,7
sprinklers & medicines	3,5	1,0
harvesting	3,5	1,0

Table 16. Cotton, days required for activities completion

Regarding the demand and generation matching, the two tables above (Table 15, Table 16), are taking for granted that the battery is always fully charged during the day. This happens only with the last solar scheme of 10 kW. In order to find the days required for farming activities to be completed in the other two cases, the following function is used:

$$DR = \frac{HR}{(ABC * PC)}$$

Where,

DR: Days Required

HR: Hours Required

ABC: Available Battery Capacity

PC: Percentage of Charging taken from table (Table 11)

This equation is enabling the available battery capacity when it is not fully charged.

3kW Installed Capacity				
WHEAT	hours required	month	PC %	**days required**
ploughing	5,1	September	60,97%	**2,4**
disc harrow	2,5	September	60,97%	**1,2**
cultivator	2,1	September	60,97%	**1,0**
seeding & fertilizing	2,4	October	40,45%	**1,7**
light cultivator	1,7	October	40,45%	**1,2**
fertiliziing	1,9	February	41,88%	**1,3**
sprinklers & medicines	2,5	April	57,49%	**1,2**
balls of hay	2,5	June	81,53%	**0,9**

Table 17. Wheat, 3kW, days required

5kW Installed Capacity				
WHEAT	hours required	month	PC %	**days required**
ploughing	5,1	September	100,00%	**1,5**
disc harrow	2,5	September	100,00%	**0,7**
cultivator	2,1	September	100,00%	**0,6**
seeding & fertilizing	2,4	October	67,42%	**1,0**
light cultivator	1,7	October	67,42%	**0,7**
fertiliziing	1,9	February	41,88%	**1,3**
sprinklers & medicines	2,5	April	95,82%	**0,7**
balls of hay	2,5	June	100,00%	**0,7**

Table 18. Wheat, 5kW, days required

3kW Installed Capacity				
COTTON	hours required	month	PC %	**days required**
ploughing	7,1	October	40,45%	**5,0**
disc harrow	3,5	March	48,04%	**2,1**
cultivator	2,9	March-April	**52,77%**	**1,6**
seeding & fertilizing	3,3	April	57,49%	**1,6**
light cultivator	2,3	October	40,45%	**1,6**
fertiliziing	2,6	November	27,53%	**2,7**
fertiliziing	2,6	March	48,04%	**1,5**
sprinklers & medicines	3,5	June-July-August	**80,16%**	**1,2**
harvesting	3,5	October	40,45%	**2,5**

Table 19. Cotton, 3kW, days required

5kW Installed Capacity				
COTTON	hours required	month	PC %	**days required**
ploughing	7,1	October	69,80%	**2,9**
disc harrow	3,5	March	80,07%	**1,2**
cultivator	2,9	March-April	**87,95%**	**0,9**
seeding & fertilizing	3,3	April	95,82%	**1,0**
light cultivator	2,3	October	67,42%	**1,0**
fertiliziing	2,6	November	45,88%	**1,6**
fertiliziing	2,6	March	80,07%	**0,9**
sprinklers & medicines	3,5	June-July-August	100,00%	**1,0**
harvesting	3,5	October	69,80%	**1,4**

Table 20.Cotton, 5kW, days required

The percentages of charging in these tables, are taken from table (Table 11). Commenting on the results it is important to mention that:

- At 3 kW installed capacity, the 5 days required for ploughing is out of the standard's that farmers usually accept, but this is up to every farmer.
- The 3 kW can cover the needs but for most cases, more than one days is required to complete a task.

- At the tables (Table 19, Table 20), the bolded percentages are averages from all months that are mentioned in the tables for the relevant activity (e.g. March-April).
- The figure of hours of ploughing in table (Table 15) is 7.1 but for the ease of calculations it is considered to be 7.
- Transfers and transportations are not covered in matching process because:
    1. They do not require specific schedule
    2. Although they are necessary to be included into the calculation of the power capacity of the diesel engine, not all farmers are using their tractors to complete them.
    3. Farming is not an everyday business, thus there are a lot of days available for the farmer to plan the transfers and transportations. This renders the matching process inaccurate and non-representative, for other cases of similar crops.

5.8. Days with relatively less solar radiation

Apart from the hourly averages, it is important to examine how these solar schemes react under relatively cloudy conditions. By examining and comparing the relatively cloudy days of February and November, which are the less sunny months that are used in this study, the energy produced from panels is calculated. The number of the days that happened to be relatively cloudy are 3 from February and 4 from November.

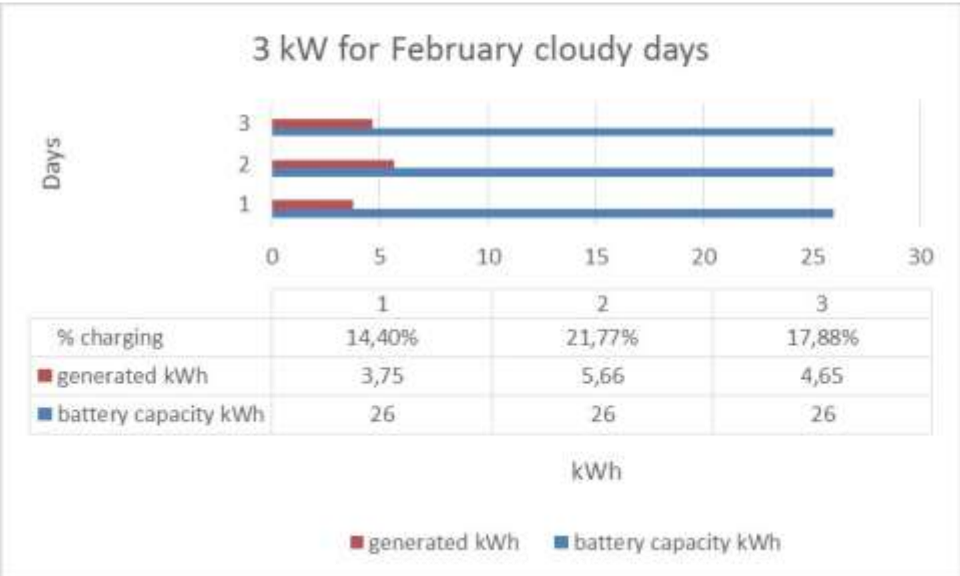
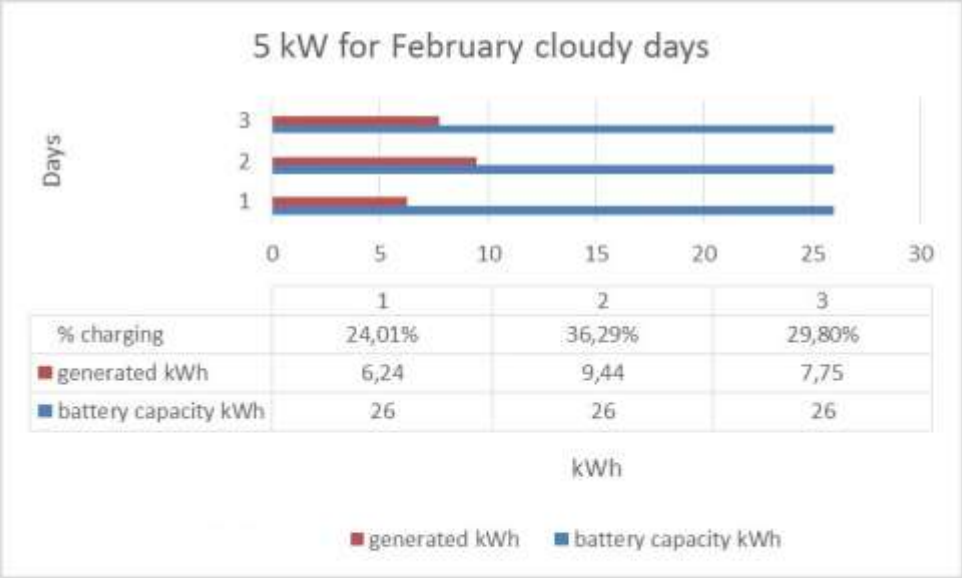
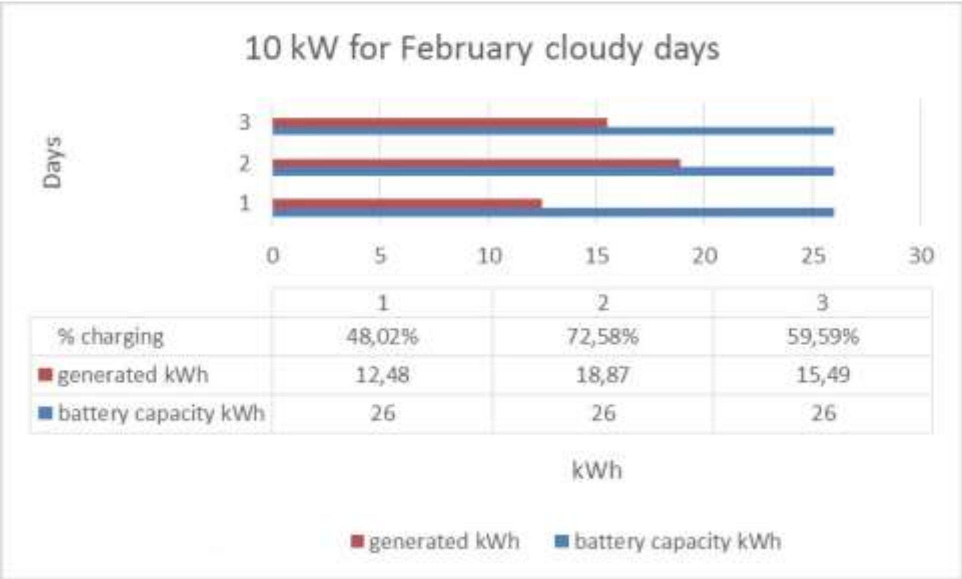


