- Turn to the topic of renewable energy usage in the modern era, when nowadays the huge wind turbines are producing electricity.
- Tell them that on this class we are going to see how people of old times used the power of the wind

• Start the construction of the pilot model (see *2.2 Construction guide* steps)
  - You may find worthy to arrive to the class with two teacher's models:
    - o One that is readily built up,
    - o The other teacher's model would be in particles to make easier the explanation towards the class.
  - You might show first to students your ready model in order to let them know how the result should be by the end of the workshop
  - Dismount your model or take your second teacher's model
  - Go step-by-step, show them the first steps at your desk and tell them to replicate it on their own models in groups. Raise their attention to the importance of cooperation and task sharing inside the group (and on class level too).
  - Go around the tables and observe students' work. In case of need of help, give them a hand and encourage them to solve some of the challenges individually.
  - When one section is done, go with the next steps of the *2.2 Construction guide.* Show them the next steps at your place and then let them to repeat the steps on their own model.
  - When a group is ready, try out the windmills

• Testing of model
  - You might go out to the school garden in case of a windy day or just open the window of the classroom. If there isn't enough wind, we can explain to the students, that windmills in real life (nowadays and in the past too) work only when there is enough wind and it is blowing more or less from the same direction.
  - Nevertheless to test our models there are two options. First is blowing the windmills, second is using a fan to generate wind. However this second option is less ecological as we use electricity.

• Conclusions
  - Encourage your students to derive their conclusions based on the experience they observed
  - Help them by asking the following questions: How much wind is needed to have the piece lifted up? What happens when there is too much wind?
  - Optional: you can start an open conversation or give as homework to redact a text about windmills. In which areas is it the most suitable to install windmills? Could they imagine living in a wind energy powered house? If they consider it a good solution for the climate change caused global problems, what do they think, why don't use everybody this systems? What else is missing in their opinion?

Extra information for teachers, instructors, tips and tricks

- Your students may try out different windmill styles, with different blade-shapes and at the end of the class their efficiency can be tested.
- However, students can try out by blowing the windmills, we can encourage them to repeat the experiment on a windy day and see the results in real life conditions

1.5. Conclusions

1.5.1. Conclusion on pedagogical guide

Each of the three workshops aims to enlarge the knowledge on renewable energies in rural schools and each of them has its specific pedagogical goal. Teachers can develop students' abilities with all of them. Depending on age, time, circumstances and the curricula teachers are free to choose the one that fits the best to their personality and their didactical aims. Thus, we cannot conclude which is the best from the three mock-ups, all have their characteristics and advantages.

1.5.2. Conclusion on calculations

The part of calculations shows the difference between renewable energies in the sizing of installations. However, all the installations require some general parameters for the dimensioning: energy demand (electricity or heating), quantity of resources (solar irradiation or wind speed and frequency) and features of the equipment (power, efficiency and dimensions). Thus, it can be concluded that renewable energies have a similar structure for the sizing, despite specific differences.

1.5.3. Conclusion on Construction guide

The construction steps detail how to build each model. The Aeroelevator model can be considered the easiest to be constructed; the Photovoltaic model might be the most complex because it contains serious electrical manipulations. However, the thermosiphon effect can be showed the most efficiently. If the mock-up is built correctly, the success is almost guaranteed and the increase of water temperature is impressive. Thus, it can be concluded that all the models can be made relatively easily, the choice depends on the time, goal, age of students and also, on the budget we have for the class.

1.5.4. Conclusion on Economical calculations

The business described in the present case study is viable and profitable at the first stage for one year and later there are several ways to grow the business to various directions. The three workshops are differing in prices; also there are solutions in terms of decreasing the number of groups per class in order to make it reachable for schools in different financial circumstances.

1.6. References

[1] Kandpal T.C. and Broman L. (2015): Renewable Energy Education A Worldwide Status Review, Stromstad, Strömstad Academy

[2] Rietbergen J. and Hadjemian N. (2010): Renewable Energy Technologies for Rural Development, New York and Geneva, United Nations

[3] Nemethy S., Dinya L., Gergely S. and Varga G.: Renewable energy production and use through sustainable ecological cycles in agriculture, Gaia Foundation, Gyongyos and Galgaheviz, Hungary

[4] Autti O. and Hyry-Beihammer E. K. (2014): School Closures in Rural Finnish Communities, Finland, Journal of Research in Rural Education

[5] From hydraulic to electric, option 1.: https://www.youtube.com/watch?v=bI5B6BJrPwk

[6] From hydraulic to electric, option 2.: https://www.youtube.com/watch?v=TXfwZ5_kyr4

[7] From hydraulic to electric, option 3.: https://www.youtube.com/watch?v=g6IN0rLcmP4

[8] From eolic to electric, option 1.: https://www.youtube.com/watch?v=YrgJ3Dj_0LM

[9] From eolic to electric, option 2.: https://www.youtube.com/watch?v=_RSG9qrcpR4

[10] From eolic to electric, option 3.: https://www.youtube.com/watch?v=VQ7cp7gbSPc

[11] From photovoltaic to electric, option 1.: https://www.youtube.com/watch?v=FXocRKM4JwY

[12] From photovoltaic to electric, option 2.: https://www.youtube.com/watch?v=svtNM5VexA4

[13] From photovoltaic to electric, option 3.: https://www.youtube.com/watch?v=EMCvzA4pJdg

[14] H disposable plastic spoons http://www.ebay.com/itm/DISPOSABLE-WHITE-PLASTIC-LOOSE-CUTLERY-FORK-KNIFE-SPOON-CATERING-TEA-PARTY-/331017178895?var=&hash=item4d12294f0f:m:m8jrQWh2J8upz-GMIWC8C9Q

[15]H CD: https://www.gigaplaza.eu/shop/%C3%ADrhat%C3%B3-dvd-lemezek/dvd-r-olcso-irhato-dvd-lemezek2013-06-27-16-30-47/tdk-dvd-r-4,7gb-16x-pap%C3%ADrtokban-1-detail

[16] H CD size http://www.multishapecdrom.com/samples.html

[17] H styrofoam http://www.ebay.com/itm/703075-White-Styrofoam-A4-Photo-Texture-Print-/400451984072?hash=item5d3ccc5ac8:g:lB8AAMXQvJVRWDkj

[18] H superglue http://www.ebay.com/itm/Repair-3g-502-Super-Glue-Instant-Adhesive-Bonding-Strong-Tube-Metal-Toys-Wood-/292090219319?hash=item4401ef0b37:g:1D0AAOSwcdRY90Nn

[19] H wooden rod http://www.ebay.com/itm/10pcs-20cm-Wooden-Arts-Craft-Sticks-Dowels-Pole-Rods-Sweet-Trees-Wood-Stick-8mm-/331903971561?hash=item4d4704b0e9:g:wYoAAOSwRQlXgEok

[20] H bigger two plastic rods http://www.ebay.com/itm/2pcs-ABS-Plastic-Round-Bar-Rods-DIY-Dollhouse-Sand-Table-Model-Craft-Tool-/122342482332?var=&hash=item1c7c2e219c:m:mdtd0OQqsEHoQEGIFxQorjA4

[21] H smaller two plastic rods http://www.ebay.com/itm/2pcs-ABS-Plastic-Round-Bar-Rods-DIY-Dollhouse-Sand-Table-Model-Craft-Tool-/122342482332?var=&hash=item1c7c2e219c:m:mdtd0OQqsEHoQEGIFxQorjA