Figure 24. 3kW for February cloudy days



	1	2	3
% charging	24,01%	36,29%	29,80%
generated kWh	6,24	9,44	7,75
battery capacity kWh	26	26	26

Figure 25. 5kW for February cloudy days



	1	2	3
% charging	48,02%	72,58%	59,59%
generated kWh	12,48	18,87	15,49
battery capacity kWh	26	26	26

Figure 26. 10kW for February cloudy days.

The percentages of battery charging levels are significantly low, even for the 10 kW installed capacity. Regarding the 3 and 5 kW capacities, it is rather rational to mention that, for days like these, it is preferable not to waste the energy for charging the battery but export it to the grid.

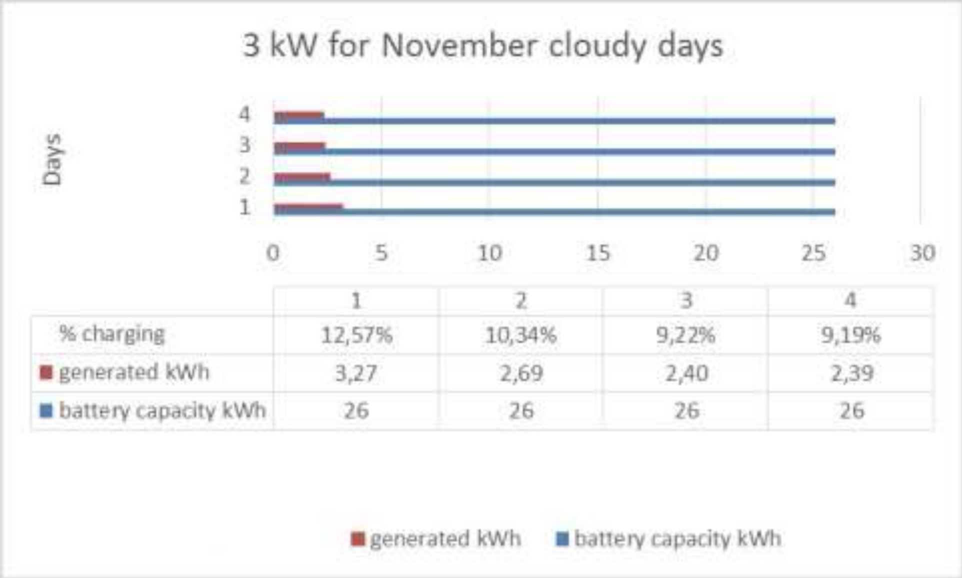


Figure 27.3kW for November cloudy days

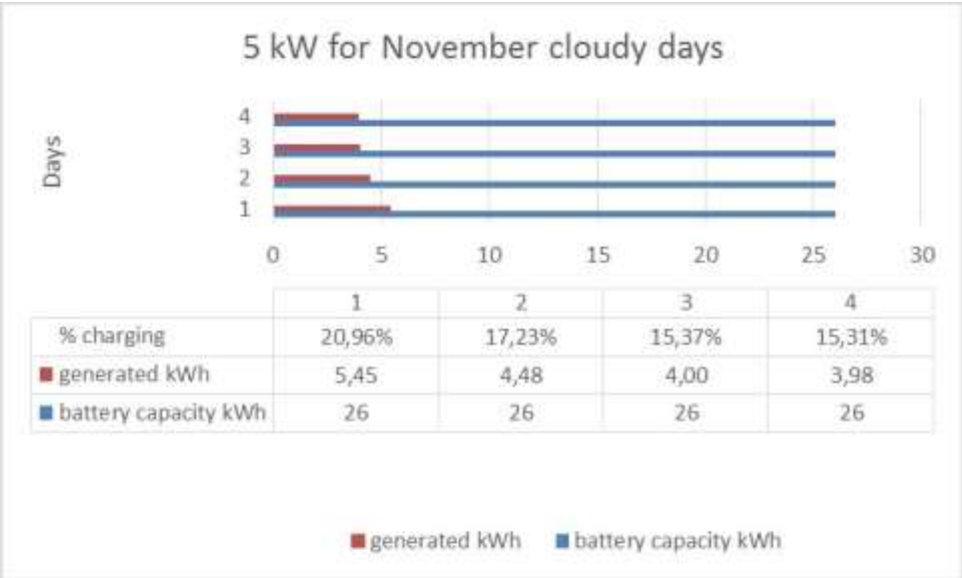
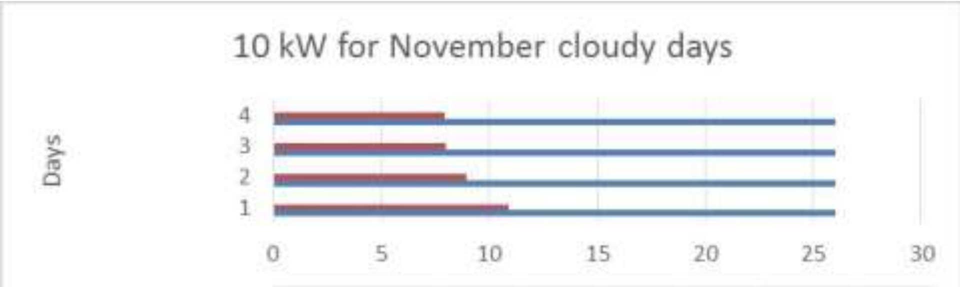


Figure 28. 5kW for November cloudy days



	1	2	3	4
% charging	41,91%	34,45%	30,74%	30,63%
generated kWh	10,90	8,96	7,99	7,96
battery capacity kWh	26	26	26	26

Figure 29. 10kW for November cloudy days

The November's cloudy days, render all the solar schemes less productive.

5.9. Conclusions

The proposed system included an AC motor that requires 5 kWh per one operational hour, a 26 kWh nominal energy capacity battery pack and three different installed solar power capacities, 3, 5, and 10 kW. After the establishment of the system (only motor and battery) a two generation demand matching processes occurred. One daily and on flexible. Last 7 days, considered cloudy, were examined to estimate the percentages of battery charging. The next table (Table 1) demonstrates all the outcomes from this analysis.

In this study the motor and battery are not subject to change, to see what benefits and advantages would occur, this could be an option but it is out of the initial targets of this study. Additionally more than three installed capacity, regarding the solar schemes, could be test, yet again time constraints interfered.

It is necessary to evaluate the validity of the annual energy yield, According to the Hybrid Energy Systems in Future Low Carbon Buildings Project of the University of Strathclyde, the ratio of kWh to kWp, for Thessaloniki is 1000-1250 kWh per kWp. The ratio in the project is 1662 kWh per kWp, which is 412 kWh more. But the source of this project is the, Photovoltaic Solar Electricity Potential in European Countries, report, which was published on 2006 (European Commission, 2006), which means that the average electric efficiency was smaller compared to contemporary technologies. Additionally as it is mention in the referenced project, optimizing the tilt can relate to higher energy yield than the proposed. Concluding the ratio of kWh to kWp of this project, is considered valid.

Regarding the daily and flexible matching, the table has yes as answer when something occurs and no when does not. Specifically for the 3kW, the ploughing is completed in more than 4 days which is considered to be relatively undesirable from farmers, however this is not a rule.

The last parts of the table indicate the percentage of battery charging during the relatively cloudy days. As the percentages are different for each case and day, and for the ease of demonstration and comparison of results, for categories were created. So instead of showing a figure, the table indicates when something is happening or not. For detailed percentages the reader can go back in the analysis and review it.

Capacities	*3kW*	*5kW*	*10kW*
Specifications			
annual energy yield kWh	4988,62	8314,37	16628,74
Surface covering m2	24,45	40,75	81,5
tilt	39	39	39
orientation	southern	southern	southern
Daily Matching (fully charge in one day)			
yes or no	**yes**	no	no
Flexible Matching			
yes or no	**yes**	**yes**	**yes**
acceptable from farmers	maybe	**yes**	**yes**
Cloudy days November percentage of charging			
0-20%	**yes**	**yes**	**yes**
20-40%	no	**yes**	**yes**
40-60%	no	no	no
>60%	no	no	no
Cloudy days February percentage of charging			
0-20%	**yes**	no	no
20-40%	**yes**	**yes**	no
40-60%	no	no	**yes**
>60%	no	no	**yes**

Table 21. Table of analysis's outcomes

6. Financial Analysis

It is important to include a financial analysis to this project. In this chapter a basic but realistic analysis is applied. A financial analysis is not just about being profitable. Finding the financial weaknesses and providing solutions is a very important result of an analysis like that. The case study occurring in this analysis is the 10 kW aiming to reveal the pros and cons of the largest capacity, because it can support the venture, even in cloudy days, by exporting the largest amount of energy to the grid.

Key Words: Capex, Opex, IRR, Feed in Tariff, Energy revenue, crop revenue, sensitivity analysis, cash flow, no subsidy, debt

6.1 Methodology

In order to fully evaluate this new project, a financial analysis is necessary. The analysis is separated in stages and has some assumptions that are mentioned and justified. In order to render the analysis and its targets more comprehensible, the methodology that is followed, is described with the next flow chart.

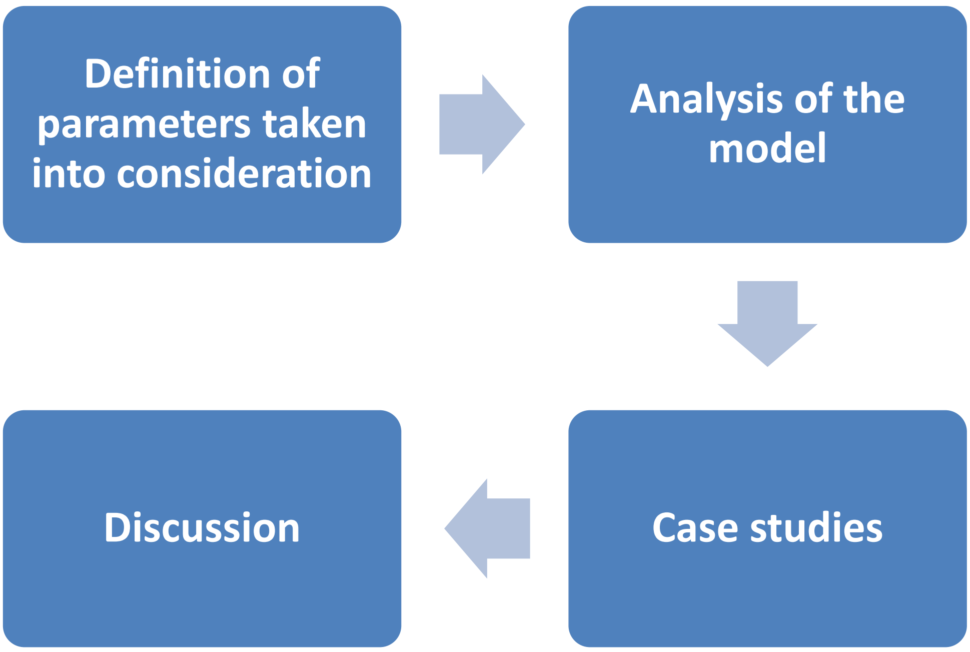


Figure 30. Flow chart of the financial analysis of the concept

6.2. Parameters taken into consideration

In order to achieve a holistic approach to the financial analysis of this concept, it is important to define all the parameters which part the whole analysis. These parameters are:

- Cost of the electric tractor
- Cost of the solar array of 10 kW capacity
- The revenue from the crops
- 25 year lifetime of the investment
- No particular subsidy
- Feed in Tariff
- IRR

6.2.1. Cost of the electric tractor

As there is a little information about the cost of an electric tractor and that is because there is no commercial size production, the cost of such a tractor is assumed to be equal with the sum of the next individual costs. More specifically the cost of the tractor includes:

- The cost of the motor
- The cost of the battery
- A 30% of the sum cost of the two above, representing the cables, converters .etc.

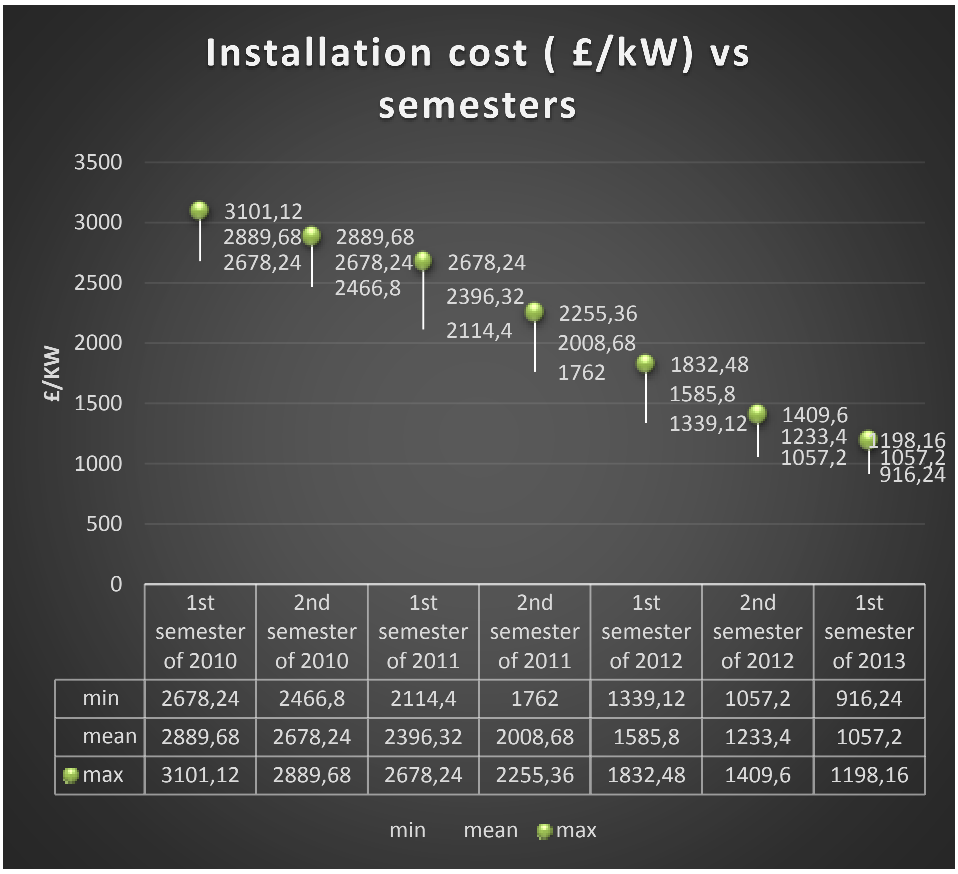
As mentioned in previous chapter, one of the sources of this study include a couple of dealers in US who are experts in providing EV kits for cars and generally electrical vehicles, to the US market. The information given was very accurate and justified from them. The costs are:

- AC motor: AC-12 48V/450 Amps – £1,517.07
- Battery unit: CALB – CA 180FI – £171.07 , 15(series) x 3(parallel) =45 battery units, equal to 7.698,15
- (1.517,07+7.698,15) x 0,3 = £ 2.764,56 for rest of equipment

Adding everything together we have, (1,517.07+7,698 15) x 0.3 + 9,215.22= 2,764.56 + 9,215.22 = £ 11.979,78. The amount is rounded to £12,000 and it is equal to the cost of the tractor. Although this figure might be subject to changed due to cheaper or more expensive equipment, the practise of estimating only the cost of the EV kit is partly true, because up to now the few farmers that want to try this concept, they have transformed their old tractors to electric tractors. (http://www.evamerica.com/farm.html)