[22] H plastic piece https://www.alibaba.com/product-detail/15mm-thick-hdpe-plastic-slab_60537245433.html?spm=a2700.7724838.0.0.Qvjnbc
[23] H generator http://www.ebay.com/itm/Micro-Physics-Experiment-DIY-Wind-Generator-LED-Small-Dc-Motor-Blade-Holder-EW-/262902526995?hash=item3d36363413:g:yYAAAOSwax5Yyj5M
[24] H rubber band http://www.ebay.com/itm/New-40-Pieces-Practical-Black-Elastic-Rubber-Band-Hair-Tie-Ponytail-Holders-BF-/252398646796?hash=item3ac421b60c:g:k2AAAOSwQjZXQY5f
[25] H Crocodile clip http://www.ebay.com/itm/1M-Long-Alligator-Clip-to-Banana-Plug-Test-Cable-Pair-for-Multimeter-LW/172396562957?_trksid=p2047675.c100005.m1851&_trkparms=aid%3D555018%26algo%3DPL.SIM%26ao%3D2%26asc%3D40130%26meid%3Dbbbd565b3ffc447e9a81d7dc48fe88b1%26pid%3D100005%26rk%3D2%26rkt%3D6%26mehot%3Dpp%26sd%3D371955725931
[26] H Crocodile clip forceps http://www.ebay.com/itm/2-4-10Pcs-Alligator-Crocodile-Test-Clip-Clamp-For-Multimeter-Tester-Probe-/172483818676?hash=item2828d634b4:g:9UIAAOSwjDZYd18I
[27] H small led diode http://www.ebay.com/itm/Micro-Physics-Experiment-DIY-Wind-Generator-LED-Small-Dc-Motor-Blade-Holder-EW-/262902526995?hash=item3d36363413:g:yYAAAOSwax5Yyj5M
[28] H small pocket knife http://www.ebay.com/itm/Outdoor-Pocket-Folding-Fruit-Knife-Small-camping-Anti-slip-handle-Blade-Knife-/361985287424?hash=item5448012500:g:MaUAAOSw03lY6LWG
[29] E superglue http://www.ebay.com/itm/FD3764-502-Super-Glue-Cyanoacrylate-Adhesive-Strong-Bond-Fast-Repair-Tool-1pc-/272675773475?hash=item3f7cbe1c23:g:x-gAAOSw9KpW~hXc
[30]E CD https://www.alibaba.com/product-detail/single-layer-style-BD-R-25GB_60631437629.html?spm=a2700.7724838.0.0.W28JVg
[31] E plastic glass http://www.ebay.com/itm/WHITE-Plastic-7oz-Disposable-Cups-200ml-Drinking-Glass-Vending-Style-Cup-180cc-/181795975245?var=&hash=item2a53e2704d:m:mlUNB2_groNKRDeGQdI_NdQ
[32] E generator http://www.ebay.com/itm/Micro-Physics-Experiment-DIY-Wind-Generator-LED-Small-Dc-Motor-Blade-Holder-EW-/262902526995?hash=item3d36363413:g:yYAAAOSwax5Yyj5M
[33] E crocodile clip http://www.ebay.com/itm/2PCS-Double-ended-Test-Leads-1M-Alligator-Crocodile-Roach-Clip-Jumper-Wire-/231217683640?hash=item35d5a5dcb8:g:gaYAAOSwTM5YuJjJ
[34] E scissors http://www.ebay.com/itm/PROFESSIONAL-HAIRDRESSING-HAIR-CUTTING-BARBER-SALOON-SCISSORS-6-5-/152116743469?hash=item236add4d2d:g:Ss8AAOSwH09ZIlEu
[35] E led diode http://www.ebay.com/itm/Micro-Physics-Experiment-DIY-Wind-Generator-LED-Small-Dc-Motor-Blade-Holder-EW-/262902526995?hash=item3d36363413:g:yYAAAOSwax5Yyj5M

[36]E plastic slab https://www.alibaba.com/product-detail/Professional-opaque-PVC-white-inkjet-printing_60553683904.html?spm=a2700.7724838.0.0.mZKXD6
[37]E hair dryer http://www.ebay.com/itm/Elle-Travel-Hair-Dryer-HDE15-Cold-Air-2-Heat-and-Speed-Setting-Fold-Away-Handle-/162009056329?hash=item25b87e0449:g:z9kAAOSwhQhY64s8
[38]P led diode http://www.ebay.com/itm/Ultra-Bright-1-8mm-3mm-5mm-8mm-10mm-LED-Diodes-Clear-Lens-Flashing-Flickering-/281491590196?var=&hash=item418a34cc34%3Am%3Amn5bDTuofxSG6pySFMbIpzg
[39]P soldering http://www.ebay.com/itm/220V-110V-75W-936-Power-Iron-Frequency-Change-Desolder-Welding-Soldering-Station-/192134755258?hash=item2cbc1fb3ba:g:-H8AAOSw4CFYz3zN
[40]P resistor http://www.ebay.com/itm/20Pcs-1-2W-0-5W-Metal-Film-Resistor-1-82-91-100-120-150-180-200-220-1-910-Ohm-/192095442830?var=&hash=item2cb9c7d78e%3Am%3AmDQz71gXzKYQdttsDPl8HFg
[41]P solar panel http://www.ebay.com/itm/New-6V-1W-Solar-Panel-Module-DIY-For-Light-Battery-Cell-Phone-Toys-Chargers-/201870519129?hash=item2f006bab59:g:qc8AAOSwc-tY2pbe

1.6.1. References for the pedagocial guide

[1] https://www.youtube.com/watch?v=VjpTKrdm5Kc
[2] http://www.paperorigamiblog.com/2013/10/fun-origami-windmill.html
[3] Partida Parany, s/n, 12600 La Vall D'Uixó, Valencia
[4] http://www.leroymerlin.es/fp/10021662/vidrioplastico-?idCatPadre=9371&pathFamilaFicha=3608
[5] https://tienda.arelux.com/productos/aislamiento-termico/mejor-aislante-termico-multicapa/
[6] Componentes Castalia, Av. Almazora nr. 22, Castellón
[7] Cebekit - Pack de 4 paneles solares experimentales, juguete educativo, color negro (Fadisel C-0137): https://www.amazon.es/Cebekit-paneles-solares-experimentales-educativo/dp/B00H98E20U/ref=sr_1_150?ie=UTF8&qid=1494945102&sr=8-150&keywords=fotovoltaico
[8] https://www.amazon.es/Sourcingmap-A12081300UX0999-Motor-micro-DC/dp/B009AQLDSS/ref=pd_sbs_60_10?_encoding=UTF8&psc=1&refRID=XTW2C34Q6VA8CVVKRFX8
[9] http://www.leroymerlin.es/fp/18896752/tablero-contrachapado-contrachapado?pathFamilaFicha=4604
[10] http://www.salvadorescoda.com/tarifas/Accesorios_Fijacion_Catalogo_Sept_2014.pdf
[11] http://todoeduca.com/estudios/educacionsecundariaobligatoria/castellon.html

Calculations and Construction guide

2. Calculations and Construction guide

The following chapter contains two main parts. Once, the Calculation and design part will show how real life cases would work through theoretical calculations based on hypothetical cases. Second, the three models' Construction guide is attached to this chapter, containing the complete list of required material, including unit price and the construction method step-by-step.

2.1. Calculations and design

2.1.1. Calculation of Domestic Water Heater systems

- ***Inputs***

Thermal energy is often used in Hot Water systems, working independently or with other heat generators (normally boilers). Normally, the Technical Building Code (CTE, Spain) establish a guide to size the minimum solar contribution for hot water.

In order to size the thermal collectors, the main factors that must be taken into account are:

- Location
- Type of building and occupation
- Type of panels, inclination, orientation and efficiency.