6.2.2. Cost of the solar array of 10 kW capacity

As the concept is related to Greece, it is more suitable to calculate the cost of the PV panels with Greek rates and prices, converted to GBP. It is a fact that the cost of the solar PV panels has significantly dropped in the last years. The Hellenic Association of Photovoltaic Companies (http://www.helapco.gr) has released a report based on data given from The Ministry of Reconstruction of Production, Environment & Energy, which includes important rates and information about the Greek Solar PV market. The next chart is sourced from these data and demonstrates the installation cost per kW capacity



	1st semester of 2010	2nd semester of 2010	1st semester of 2011	2nd semester of 2011	1st semester of 2012	2nd semester of 2012	1st semester of 2013
min	2678,24	2466,8	2114,4	1762	1339,12	1057,2	916,24
mean	2889,68	2678,24	2396,32	2008,68	1585,8	1233,4	1057,2
max	3101,12	2889,68	2678,24	2255,36	1832,48	1409,6	1198,16

Figure 31. Installation cost (£/kW) vs semesters

From the information given from the chart, the mean installation cost £/kW has fallen from the 1st semester of 2010 to the 1st semester of 2013 from £2,889.68 to £1,057.2 per kW, which is around 60%. It is a fact that a lot of peopled invested in the photovoltaics (domestic scale) market.

All information and data are taken from the report that mentioned above and the conversion from EUR to GBP was based on the rates given from Yahoo.

6.2.3. Revenue from the crops

The revenue from the crops, is considered to be only the money that are gained by selling the produced crop. For needs of this study the production it is assumed to be the same for the whole lifetime of the project.

Both wheat and cotton prices tend to fluctuate in short periods of time. The main reason which affects this phenomenon is that both are commodities in the stock market. According to the Ministry of Reconstruction of Production, Environment & Energy, and Rural development the prices for wheat and cotton were approximately £162/ton and £350/ton respectively for the year 2013. In order to maintain the financial analysis simple and the two mentioned prices were used.

6.2.4. Lifetime of the project

Most of the time this kind of investment has got a life time of 25 years. This figure is related to a lot of other agents that can affect the whole analysis, such as guaranties for the panels, acceptable degradation factors etc. Thus it is not going to be altered. Even if the farmer decides to quit the farming business, it is still a very reliable source of income. For this reason apart from studying the investment as a whole parted from the crops and the solar, it is analysed as a separated investment.

Throughout the years, solar cells tend to lose their efficiency and ware down. This is defined in the analysis by the degradation factor and it is equal to 0.5% reduction, in the annual energy yield of the panel.

6.2.5. No subsidy for crops

The EU provides a great variety of subsidies in crops. These subsidies and their effects, are out of the scope of this study.

6.2.6. Feed in Tariff (Greece)

As in many countries which try to achieve goals and target of renewable energy production, Greece also has a Feed in Tariff, for those who own solar arrays and export energy to the grid. As in (6.2.2. Cost of the solar array of 10 kW capacity), the same report provides information about the revenues that come from the energy that is exported to grid.

If the decrease of the installation cost is one of the advantages in the solar PV panel business, the new laws defining the selling price, is the drawback. More specifically, due to the rigorous falling of prices of panels, in order to maintain the regular function of the market, the selling price of the energy was decreased too. But the main flaw is that a haircut occurred in the fixed prices, thus a lot of existing investments are suffering the market’s reform consequences.

The next table demonstrates the prices for the recent past years.

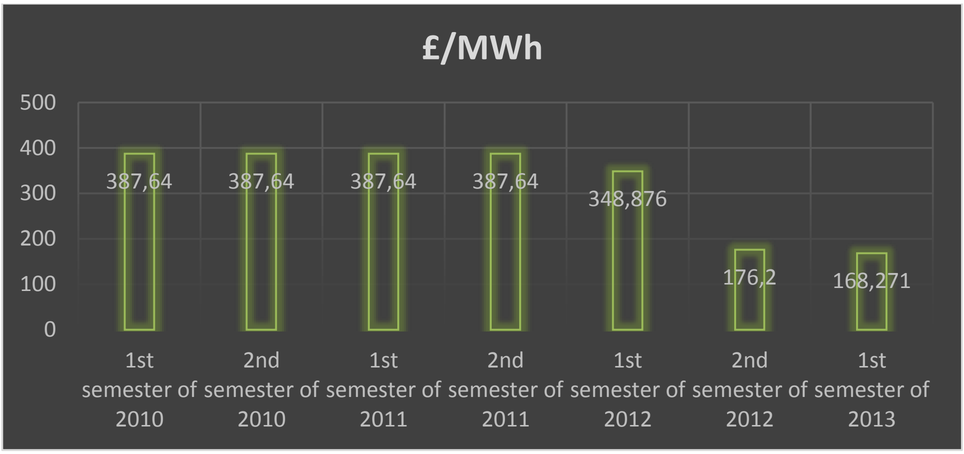


Figure 32. Feed in Tariff (£/MWh)

From the 1st semester to the 2nd semester of 2012, the prices were nearly halved. This unwanted situation might be compensated from the crop's revenue when the investment is analysed as a whole. For the needs of this analysis the price will be equal to the one on the 1st semester of 2013.

6.2.7. IRR

The IRR, which stands for internal rate of return of an investment, expressed in percentage, is the index that defines the feasibility of the investment. In most cases, developers, seek to find solutions in order to achieve the best IRR, but in reality the rate might be less, or even not applicable for the interests of the developers.

In order to define the degree of feasibility of the investment, there are three IRRs that can express that:

- Best case scenario IRR%
- Realistic case scenario IRR%
- Worst case scenario IRR%

The quantification of the above is set to be as:

- Best case IRR = 16-25%
- Realistic case IRR=10-15%
- Worst case IRR < 10%

The IRR will be the output of the sensitivity analysis, and it is important to identify which factor has the greater impact on IRR, in order to secure or eliminate it.

6.3. Analysis of the model

The structure of the model is defining the process that was used to determine whether there is value on this concept or not. In order to justify the outcomes of the analysis properly, it is important to analyse the inputs of the mentioned model and of course generate a case study, which will be the basic rule on the sensitivity analysis.

INPUTS	
Installed Capacity kWp	10
Lifetime of project	25
CAPEX £	
Panels	10570
EPC Works	900
Grid connection	600
Tractor cost	12000
Total Capex	24070
OPEX £	
Inverter replacement	550
Battery replacement	961,125
Total Opex/year	1511,125
Total Opex (% of Capex)	6,3
INCOME	
Installed capacity	10
Year One Energy Yield	16628
Wheat crop tons	20
Cotton crop tons	8,4
Annual Degradation factor	0,005
Price of sold energy £/MWh	168,721
Price of sold Wheat crop £/ton	162
Price of sold Cotton £/ton	650
DEBT	
Debt term (years)	10
Debt of total investment cost (%)	50,00%
Debt interest rate (%)	7%

ANALYSIS	
COST ANALYSIS	
Capex/kW solar	2407,00
Opex/kW solar	151,11
Opex as % of Capex	6,28
Opex as % of Energy Revenue	56,59
Opex as % of Wheat Revenue	46,64
Opex as % of Cotton Revenue	51,40
Opex as % of Total Revenue	17,07
REVENUE ANALYSIS	
Energy Revenue year 1	2671
Wheat Revenue year 1	3240
Cotton Revenue year 1	2940
Total Revenue year 1	8851
DEBT ANALYSIS	
Debt Amount	12035
Annual Debt Service	-1.713,51 £

Figure 33. Financial model spreadsheet

The financial model was broken down into main components. Regarding the inputs, there are six components:

- Capex
- Opex
- Income
- Debt
- The installed capacity in kWh
- Lifetime of the project in years

The first outcomes from the analysis are generated from the spreadsheet and provide to stakeholders the first valuable information that is required.

6.3.1. CAPEX and OPEX

Usually the starting point of an investment, is to set the CAPEX and OPEX by breaking down both, into the separated parts. The CAPEX is the initial cost of the investment before operation and the OPEX is the costs arising from the economic year 1 to the end of the lifetime of the project. This can be very complex if the analysis occurs solar arrays, larger than domestic scale. In this case the capacity is equal to 10kW and the breakdown is simpler. The breakdown of the CAPEX is unveiling the next parameters that require quantification:

- Cost of the panels £/kW capacity
- Cost of the EPC Works
- Grid Connection (if applicable)

And regarding the breakdown of OPEX the parameters are:

- Maintenance (if applicable)
- Inverter (if applicable)
- Insurance (if applicable)
- Land lease (if applicable)

By introducing all the parameters to this study it is easy to justify which are included. The cost of the panels and the cost of the EPC works are fundamental parts of this study. In this scale also, the cost of the grid connection is important and needs to be included.