In this example, it is considered that the installation is located in the province of Castellón (Spain) and the building is a single-family household with 4 inhabitants. Following the CTE, the daily consumption of hot water is 22 litres/person.

The solar thermal collector selected is a SOL 2300 XBA of the company ESCOSOL. The dimension of the collector is 1.903x1.216 m and its efficiency is 0.749. It is selected a recommended inclination of 45º and South orientation.

- ***Irradiation and orientation***

The average daily irradiation H (Wh/day·m^2) of Castellón is obtained from the PVGIS:

Table 1 – Average monthly irradiation

Month	H_h
Jan	2290
Feb	3240
Mar	4740
Apr	5640

May	6630
Jun	7420
Jul	7350
Aug	6350
Sep	4950
Oct	3760
Nov	2570
Dec	2000
Year	4750

The average value of Castellón is 4750 Wh/day·m^2, which is 4087 kcal/day·m^2.

The inclination corrector factor (K) for latitude of 40º is shown in the next table (source: CENSOLAR):

Table 2 – Inclination corrector factor

Incl°	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
0	1	1	1	1	1	1	1	1	1	1	1	1
5	1,07	1,06	1,05	1,03	1,02	1,01	1,02	1,03	1,05	1,08	1,09	1,09
10	1,14	1,11	1,08	1,05	1,03	1,02	1,03	1,06	1,1	1,14	1,17	1,16
15	1,2	1,16	1,12	1,07	1,03	1,02	1,04	1,08	1,14	1,21	1,25	1,24
20	1,25	1,2	1,14	1,08	1,03	1,02	1,03	1,09	1,17	1,26	1,32	1,3
25	1,3	1,23	1,16	1,08	1,02	1	1,02	1,09	1,19	1,3	1,38	1,36
30	1,34	1,26	1,17	1,07	1,01	0,98	1,01	1,09	1,2	1,34	1,43	1,41
35	1,37	1,28	1,17	1,06	0,98	0,95	0,98	1,07	1,21	1,37	1,47	1,45
40	1,39	1,29	1,16	1,04	0,95	0,92	0,95	1,05	1,21	1,39	1,5	1,48
45	1,4	1,29	1,15	1,01	0,91	0,88	0,92	1,03	1,2	1,39	1,52	1,5
50	1,41	1,28	1,13	0,98	0,87	0,83	0,87	0,99	1,18	1,39	1,54	1,52
55	1,4	1,27	1,1	0,94	0,82	0,78	0,82	0,95	1,15	1,38	1,54	1,52
60	1,39	1,24	1,07	0,89	0,77	0,72	0,77	0,9	1,12	1,36	1,53	1,51
65	1,37	1,21	1,03	0,84	0,71	0,66	0,71	0,85	1,07	1,34	1,51	1,5
70	1,34	1,17	0,98	0,78	0,64	0,59	0,64	0,79	1,02	1,3	1,49	1,47
75	1,3	1,13	0,92	0,72	0,57	0,52	0,57	0,73	0,97	1,25	1,45	1,44
80	1,25	1,08	0,86	0,65	0,5	0,45	0,5	0,66	0,9	1,2	1,41	1,4
85	1,2	1,02	0,8	0,58	0,43	0,37	0,42	0,58	0,84	1,14	1,35	1,35
90	1,14	0,95	0,73	0,5	0,35	0,29	0,34	0,5	0,76	1,07	1,29	1,29

Therefore, the average value of K is 1.19.

- ***Number of solar collectors***

In order to know the number of collectors required, it is necessary to calculate the total area of capture in m^2. The equation used is:

$$S(m^2) = C \cdot \frac{Ta - Te}{H \cdot K \cdot Rc}$$

Where:

S: Total area of capture in m^2

C: Daily consumption in litres/day

Ta: Temperature of accumulation in ºC (it is considering 60ºC, attending to CTE)

Te: Temperature of entrance in ºC (following the UNE 94.002:2005, the average in Castellón is 14.58)

Rc: Efficiency of the collector (0.749)

Considering that:

$$C = 4 \cdot 22 = 88\ litres/day$$

The value of the total required area is:

$$S = \frac{88 \cdot (60 - 14.58)}{4087 \cdot 1.19 \cdot 0.749} = 1.097\ m^2$$

The numbers of required collectors are:

$$Number\ of\ collectors = \frac{1.097}{(1.903 \cdot 1.216)} = 0.474$$

Therefore, it is necessary only one solar collector for this example.

2.1.2. Calculation of Photovoltaic systems

- ***Energy demand***

The first step in order to size a photovoltaic system is to know the daily consumption of energy required. The two parameters required are the power consumption and the operating hours of all the equipments that need energy. The total energy can be calculated as:

$$Ed\ (Wh) = \sum (P(W) \cdot h)$$

In this example, it is considered a total energy demand of 1 kWh for the sizing of the installation (it is enough energy for domestic lighting).

- ***System losses***

All the photovoltaic systems have losses or Performance Ratios (PR) that must be taken into account. The PR can be calculated with the next equation:

$$PR = 1 - (Loss_{orient} + Loss_{shade} + Loss_{dirt} + Loss_{cable} + (1 - Perf_{inv}) + \left(1 - Perf_{reg}\right) + (1 - Perf_{bat}) + Loss_{deter}$$

Where:

$Loss_{orient}$: losses due to orientation.

$Loss_{shade}$: losses by shadows.

$Loss_{cable}$: losses by wiring.

$Loss_{dirt}$: losses by dirt.

$Perf_{inv}$: performance of the inverter

$Perf_{reg}$: performance of the regulator

$Perf_{bat}$: performance of the battery

$Loss_{deter}$: losses due to deterioration of the panels.

It is considered a direct generation system because is more similar to the pedagogic model, being also simpler. Normally, a PR of 0,8 is established of direct photovoltaic installations.

- ***Sizing of the photovoltaic field***

In order to define the number of PV panels to be installed, it is required to know the irradiation of the area. This irradiation is obtained from official databases, depending on the region. One of the most important databases in Europe is PVGIS (Photovoltaic Geographical Information System).

This tool can serve for the estimation of the performance of grid-connected PV, monthly radiation, daily radiation or stand-alone PV. For this simple case, it is used the PV Estimation tab.

It is necessary to establish a value of peak PV for the installation. It is considered Atersa A250P photovoltaic modules (manufactured close to the location).

The required parameters for the PV estimation are shown in the next table:

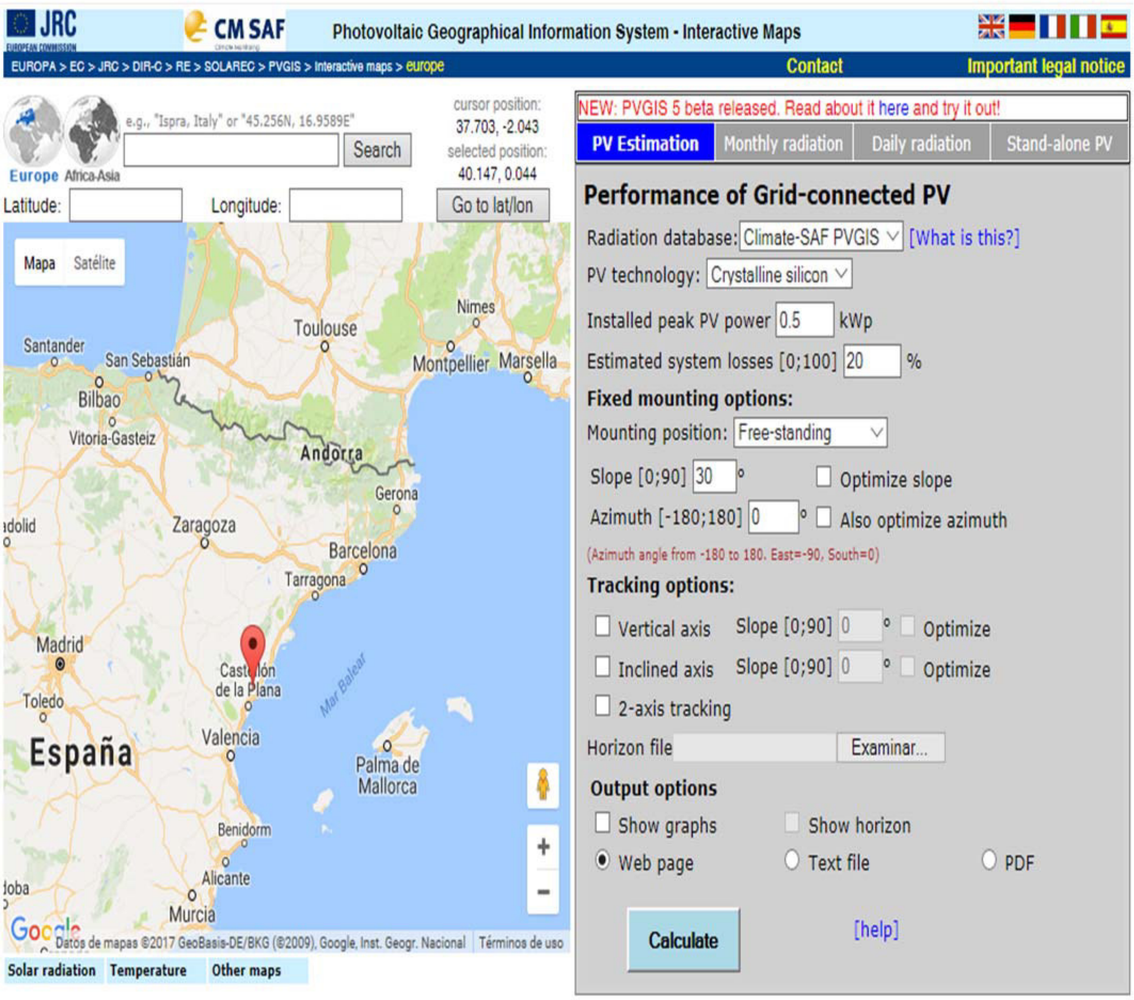
Co-funded by the Erasmus+ Programme of the European Union

Table 3 – Required parameters for photovoltaic estimation

Parameter	**Value**
Location	Province of Castellón
PV technology	Crystalline silicon
Installed peak PV power	0.5 kWp
Estimated system losses	20 %
Slope	30º

This information is introduced in the PVGIS:

Table 4 – Data for PVGIS



The installed peak PV power is equivalent to two Atersa modules of 250 Wp. The results given by the PVGIS are:

Table 5 – Results of PVGIS

Fixed system: inclination=30°, orientation=0°				
Month	E_d	E_m	H_d	H_m
Jan	1.37	42.3	3.68	114
Feb	1.73	48.5	4.71	132
Mar	2.14	66.4	5.96	185
Apr	2.15	64.6	6.12	184
May	2.29	71.0	6.60	205
Jun	2.40	72.0	7.02	211
Jul	2.38	73.7	7.05	219
Aug	2.23	69.1	6.62	205
Sep	1.98	59.4	5.78	173
Oct	1.75	54.1	4.99	155
Nov	1.45	43.5	4.00	120
Dec	1.25	38.9	3.38	105
Yearly average	**1.93**	**58.6**	**5.50**	**167**
Total for year		**704**		**2010**

Where:

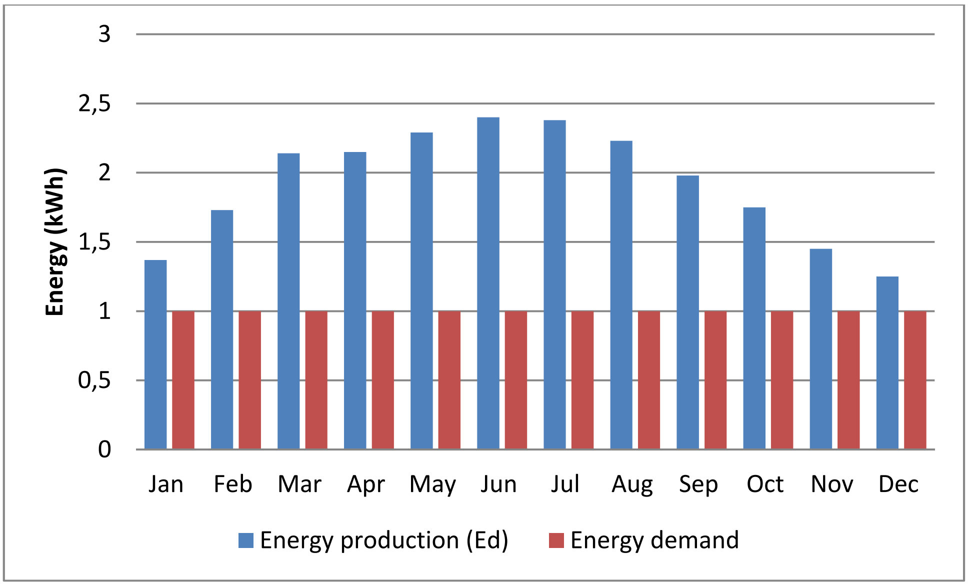
E_d: Average daily electricity production from the given system (kWh).

E_m: Average monthly electricity production from the given system (kWh).

H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2).

H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2).

Comparing the average monthly electricity production from the system with the energy demand considered, it is obtained the next graph:



Graph 1 – Energy demand and average daily electricity production per month

It is shown that the PV installation provides enough energy for the supplying of the demand. Nevertheless, in order to do a correct study, it must be considered the daily radiation because solar systems do not produce energy during the night. However, for this example the results are valid.

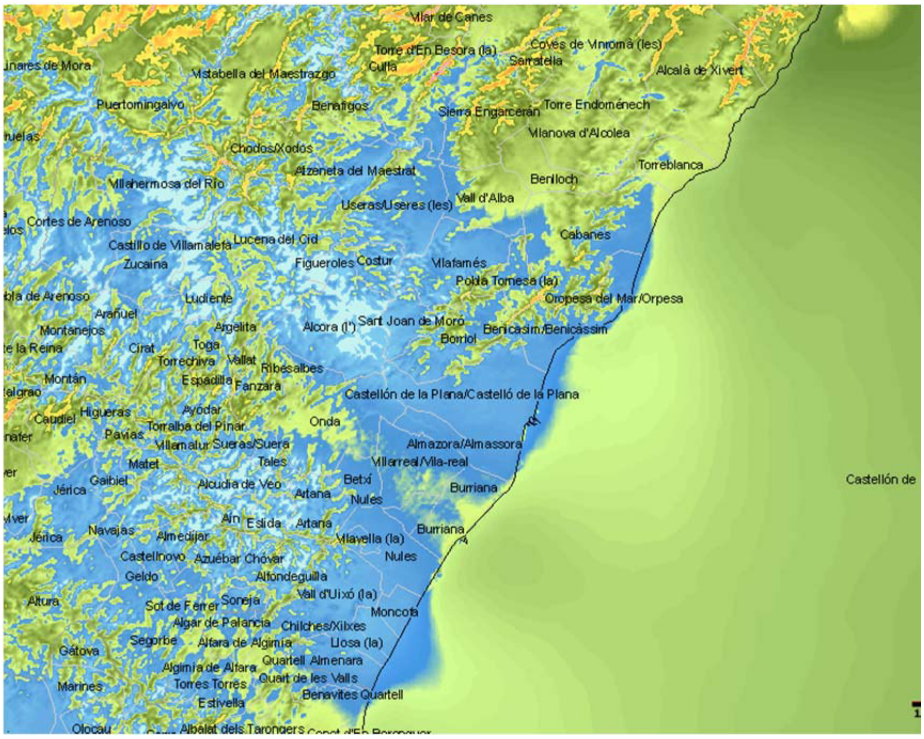
2.1.3. Calculation of wind turbine systems

- ***Energy demand***

The energy demand is calculated as it is shown in the point "*2.1.2 Calculation of photovoltaic systems*". In this example, in order to size a wind turbine, it is considered a daily energy demand of 1 kWh/day for lighting.