Cost of the Panels £/kW capacity	**£ 1057**
Cost of the EPC Works	**£ 900**
Grid Connection	**£ 563 to £705 for capacity < 10 kW**

Table 22. CAPEX breakdown

As the scale of the solar array is small enough, there are no maintenance costs entering into the study, additionally it is assumed that there is no land lease because the farmer owns either the land or the building (roof) that PV panels are installed. Regarding the insurance costs, in this case they are not taken into consideration, because different insurance companies are offering different insurance packages. This insurance packages are bonded with various characteristics (types of loans, locations, size of insurance company .etc.), which their study is out of the scope of this paper. Thus regarding the OPEX the cost of replacement of the inverter is important to be included. Consultants are widely suggesting that due to the lifetime of inverters (10 years commonly), it is safe, to save a 10% of its value every year in order to replace it when it will break down. The cost of the inverter is calculated to be around £ 550 per 1 kW solar capacity.

In contemporary EV industry, most of the manufactures, suggest a battery lifetime of 8 years (Tesla, Nissan .etc.). So, apart from the inverter, it is necessary to calculate the battery replacement as an operational expenditure from year 1 to year 8.

Inverter replacement	**£ 550**
Battery replacement	**£ 961**

Table 23. OPEX breakdown

6.3.2. Energy & crops prices and revenues

In order to investigate the incomes from this concept it is important to quantify the energy yield from the solar array for every year and the harvested crops. After that, by using the selling prices for both products, individual incomes are calculated. In this case the selling prices are:

£ / MWh exported	**168.721**
£ / ton of wheat	**162**
£ / ton of cotton	**350**

Table 24. Selling prices from energy, wheat and cotton

According to the previous chapter, for the climate conditions of Thessaloniki, a 10 kW capacity solar scheme, generates 16,628 kWh per year. By introducing this figure to the degradation factor of 0.5% on the energy that is produced, the energy profile of the 25 years lifetime is extracted.

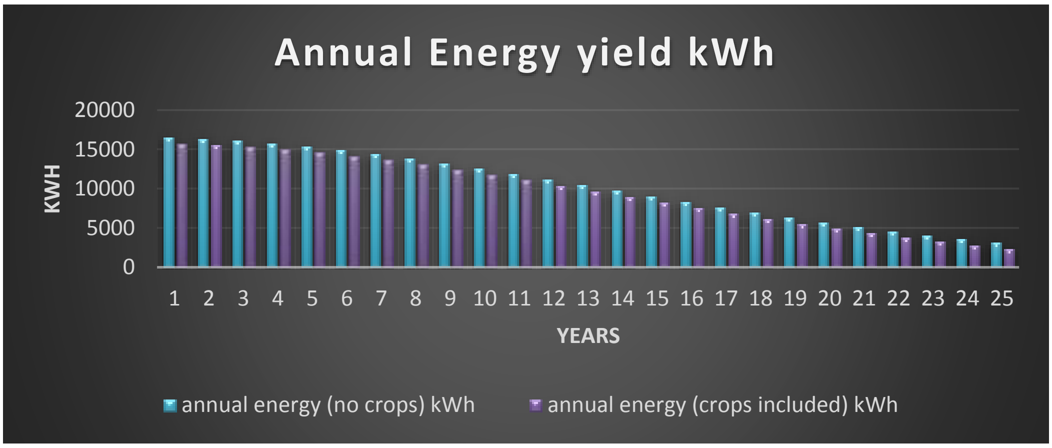


Figure 34. 10kW Annual energy yield (kWh), degradation factor included

Note that these are the rates of the total energy that is generated. A part of this energy is consumed for battery charging. In order to include both crops in one financial report it is assumed that each year 800 kWh are consumed from the farmer, in order to fulfill all activities. The reason that this figure is as high as that is because, the reliability of the concept is not practically proved and, additionally as mentioned before, there is space for the tractor to be used for both crops. Another reason, not accurately specified, is that it is quite common that problems can occur in farming activities, hence they might be repeated many times more than, initially planned.

Both wheat cotton prices are assumed to be the same and the crops production as well.

6.3.3. Debt

The most common capital source, if someone cannot afford the initial costs, is a loan from a bank. In this study the base case scenario's loan has 7% interest, 10 years repayment period and it covers the 50% of the initial cost.
Although it is an aid for starting this investment, it is very important to examine how it affects the whole investment. So it is one of the most crucial factors that must be tinkered in the sensitivity analysis, to examine any better alternatives.

6.3.4. Project cash flow

This part of the model is the heart of the analysis, as it breaks down all the factors into the years of the lifetime of the project. Here, all revenues and expenditures are demonstrated for every year.

At first the production from solar PV panels, wheat and cotton are given for each year. The important element here is the decrease of the annual energy yield from the panels through the lifetime. The next step is to calculate all revenues from all sources. Yet again attention must be paid on the decrease of the energy revenue.

The Opex is further analysed, as the inverter and the battery share different lifetimes, 10 years and 8 years respectively. Hence after the operational year 20, the Opex is consisted only form the savings for the battery replacement.

Regarding the expenditures the analyses is completed by breaking down the depreciation, the annual debt payment and last but not least the annual interest payments on the loan. These are very important to be analysed and demonstrated as they affect the IRR of the investment.

All the IRRs and cumulative cash over the lifetime of the project are calculated for all the possible revenue combinations.

6.4. Case studies & Sensitivity analysis

In this project, 4 different case studies are analysed and demonstrated. These studies aim to find the more suitable economically alternatives of the initial concept. In every case, a sensitivity analysis is included. The case studies are:

1. Base case study, only source of revenue is the energy yield
2. Case study where the revenue from wheat and energy is taken into consideration
3. Case study where the revenue from cotton and energy is taken into consideration
4. Case study where the revenue from wheat, cotton and energy is taken into consideration

The steps that are followed in the sensitivity analysis are:

1. No loan in the initial cost
2. No interest in the loan of the initial cost
3. 25% loan contribution
4. 50% of the Capex is covered by subsidy

For all the above cases, the value of each is measured from the IRR, which was previously explained when it is acceptable, not acceptable and desirable.

All the useful results and outcomes are discussed in the next part of the chapter.

6.4.1. Base case scenario

The base case scenario is examining whether the whole cost of the concept can be offset by the revenue that is coming from the exported energy. There is a 50% of the initial cost is covered by a loan from the bank. The repayment period is 10 years and the interest rate is 7%.

COST ANALYSIS	
Capex/kW solar	**2407,00**
Opex/kW solar	**151,11**
Opex as % of Capex	**6,28**
Opex as % of Energy Revenue	**56,59**
Opex as % of Wheat Revenue	**46,64**
Opex as % of Cotton Revenue	**51,40**

Opex as % of Total Revenue	17,07

Table 25. Cost analysis from spreadsheet

As we observe the ratio of the Opex/Energy revenue is quite high, approximately 60%, which demonstrates the weakness of the investment (solar energy revenue only) to support its own operational expenditures. Although this rate is not beneficial, it is important to mention that the revenue from the energy, is called upon to compensate cost that are out of the classic solar power investments, such as the cost of the tractor and the cost of the batteries.

In this case, no comment on the IRR's behavior is done, because the cash flow of the project is negative for all years.

Now the first step of the sensitivity analysis aims to investigate, what would happen if the farmer possessed all the capital for the initial cost of the investment. This change, is applied by change the "Debt of total investment cost %" to zero. As the next part of the matrices from the project cash flow, demonstrate the only change is that for the first 5 operation years the cash flow is positive. After that it is negative due to the depreciation, Opex costs and the degradation of the cells.

terest on Loan	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
OTAL REVENUE	8850,5	8822,4	8780,7	8726,3	8659,7	8582,1	8494,5	8398,0	8294,0	8183,9
roject cash flow-no crops	196,6	168,4	126,8	72,3	5,8	-71,8	-159,5	-255,9	-359,9	-470,0
roject cash flow NET (wheat)	3436,6	3408,4	3366,8	3312,3	3245,8	3168,2	3080,5	2984,1	2880,1	2770,0
roject cash flow NET (cotton)	3136,6	3108,4	3066,8	3012,3	2945,8	2868,2	2780,5	2684,1	2580,1	2470,0
-24070	196,6	168,4	126,8	72,3	5,8	-71,8	-159,5	-255,9	-359,9	-470,0
-24070	3436,6	3408,4	3366,8	3312,3	3245,8	3168,2	3080,5	2984,1	2880,1	2770,0
-24070	3136,6	3108,4	3066,8	3012,3	2945,8	2868,2	2780,5	2684,1	2580,1	2470,0

Figure 35. Project cash flow from spreadsheet (I)

In case where the farmer could get a loan from the bank with zero interest, assuming that the concept is getting support for its green character the results on the cash flow are still negative but significantly decreased.