- ***Wind energy potential***

The calculus and sizing of the wind installation is based on different maps and historic databases of wind. For example, the Institute of Diversification and Saving Energy (IDAE, Spain) has different wind maps.



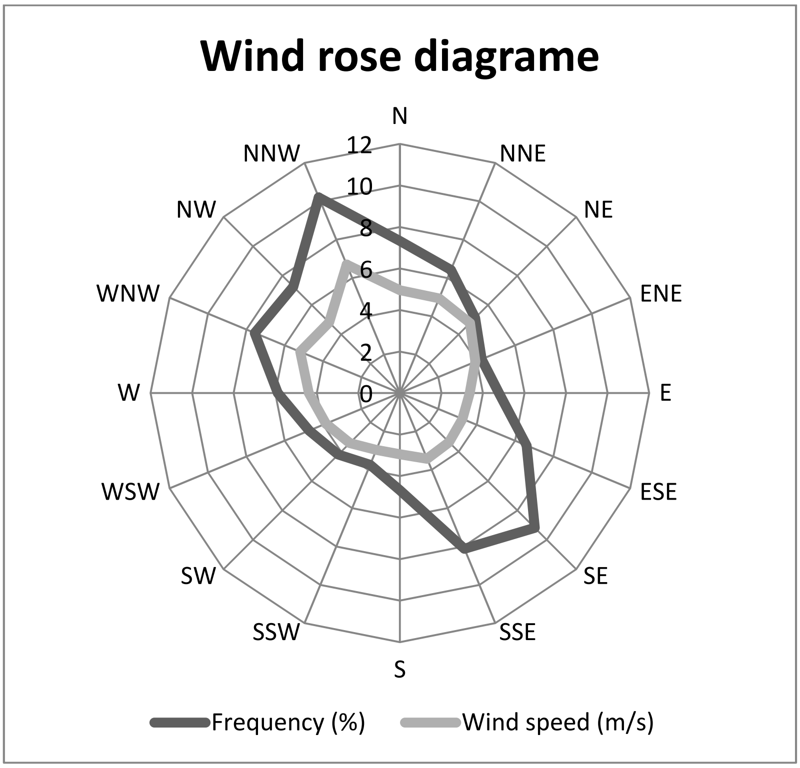
Map 1 - Average wind speed in the province of Castellón

Moreover, IDAE also allows the calculus of the wind rose diagram selecting one point in the map. The database gives information about the average frequency and speed in every direction:

Table 6 – Average wind frequency and speed in every direction

Direction	Frequency (%)	Speed (m/s)	Power (%)	Weibull C (m/s)	Weibull K
N	7.33	4.952	8.67	5.807	1.834
NNE	6.42	4.935	7.51	5.757	1.812
NE	5.12	4.775	6.13	5.545	1.646
ENE	4.26	3.939	3.31	4.681	1.569
E	4.77	3.37	1.43	3.883	2.147
ESE	6.6	3.258	1.57	3.742	2.485
SE	9.18	3.349	2.29	3.863	2.681
SSE	8.12	3.426	2.41	4.01	2.442
S	4.68	2.952	1.06	3.52	2.105
SSW	3.74	2.97	0.95	3.56	1.949
SW	4.19	3.409	1.81	4.06	1.742
WSW	4.73	3.853	3.14	4.545	1.64
W	5.88	4.383	5.72	5.186	1.654
WNW	7.56	5.198	10.95	6.035	1.718
NW	7.25	4.819	9.01	5.747	1.724
NNW	10.2	6.693	34.05	7.838	1.661

The wind rose diagram is the representation of the frequency and speed in this location:



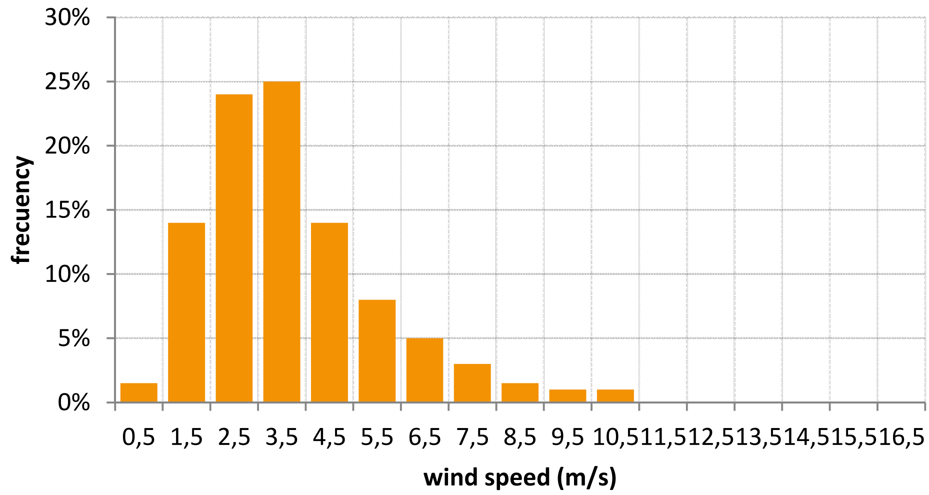
Graph 2 - Wind rose diagram

Moreover, another important tool is the database provided by National Centre of Renewable Energies (CENER, Spain). In this database can be extracted the histogram of frequency and speed of the wind. Knowing the frequency of the wind, the yearly hours of wind can be obtained as the number of wind hours per frequency.

Table 7 – Wind speed, frequency and windy hours/year

Speed (m/s)	Frequency	Hours/year
0.5	1.5%	128.77
1.5	14.0%	1201.87
2.5	24.0%	2060.35
3.5	25.0%	2146.20
4.5	14.0%	1201.87
5.5	8.0%	686.78
6.5	5.0%	429.24
7.5	3.0%	257.54
8.5	1.5%	128.77
9.5	1.0%	85.85
10.5	1.0%	85.85

11.5	0.0%	0.00
12.5	0.0%	0.00
13.5	0.0%	0.00



Graph 3 - Wind speed and frequency

- ***Selection of the wind turbine***

For this example it is not required a wind turbine with big nominal power. It is selected the Enair 30Pro of Enair Energy S.L. The main characteristics are the following:

Graph 4 – Characteristics of selected wind turbine

Table 8 - Characteristics of selected wind turbine

Enair 30PRO	
Number of blades	3
Material of blades	Glass fiber with resins and polyurethane core
Generator	250rpm nominal | Neodymium magnets
Power	3000W
Nominal power	1900W (IEC 61400-2)
Tension	24 / 48 / 220V
Wind class	CLASS I / IEC 61400-2 / NVN I - A
Turning sense	Schedule
Swept Area	11,34m²
Wind to Start	1,8m/s
Rated Speed	11m/s
Speed variable pitch regulation	12m/s
Supported Speed	60m/s
Efficient generation range	From 2 to 60m/s
Type	Windward horizontal windward axis rotor

Speed (m/s)	Cp
0.5	0
1.5	0.000
2.5	0.046
3.5	0.034
4.5	0.474
5.5	0.562
6.5	0.524
7.5	0.410
8.5	0.363
9.5	0.319
10.5	0.249
11.5	0.204
12.5	0.170
13.5	0.146
14.5	0.118
15.5	0.097
16.5	0.080

The values of the Coefficient Power (Cp) are obtained from the Power curve given by the manufacturer.