In the case where the farmer does not have all the capital but can afford to lend only 25% of the total cost, with interest rate at 7% the results on the cash flow are still negative.

The last step of the sensitivity analysis is to support the investment by subsidizing the 50 % of the total costs. This part is very important because all the renewable energy projects are subsidized in order to be feasible. The results on the cash flow, are matching the case where the farmer lends zero money to support the investment. The results are demonstrated in the next table.

OTAL REVENUE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
roject cash flow-no crops	249,6	221,5	179,8	125,4	58,8	-18,8	-106,5	-20
roject cash flow NET (wheat)	3489,6	3461,5	3419,8	3365,4	3298,8	3221,2	3133,5	303
roject cash flow NET (cotton)	3189,6	3161,5	3119,8	3065,4	2998,8	2921,2	2833,5	273
-12035	249,6	221,5	179,8	125,4	58,8	-18,8	-106,5	-20
-12035	3489,6	3461,5	3419,8	3365,4	3298,8	3221,2	3133,5	303
-12035	3189,6	3161,5	3119,8	3065,4	2998,8	2921,2	2833,5	273
-24070	6429,6	6401,5	6359,8	6305,4	6238,8	6161,2	6073,5	597

Figure 36. Project cash flow from spreadsheet (II)

6.4.2 Scenario II (revenue from wheat is included)

This scenario represents the outcomes if the revenue from the wheat crop is taken into consideration. It is important to examine if the concept can be standalone or requires amendments in order to be viable.

From the table 657, the ratio of the Opex/wheat revenue is 46% which is less than the energy revenue on its own. The next step is to examine the project cash flow and the IRR of the project.

16	Depriciation		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	Interest on Loan		-842,5	-781,5	-716,2	-646,4	-571,7	-491,8	-406,3
18	TOTAL REVENUE		8850,5	8822,4	8780,7	8726,3	8659,7	8582,1	8494,5
19	Project cash flow-no crops		-1516,9	-1545,1	-1586,7	-1641,2	-1707,7	-1785,3	-1873,0
20	Project cash flow NET (wheat)		1723,1	1694,9	1653,3	1598,8	1532,3	1454,7	1367,0
21	Project cash flow NET (cotton)		1423,1	1394,9	1353,3	1298,8	1232,3	1154,7	1067,0
22		**-24070**	-1516,9	-1545,1	-1586,7	-1641,2	-1707,7	-1785,3	-1873,0
23		**-24070**	1723,1	1694,9	1653,3	1598,8	1532,3	1454,7	1367,0
24		**-24070**	1423,1	1394,9	1353,3	1298,8	1232,3	1154,7	1067,0
25		**-24070**	4663,1	4634,9	4593,3	4538,8	4472,3	4394,7	4307,0
26	*IRR% (energy + wheat)*		*5%*		*IRR% (energy)*				*#NUM!*
27									
28	*Cummulative Cash over Lifetime*		*46170,2*		*Cummulative Cash over Lifetime*				*-34829,8*
29									

Figure 37. Project cash flow from spreadsheet (III)

The cash flow is positive for the whole lifetime of the project and the IRR is 5%. The IRR is not acceptable according to the initial goals that were introduced to the study. The farmer is closing this investment after 25 years with £ 46,170 which is converted into 65,507 EUR for the Greek standards.

In the case of no loan is introduced in the investment the IRR is 11% and the farmer exits the investment with cumulative cash over lifetime of £ 63305 which equals to 89,819 EUR. This investment is considered to be acceptable.

Going back to the 50% loan contribution to total investment with zero interest rate, the IRR is 7% and the cumulative cash over lifetime is £51,270 equal to 72,744 EUR.

If the loan percentage is lessen to 25% the IRR is 8% and the cumulative cash over lifetime is £ 54,737 which is equal to 77,663 EUR.

If the project is subsidized with 50% on the initial cost (50% loan, 7% interest) the IRR is 24% which considered to be very desirable and the farmer leaves the investment with cumulative cash over lifetime of £ 66,772, which is equal to 94,738 EUR. This part is proving why most of the renewable project are subsidized.

6.4.3. Scenario III (revenue from cotton is included)

This is the same with the previous scenario but for the cotton crop. At first there is a 50% loan on the total cost with 7% interest rate. In this case the IRR is equal to 4% and the farmer completes the investment by having a cumulative cash over lifetime of £ 38,670 which is equal to 54,866 EUR. This is considered to be not acceptable investment like the previous scenario.

If the farmer can afford to pay for the total cost and avoids the loan option, the investment is considered to be acceptable, because the IRR reaches the 10% and the farmer gets a cumulative cash over lifetime of £ 55,805 which is equal to 79,178 EUR.

In case of supporting the total cost with 50% lending money at no interest the IRR drops again to low levels, 5%, and the cumulative cash over lifetime is £ 43,770 which is equal to 63521 EUR.

If the interest rate is at 7% but the percentage of borrowed money is lessen to 25% the IRR is equal to 6% and the cumulative cash over lifetime is £ 47,237 which is equal to 67,021 EUR.

If the farmer gets a subsidy of 50% on the capex the IRR climbs to 21%, which is a desirable result, and exits the investment with a cumulative cash over lifetime of £ 59,727 which is equal to 84,743 EUR.

6.4.4. Scenario IV (revenue from cotton & wheat is included)

As previously discussed, with a careful and effective programming of the farming activities, the same tractor could serve both crops simultaneously. Off course this leaves a larger margin of profit.

Starting with 50% of the total cost covered by a loan from the bank with interest rate at 7% the IRR is equal to 19% and the farmer gets a cumulative cash over lifetime of £ 119,670 which is equal to 169,792 EUR.

If no money is borrowed and the farmer spend from his own capital, the IRR climbs to 25% and the cumulative cash over lifetime of the project is £136,805 which is equal to 194,104 EUR. This proves to be a very beneficial investment according to the IRR rate.

If the money that is borrowed (50% of the total cost) is interest free, the IRR is 21% and the cumulative cash over lifetime is £124,770 which is equal to 177,028 EUR. Yet again another profitable investment according to the IRR.

If the loan is halved (25% of total cost of investment) with interest rate at 7% the IRR is 22% and the cumulative cash over lifetime is £ 128,237 which is equal to 181,948 EUR.

By applying a 50% subsidy on the initial cost of the project the IRR is extremely high to 49% and the cumulative cash over lifetime of £ 140,727 which is equal to 199,669 EUR.

6.5. Discussion of the results

In this part of the chapter, the results from the case studies and its sensitivity analyses are compared and discussed. The next table gathers all the outcomes from the previous analysis.

Sensitivity Analysis	Scenario I		Scenario II		ScenarioIII		Scenario IV	
No change	*IRR %*	null	*IRR %*	5	*IRR %*	4	*IRR %*	19
	Cash £	negative	*Cash £*	46170	*Cash £*	38670	*Cash £*	119670
No loan	*IRR %*	null	*IRR %*	11	*IRR %*	10	*IRR %*	25
	Cash £	positive for 5 years	*Cash £*	63305	*Cash £*	55805	*Cash £*	194104
No interest, loan50%	*IRR %*	null	*IRR %*	7	*IRR %*	5	*IRR %*	21
	Cash £	negative	*Cash £*	51270	*Cash £*	43770	*Cash £*	124770
Interest 7%, loan 25%	*IRR %*	null	*IRR %*	8	*IRR %*	6	*IRR %*	22
	Cash £	negative	*Cash £*	54737	*Cash £*	47237	*Cash £*	128237
Total cost subsidized 50%	*IRR %*	null	*IRR %*	24	*IRR %*	21	*IRR %*	49
	Cash £	positive for 5 years	*Cash £*	66772	*Cash £*	59727	*Cash £*	140727

Table 26. Results from sensitivity analysis in the 4 scenarios

The first clear result is that there is no feasible solution, when trying to compensate the whole investment by taking into consideration only the revenue from the energy yield of the PV panels. The fact that the investment is not feasible, even if there is subsidy to cover the project costs, proves that the investment of PV panels can be profitable only when it is standalone, and generates energy to offset its costs. This drive us to the conclusion that choosing not to include the revenues from the crops to the study is not proving anything useful for the stakeholders who might support this concept and transform it into commercial scale production business. Another very important conclusion is that, even sunny locations such as Thessaloniki in Greece, are unable to support financially this project (revenue only from solar energy), hence locations with less solar radiation might prohibit this project.

The second outcome of the financial analysis is that, when examining the crops separately, there is adequate margin of profit for both crops. In these cases the revenue from the crops is included to the study. There are two ways where this can be achieved. The first requires that the farmer has the expected capital and does not borrow money from the bank and the second is by getting a subsidy, which supports the initial cost of the project. The first one proves that the farmer can get a profit by investing his own money but leaves a small margin for this concept to survive in the market. The second one seems the only feasible solution that can render the concept desirable and trustworthy because in both cases the IRR exceeds the 20%.

The third result that stems from the analysis, is that if there is a well-constructed farming activity calendar and the same tractor is used for multiple crops, the margin of profit can support the concept as a new trend in farming business. Leaving the ability to the farmer to borrow the 50% of the money, required for the investment, while achieving an IRR of 19% is a very positive outcome, regarding this concept. Actually the fact the IRR exceeds the 20% with alternatives that are more easily applied than getting subsidy for a project, can draw the attention of financial institutions, such as banks, who seek new ways to invest their capital, by creating financial products that can help the farmer (small loans, or loans with preferential interest rates). This is called a win-win situation in the market and leaves a margin of profit in both sides. Finally the fact that the investment is boosted when subsidy is introduced, which is quite large (50% of total costs) leaves the margin of providing the farmers with smaller subsidies while still allowing them to gain a very desirable profit.

Last but not least, note that due to the small land that is owned from the average Greek farmer, these amount of profits can be proved to be a very reliable source of revenue to the total family income. Most of the farmers are using this business as source for supportive income and not as the main source. This is rooted to the farming culture of the Greeks. Additionally it is important to consider the relationship of the GDB and EUR currencies and evaluate the local value of the income. Hence if this concept is scaled up regarding the acres, the number of crops and the solar generation it can offer the farmer larger incomes but as always under one condition, which is the good management of the farming activities and the energy that is required.

7. Environmental Issues

The part of the agricultural industry that was reviewed in this paper is only a proportion of it. The agricultural industry is a very broad sector and includes different activities that are related to the food production. From livestock to fishery and from raw crops to the food processing, numerous industrial applications are hidden. As the food is one of the fundamental needs of humanity, it requires and consumes large portions of energy. All these activities are responsible for a share to the CO_2 emissions that are released to atmosphere and troubles the minds worldwide.

Key Words: Reports, FAO, GHG & CO_2 emissions, EU 2020, EU 2030, EU 2050, Sustainability

7.1. Reports

Unfortunately there is a lack of reports occurring the environmental impact assessment of agricultural. However lately, large organizations and institutions are focusing of this subject and aiming to tackle this impact.

According to FAO (Food and Agriculture Organization of the UN) "*emissions from agriculture, forestry and fisheries have nearly doubled over the past fifty years and could increase an additional 30 percent by 2050, without greater efforts to reduce them*". The same source continues by mentioning that "*This is the first time that FAO has released its own global estimates of greenhouse gas (GHG) emissions from agriculture, forestry and other land use (AFOLU), contributing to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)."* (FAO, 2014)

This report demonstrates various aspects of this issue. One of these contains some figures for the energy use that is taking place. FAO claims that since the 1990 the emissions, from fossil fuels and electricity that are consumed to power the industry, have increased by 75%, which is translated in exceeding 785 million tons of CO_2 eq. in 2010. (FAO, 2014)

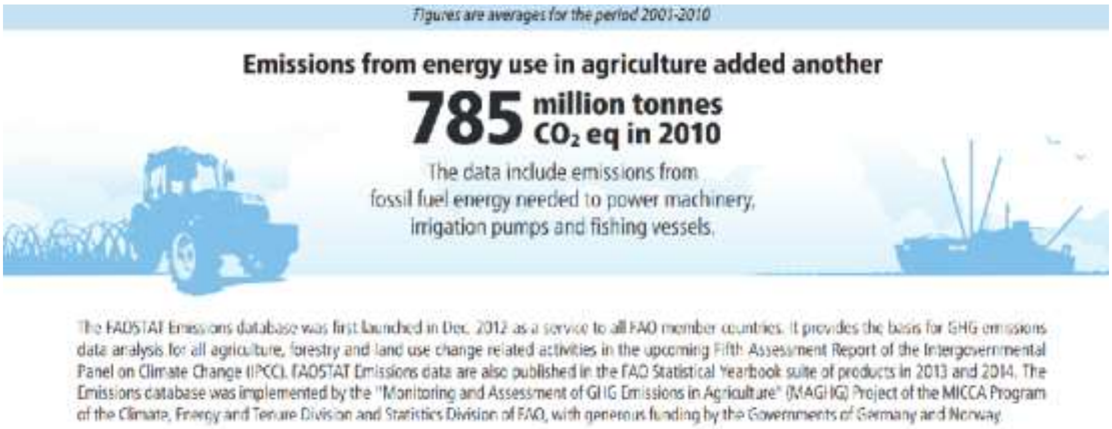


Figure 38. FAO report for energy consumed and carbon emissions (FAO 2014)

Except FAO, other organizations have published same reports. The US government has released the United States Climate Action Report 2014 (USA CAR, 2014). The next table is demonstrating the historical and projected US GHG from each sector from 1990 to 2030. It is obvious that the agriculture holds a quite important share in the whole pie.

Table 5-3 **Historical and Projected U.S. Greenhouse Gas Emissions Baseline, by Sector: 1990–2030** (Tg CO_2e)

Emissions from the energy, transportation, and waste sectors are projected to decline from 2005 to 2020, while emissions from the industrial processes and agriculture sectors are projected to increase, and sequestration from land use, land-use change, and forestry is projected to decline.

Sectors[b]		Historical GHG Emissions[a]				Projected GHG Emissions			
		2000	2005	2010	2011	2015	2020	2025	2030
Energy		4,258	4,321	4,104	3,981	3,936	4,038	4,141	4,207
Transportation		1,861	1,931	1,786	1,765	1,710	1,702	1,660	1,627
Industrial Processes		357	335	308	331	378	438	504	536
Agriculture		432	446	462	461	461	485	498	512
Forestry and Land Use		31	25	20	37	30	27	40	35
Waste		136	137	131	128	127	126	125	123
Total Gross Emissions		**7,076**	**7,195**	**6,812**	**6,702**	**6,643**	**6,815**	**6,967**	**7,041**
Forestry and Land Use (Sinks)[c]	high sequestration	-682	-998	-889	-905	-884	-898	-917	-937
	low sequestration					-787	-614	-573	-565
Total Net Emissions	**high sequestration**	**6,395**	**6,197**	**5,923**	**5,797**	**5,759**	**5,918**	**6,050**	**6,104**
	low sequestration					**5,856**	**6,201**	**6,394**	**6,476**

[a] Historical emissions and sinks data are from U.S. EPA/OAP 2013. Bunker fuels and biomass combustion are not included in inventory calculations.

[b] Sectors correspond to inventory reporting sectors, except that carbon dioxide, methane, and nitrous oxide emissions associated with mobile combustion have been moved from energy to transportation, and solvent and other product use is included within industrial processes.

[c] Sequestration is only included in the net emissions total.

Figure 39.Historical and projected US GHG from 1990 to 2030, United States Climate Action Report 2014

The last source that is used in this paper is from an article of the Nature (http://www.nature.com/) where the Consultative Group on International Agricultural Research (CGIAR, 2015) is claiming that the 1/3 of the global GHG emissions is coming from agriculture. CGIAR is claiming that "*that reducing agriculture's carbon footprint is central to* *limiting climate change. And to help to ensure food security, farmers across the globe will probably have to switch to cultivating more climate-hardy crops and* ***farming practices***".

7.1.1. Comments on the reports

It is important to submit a few comments regarding the above sources and reports. Usually when it comes to GHG emissions that are related to agriculture, these reports focus on gases that are emitted from farming activities in the soil, such tillage, the fertilizer's industry and off course cattle industry. So the proportion of the GHG emissions that comes from the machinery thus the farming tractors it is considered not to be one of the primary sources. Even if the then study focuses on the energy that is consumed, for example in FAO's report, it is mentioned that 785 million tons of CO_2 eq. emissions is connected with power requirements of machinery, irrigation pumps and fishing vessels, there are no clear data for the farming tractors and their contribution analysed in depth. However the fact that these report are not matching 100% this treatise, it is impossible to assume that the emissions from the farming tractors are not a significant contribution to the depletion of the environment.