- ***Wind power generation***

The power supplied by the wind turbine depends on the Coefficient Power (Cp), the swept area (A = 11.34 m^2), and the wind speed (v), considering constant the air density (ρ=1.225 kg/m^3). The equation used is:

$$P\ (W) = \frac{1}{2} \cdot Cp \cdot \rho \cdot A \cdot v^3$$

Considering the data of the manufacturer, the power that can be produced by the wind turbine is:

Table 9 - Power produced by the wind turbine

Speed (m/s)	Cp	P (W)
0.5	0	0
1.5	0.000	0
2.5	0.046	5
3.5	0.034	10
4.5	0.474	300
5.5	0.562	650
6.5	0.524	1000
7.5	0.410	1200
8.5	0.363	1550
9.5	0.319	1900
10.5	0.249	2000
11.5	0.204	2150
12.5	0.170	2300
13.5	0.146	2500
14.5	0.118	2500
15.5	0.097	2500

The total energy produced is the multiplication of the power and the number of hours per year:

Table 10 - Total energy produced

Speed (m/s)	E (Wh/year)
0.5	0
1.5	0
2.5	10301.76
3.5	21462
4.5	360561.6
5.5	446409.6
6.5	429240
7.5	309052.8
8.5	199596.6
9.5	163111.2
10.5	171696
11.5	0
12.5	0
13.5	0
14.5	0
15.5	0
TOTAL (kWh/year)	**2111.43156**

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Therefore, the annual energy produced by one Enair P30 is 2111.43 kWh/year. This means that the daily energy production is:

$$Daily\ energy = 5.78\,\frac{kWh}{day}$$

We can see that the smallest model of the company Enair can give more energy than the necessary, so it is only required one wind turbine.

2.2. Construction guide

In this chapter the concrete construction steps are shown step-by-step in order to give a hand to the workshop leader and the students. At the end of each of the three mock-ups, photo illustration helps to learn more about the important points. At the very end (*5 Project plans*) of the present case study, layouts help the best reconstruction of the mock-up built by us. However, these have to be considered as guides, several variations of the mock-ups exist depending on personal fancy and possibilities. We encourage teachers and workshop leaders to experiment with other solutions.

2.2.1. Domestic Water Heater Mock-up

The workshop aims to let the participants experiencing the heating power of the Sun. As an output, a mock-up of homemade water heating system will be produced by groups of the participants.

- ***Required tools***

  - Drill
  - Scissor and cutter
  - Thermometer
  - Glue or silicone
  - Punch (to make holes)

- ***Required material***

Table 11. List of materials for Domestic Water Heater Mock-up

Required material	Suggested size	Pieces	Approximate price (for one unit)	Preferred characteristics	Where to get it from?
Box	30x50 cm	1	0	Wood	Greengrocer
Container (plastic water can)	5 liter	1	0	Plastic/non-corrosive metal	Household
Tube type 1 (thin)	Length: 10-12 m	Diameter: 4 mm	0.5 €	Black plastic	Cooperative or other garden shop
Tube type 2 (thick)	Length: 1.2 m	Diameter: 16 mm	0.5 (4 € /25 m)	Black plastic	Cooperative or other garden shop
Glassware or polymethyl methacrylate	30x50 cm	1	3 € (9 € / 1x 0.5mx 2.5 mm piece)	Transparent, few mm thick, rigid	Leroy Merlin
Foam rubber	50x30x2 cm 55x10x2 cm 37x10x2 cm	1 2 2	0	Bottom of box Side Side	Household, old wrapping of electro domestic

	55x5x2 cm 30x5x2 cm 14x14x2 cm	2 2 1		Top Top Top of the container	machines for example
Multilayer insulation (13 layers)	67x15 cm 22x15 cm	1 1	11,15 €/m^2	Fitting to the size of container	Construction store, Arelux for example
Small joints (between tube type 1 and 2)	4 mm	2x22=44	1.8 € (0.039 € /piece)		Cooperative or other garden shop
Big joints (between tube type 2 and 2)	16x16 mm	4	0.1 € (/piece)		Cooperative or other garden shop
Cable gland	See link	2	2.9 € (/piece)	3/4	Cooperative or other garden shop
Thread connection	See link	2	0.2 € (/piece)		Cooperative or other garden shop
Cover for the tubes type 2	Diameter: 16 mm	2	0.06 € (/piece)		Cooperative or other garden shop
Aluminum foil	50x70 cm	1	0	Fitting to the box from inside	Household

The model is built from the following materials or was bought in the following stores (see addresses or links among *1.5 References*)

- Cooperative Agricol San Vicent [3]
- Leroy Merlin [4]
- Multilayer insulation [5]

- ***Construction step by step***

There are going to be 3 main steps:

- Prepare the box
  - Adjust the box if needed. In our example the box was too much high compared to the needs, thus we cut it to the height of 10 cm. We used a simple, (standard 50x30 cm), fruit carrier wooden box (Figure 1)
  - Drill or cut the box on the sides: once where the tube enters and second where the hot water tube exit. In some cases you might need space for the taps at the end of the thick tubes; in this case you may drill two additional holes. (Figure 2)
  - Cut the foam rubber to the size of the box. It is possible to cover the box from 5 sides (bottom and the 4 vertical side walls), that would ensure better isolation for

the system. Put the foam rubber inside the box, glue it if needed. Make sure you let room for the leaving tubes (Figure 3).

- Cover the box inside with aluminium paper, the sides too.
- When the tubes will be inside the box, we will have to cover the box with plastic glassware or polymethyl methacrylate to ensure the glasshouse effect inside the box. (Figure 7)
- In our example the bottom of the isolation is inside the box, and the walls are covered from outside of the box. To ensure the best isolation inside the box, after gluing the glassware on the top, we covered it again from the top as a "frame". (Figures 8-9-10-11)

o Prepare the tubes

- Cut the tubes. The tube type 1 is a thin, flexible, possibly black plastic tube. The tube type 2 is a thicker, more rigid, possibly black plastic tube. Sizes always depend on the size of the box. Adjust the length of the tubes, if you cannot find the same size of box.
- Place the two (30 cm long) thick plastic tube parallel on the table, approximately 50 cm apart. Pin the thick tube with the small joints in one line, equal distance apart (1-2 cm) (Figure 5). The more joints we can pin, the more efficient will be our thermosiphon. In the example we used 22 joints, you are free to do as much as you can. Repeat the same with the other thick tube. Attach the thin tubes with the small joints, one by one by creating the connection between the two thick tubes.
- Close the thick tubes with the cover. In our example on the top on left hand side and on the bottom on the right hand side.

o Prepare the container

- Cut a 5-8 l plastic water can's top. The best is looking for a bottle that is made of more rigid plastic and has rectangular shape and the sides are flat and smooth.
- Drill the container and set the cable gland and thread connection in. Screw it tightly. The best repartition is that if you make a hole on one side, close to the top of the container (here is going to enter the warm water) and you drill a hole on the front side, but close to the bottom of the container (here is going to run out the cool water. Be careful at the top hole: the water level has to cover the hole and the tap should fit to the top of container. The suggestion is to drill the hole approx. 5 cm distance from the top.
- Cover the container the closest possible from the bottom and the four sides. If you cannot ensure it with foam rubber, use multilayer insulation. Let the holes freely as the tubes will be connected here. (Figures 4)
- Cut the tap out of foam rubber fitting to the size of container

o Setting the system up

- Put the combined thin and thick tubes into the box (on the aluminium foil) (Figure 6)
- Make the thick tubes exit on the holes you prepared previously on the box
- Connect with the big joints to the rest of thick tubes and finally

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- Connect it to the container (Figure 11)
  Be careful: The box is going to have an inclination, therefore the upper part will collect the warmer water and the cooler water will always be on the bottom part of the system. Therefore the exit of warm water will be on the upper part of the box and will bring the water to the upper part of the container. The Lower part of the container will be connected with the lower part of the box (Figure 13).
- Cover the box with plastic glassware (Figure 7).
- Put the last parts of the insulation as an outer "frame" by closing the possible leakage between the outside foam and the plastic glassware (Figures 8-9-10).
- Put the system to its place, favourably into full Sun in the school garden. Make sure, the container's bottom is at higher level than the (warm) thick tube
- Fill up the system with water. Make sure all the air exit the system, otherwise it is not going to work (properly). Measure the temperature in the container and outside.
- Cover the container, but be sure you can open it later to measure the elevation of the water temperature.
- Adjust the inclination to the direction of the Sun on an hourly basis (Figures 14).

- ***Illustration for construction***

Figure 1

Figure 2

Figure 3

Figures 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figures 14

2.2.2. Photovoltaic Energy in Domestic Lighting

The workshop is aiming to experience the solar energy and to learn how we produce electricity with the help of photovoltaic panels. As an output, a mock-up of a house equipped with photovoltaic panels producing electricity will be built; the electricity will be used for lightning and elevation.

- ***Required tools***

  - Drill
  - Drill bit (diameter: 6 mm and 8 mm)
  - Cutting pliers
  - Wrench
  - Saw
  - Soldering iron
  - Tin
  - Silicone (or wood-aluminium glue)

Optional for testing:

  - Multimeter to measure tension

- ***Required material***

Table 12. List of required material for Photovoltaic Energy in Domestic Lighting

Required material	Suggested size	Pieces	Approximate price (for one unit)	Preferred characteristics	Where to get it from?
PV cells	4x4 cm	4	9 € (the pack of 4 cells)	110 mW, 1.5 V75 mA	Amazon (see details below)
Plywood	30x21 cm 30x16 cm 30x9 cm 16x13x9 cm	1 1 1 2	1.6 € (250 x 122 x 0,5 cm / 24 €)	0.5 cm thick plywood	Household, DIY shop or Leroy Merlin
Screws	8 mm	8	0.9 € (1.8 €/ 16 pieces)	Length: 6.5 cm	Household or DIY shop
Nut	8 mm	14	0.5 €	Fitting to the screws	Household or DIY shop
LED light	3 Ampere and 6 Volt	4	1.21 € (/ piece)	White, luminous	DIY shop or electric store
Switch	1 cm	4	1.45 € (/piece)	On-off switch	DIY shop or

(type 1)					electric store
Switch (type 2)	1 cm	1	2.4 € (/piece)	3 stages switch	DIY shop or electric store
Electronic resistance	2200 Ω	4	0.1 € (/piece)		DIY shop or electric store
Cable	2 meters	1	0.3 €	Diameter : 0.25 mm	DIY shop or electric store
Insulating tape	40 cm	1	0 (0.65 € / roll)		Household or DIY shop
Motor	1.3 Ampere and 6 Volt, speed 30 rpm	1	12.2 €	Diameter : 12 mm	Amazon or electric store
Threaded rod	20-30 cm	1	1.8 € (3.6 / 2 pieces)	Diameter: 6 mm	Household or DIY shop
Clamp	Diameter: 12 mm	1	0.16 e / piece (13.32 € / 100 pieces)	Connection: 6 mm	Household or DIY shop
Small joint	4 mm	1	0 (0.039 € /piece)	It can be the same that used for the water heater mock-up	Cooperative or other garden shop

The model is built from the following materials or was bought in the following stores (see addresses or links among references)

- Electric store [6]
- Amazon – pv cells [7]
- Amazon – motor [8]
- Plywood [9]
- Clamp [10]
- Joint [3]

- ***Construction step-by-step***

    - Preparation of wooden material (LEDs and elevator)

- Prepare the guiding layouts from the *5 Project plans* (Figure 15)
- Prepare the next point on this present chapter where you may find the pictures that will help you (*2.2.2.4 Illustration for construction*)
- Draw the following draft of elements on the plywood (see Table 13.):

Table 13. - Preparation of wooden material for Photovoltaic mock-up

Rectangles of the following sizes	30x21 cm (this is going to be the “basement”) 30x16 cm (this is going to be the “roof”) 30x9 cm (this is going to be the “front”)
2 triangles of	16x13x9 cm (these are going to be the two covers from the sides in order to make darkness)

- Cut the above mentioned forms out of plywood with a saw and cover one side by aluminium paper (Figure 15)
- Drill holes on the plywood as indicated in *5 Project plans*
    - 6 holes of 8 mm diameter
    - 6 holes of 6 mm diameter for the four on-off switches, the 3 stage switch and the threaded rod (for the elevator)
    - 8 holes of 4 mm diameter for the four LEDs
- Prepare the screws and the nuts
- In the four corners screw the 4 “legs” of the “basement”. The length of the “legs” can be different, the main aim is to lift the basement in order to be able to do the manipulations with the electric stuff (the bottom part of our switches require minimum 2.5 cm and the cables also need room) (Figures 16-17)
- Turn the nut on the four screws to make it stable
- Continue with the electric part and later come back to finish the “house” (set up the “roof” and the side covering triangles).

Preparation of electrical part (LEDs and elevator)

- Set in the 4 switches and the 3 stage switch in their corresponding holes (Figures 18).
- Put the 4 white LED diodes in their holes, folding the long pin towards the led on its side and the short pin towards the switches (Figures 19).
- Weld with a 30W soldering iron a resistance of 2K2 Ω at the end of each of the switches and the other end of the resistance weld to the short pin of each led diode (Figures 19-20).
- Weld the neighbouring long pins of the LED diodes between them. At the last pin weld a cable that will go until one of the intermediate pins of the 3 stage switch. You will leave also welded a piece of cable of 40 centimetres to connect to the positive pole of the photovoltaic cells.
- Weld the other intermediate pin of the 3 stage switch with a cable and drive further the cable and weld it to the free pins of the on-off switches. Leave minimum 30 cm of cable for connect later with the negative poles of PV cells.
- Look at the 6 pins of the 3 stage switch. You have already connected the two middle pins. Now connect the rest as per the followings: right-up corner pin with

the left down corner. And with another short cable the left-up pin with the right-down pin (Figure 22).

- Get a new pair of cable and weld them to the two down pins and let the rest 55 cm to be connected later to the motor (Figure 22).
- Now continue with the tinkering part, build the “roof” and the sides.
- Insert the two 8 mm screws into the two holes that have left in the middle of your basement. These two screws will be the two supporting pillars, so make sure you pin it through from the opposite direction than the four other “legs”. Strengthen it with two nuts. (Figures 23).