7.2. How the project corresponds to the EU targets

The three main environmental packages that the EU follows are the:

1. 2020 climate and energy package
2. 2030 framework for climate and energy policies
3. 2050 roadmap for moving to a low-carbon economy

Source: http://ec.europa.eu/clima/policies/index_en.htm

7.2.1 2020 climate and energy package

The frame of these target is widely known as the 20-20-20 target:

- A 20% reduction in EU greenhouse gas emissions from 1990 levels;
- Raising the share of EU energy consumption produced from renewable resources to 20%;
- A 20% improvement in the EU's energy efficiency.

This concept is corresponding into two of the commitments of the 20-20-20 target, the **commitment to low carbon economy** and to **the promotion of the green growth and jobs**. The way that this can be done is because this study introduces a low carbon farming business to the agriculture economy and of course a good way to promote the green growth of the country. Note that the financial analysis proved that this concept can draw the attention regarding the subsidies and other forms of financial support.

7.2.2. 2030 framework for climate and energy policies

The frame of this direction is summed up to the next targets:

- Reducing GHG emissions by at least 40%
- Increasing the share of renewable energy to at least 27%
- Increase energy efficiency to at least 27%
- Reform of the EU emissions trading system
- New governance system

The concept corresponds to the first two targets by aiding to achieve the percentages that are set as goals. Yet again the contribution is still questioned because there is no commercial scale of this concept.

7.2.3. 2050 roadmap for moving to a low-carbon economy

This goal is more generic and contains targets that are related more to the lifestyle of modern societies, rather than the actual results from the energy consumption behaviour of the industries. The targets are:

- Need for bigger climate efforts
- Towards a low-carbon society
- Innovation, green growth and jobs
- Saving energy and resources
- Cleaner air

Due to the generic nature of these targets, it can be assumed that this study applies all of them. But two are the targets that the concept corresponds accurately, the **low-carbon society** and the **innovation, green growth and jobs**. Altering the agricultural industry of a country to low carbon industry is impacting the society. This is happening because the food industry is one of the corner bricks for every society. The fact that this concept is still away from reaching the commercial scale, proves its innovative character. Last but not least the evidence from the financial analysis, regarding the profits from this business, renders this concept a reliable type of job, which can add to the green growth.

7.3. Sustainability and GHG emissions.

It is acceptable that the reduction of GHG emissions are not completely corresponding to Sustainability. Although this concept is responding to the call of replacing the fossil fuels with a renewable energy source, it is still under ambiguity of how sustainable it can be considered. The reason that justifies this ambiguity is the absence of the environmental impact assessment of the battery and solar cell manufacturing, in this study (out of the scope of this study). If for example the factories that supply the market with these two products use electricity that is generated from fossil fuels, this raise doubts about the overall sustainability of the project. The reason that it is out of the scope of this study is that the composition and discussion of EIA reports is, from its own, a subject to be analysed in a separate study. Some may argue that this is not correct due to the small scale of the project, however when a project-concept is introduced with the aim to become mainstream and not another alternative, it must meet all the environmental demands.

8. Conclusion and Discussion

Concluding this study it is important to comment all important points that stemmed out. The first is that this project is proved feasible. Although many assumptions occurred, the results can be judged as rational and realistic. From a technical aspect, this project is parted from matured and relatively simple technologies such, as PV panels, batteries and electric motors. Hence major problems of compatibility between technologies do not occur. This is very important when it comes to applicability in real conditions. Financially the project is feasible and under certain conditions it can be very profitable. Last but not least the project, as an idea, seems to comply with the EU environmental standards and goals, while offering solution to the matter of the environmental degradation from farming activities.

Key words: Technical, Financial, Environmental, compatibility, EU, batteries, assumptions,

8.1. Technical Aspects

8.1.1 Potentials

As mentioned in the previous paragraph, this study proves that the project has a lot of potentials regarding its application. All technologies that were combined have proven their reliability and of course their drawbacks (battery unreliable technology) through last decades. It is important for example to have for granted that the proposed PV panel will produce the electricity that is predicted, because it is generally acceptable that polycrystalline technology can reach electric efficiency of 12%.

Although the technical details of the farming tractor are not analysed in this study, the simplicity of the technology (e.g. motors, cables, charging controllers, meters, batteries etc.) offers margin in success of the functionality of a real electric farming tractor that resembles the hypothetical one, which is used in this study.

A very popular advantage in EV industry is the available torque that the electric motors produce from zero rpm. This can be more beneficial in farming tractors, where large traction forces are required in order to pull the heavy farming machinery.

The fact that a 3 kW can support the farming activities, apart from ploughing, is very important clue for farming, especially in remoted areas, considering the predictions of cost reduction of solar panels. Adding to this PV panels are predicted to increase their efficiency. It is a common opinion that off the grid residencies can be a solution for remoted areas, the same applies in farming practises, but in this case for fossil fuels.

One of the great problems regarding the increased installed capacity is solar PV panels, is that they have taken over farming land areas. By combining these two sectors (Energy and Farming) the land that was deprived from farming in order to install panels, can now be used for farming reasons.

8.1.2 Concerns and drawbacks

However this study also revealed some drawbacks, such as constrains in installed capacity, batteries are still considered an unreliable technology etc. One of the fundamental drawbacks is that there is not any experience and information from same projects. This always adds doubts about the application, in reality, of this project.

Although one of the main drawbacks of batteries, which is the weight, is considered to be advantage for this project, the other one, which is the reliability and autonomy are still a big problem. The results can be seen in the EV industry, where only the recent years there is an adequate progress regarding these issues, with Tesla, Nissan and other manufactures producing EV’s with long autonomy and reliability while not being too expensive. Unfortunately up to this point there is no commercial scale model produced by any manufacturer in farming tractors, meaning that there is still a long road in tractor’s industry.

The relatively low efficiencies of panels and batteries is another problem for farming tractors autonomy. These efficiencies are related to a small specific power, hence to the daily available energy that a farmer can get in order to complete the activities. Even though it is acceptable to complete farming activities in more than one days, farmers prefer to complete the activities as soon as possible.

Focusing especially in batteries, as previously reported, many factors can affect the real performance. Although this study is not analysing these factors and their effects, a lot of problems may prove to be obstacles for the applicability of this project. The author of this thesis aims to support this concept of electric farming tractors, in the future, with additional research in batteries' performance.

8.2. Financial Aspects

The IRR method used to assess the value of this project. Different scenarios went through a series of changes (sensitivity analysis) to examine their impact on the IRR. In all scenarios the two changes that increased the IRR were:

- No loan on initial cost
- 50% of initial cost to be subsidized

Apart from these two changes one more took place and dramatically increased the value of the investment. That change proposed the for the 10 kW installed capacity the same system could serve both crops and produce the highest income.

In a more generic approach, the point that values most in this analysis, is that this concept can only be assessed as a good investment only when the revenues from the crops are included in the overall profits.

8.3. Environmental Aspects

This project examined if it complies with the roadmaps and frameworks that were set in the past, as well as those that are set for the future, in order to preserve the environment. Although this chapter (7. Environmental Issues) can be considered short, compared to the huge EIA reports that are complementing all projects, it provides the basics regarding this issue. Even if this project proves not to have the potentials to go mainstream, it is still important to have reliable alternatives, regarding the energy supply for farming activities. Despite the fact that the previous sentence may fit better in an energy rather than environmental comment, this might turn out to be inaccurate because all issues of energy resourcing and environmental preservation are under the umbrella of sustainability. However, as this project enables technologies, such as solar

PV panels and batteries, there are a lot concerns about the overall sustainable character of this project.

8.4. Future Work

As this project is not yet applicable and tested, it is pointless to talk about future work regarding finding ways to improve its applications. The close future work that can be done can be summarized on the next bullets:

- Replace assumptions with real data, or empirical information
- Focus more on efficiencies, especially in batteries
- Examine other renewable technologies regarding the energy production such as burning biomass to produce electricity, wasted materials, wind turbines where solar radiation is inadequate etc.
- Financially compare fossil fuels with renewable electricity
- Assessment of GHG emission reduction
- Analyse the technical details of an electric farming tractor
- Examine the impact of the predicted reduction of PV panels cost, through the next years
- Examine other locations

All of the realistic improvements and future work concerns only research purposes. Hopefully the further future work will enable actual amendments in its applications.

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