Decoration and setting the system up

- Place the “roof” on; make sure, the longer side of the “roof” matches with the longer side of the basement and the other side lays on the two “pillars”. You have two options, glue the wooden parts together with silicon, or you drill the two together (while you keep the angle between them around 30-40°). In our example, as you can see on the photos we did like this, however – as they are not regular circles, but rather ellipses on the reason of the angle between the two wooden parts, they do not appear on the mechanical draws *(5 Project plans).*
- Glue the triangles to the sides and the front piece leaving the window at the bottom (Figures 23).
- Glue with double-sided tape the solar panels on the “roof”, leaving the cable connections at the top
- Screw the 40 cm long rod with a nut and fix it underneath with another nut (Figures 23).
- At the top of the rod, screw the 12 mm clamp and in the clamp and place the motor inside (Figures 27).
- Strengthen the clamp together with the motor with two screws
- Weld the 2 cables that we had left prepared before to the 2 outputs of the motor (Figure 22).
- Connect the positive pole of one cell to the negative pole of the next leaving at the ends of the 4 cells only one positive pole that we will weld to the cable that comes from the LED diodes and the negative pole that we will weld to the cable that comes from the switches (Figures 24).
- Push the small joint into the pin of the motor. Knot the thread on with the piece at the end
- Try out the switches one-by-one. Observe how many of them you can switch on (it depends on the light arriving on the PV cells) (Figures 25-26).
- Try out the 3 stage switch. If it works well, in upper stage it turns to one direction, after leaving pushing it, it jumps back to the middle stage and in lower stage the motor turns the wings to the other direction (Figures 27-28).

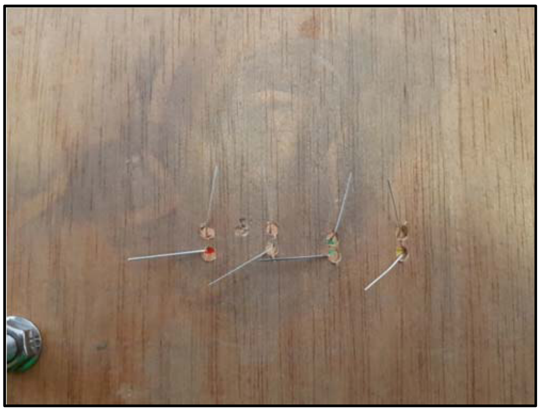
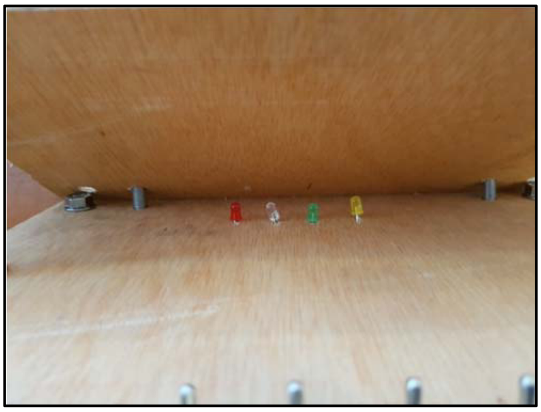
- ***Illustration for construction***

Figure 15

Figure 16


Figures 17


Figures 18

Figures 19

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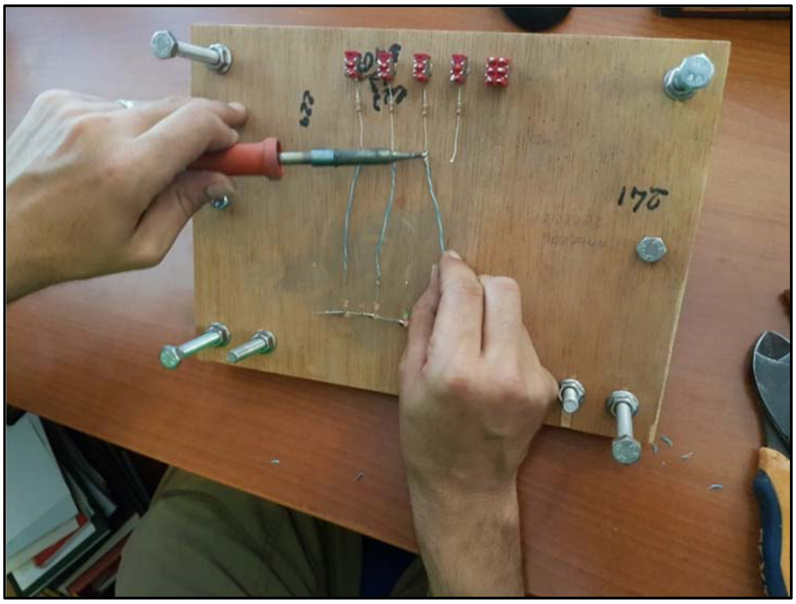
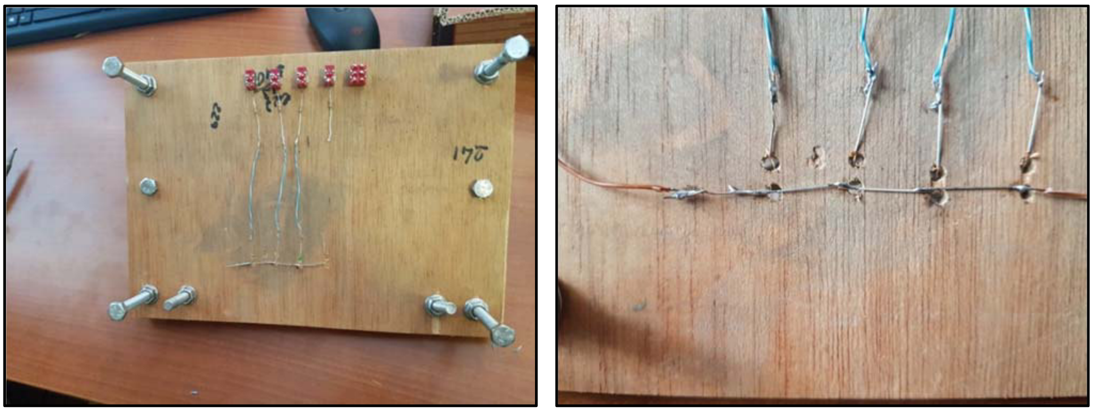


Figure 20



Figures 21

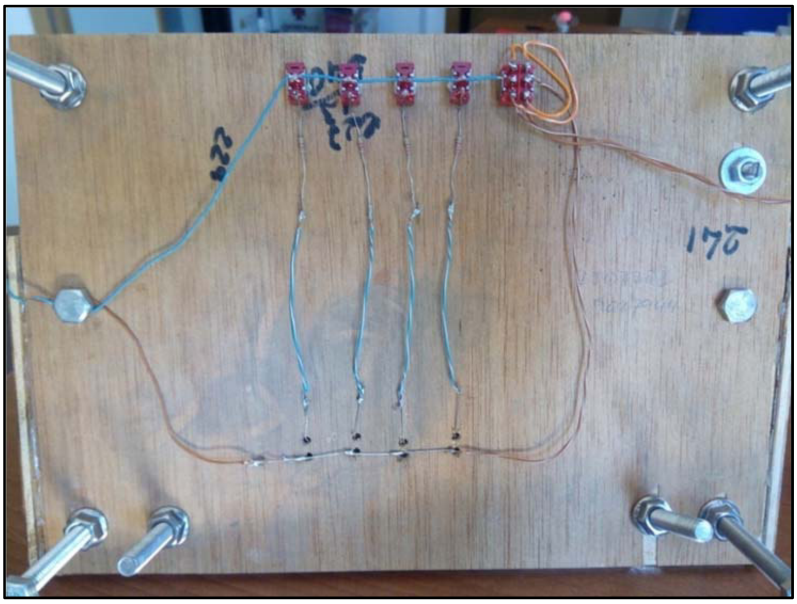


Figure 22

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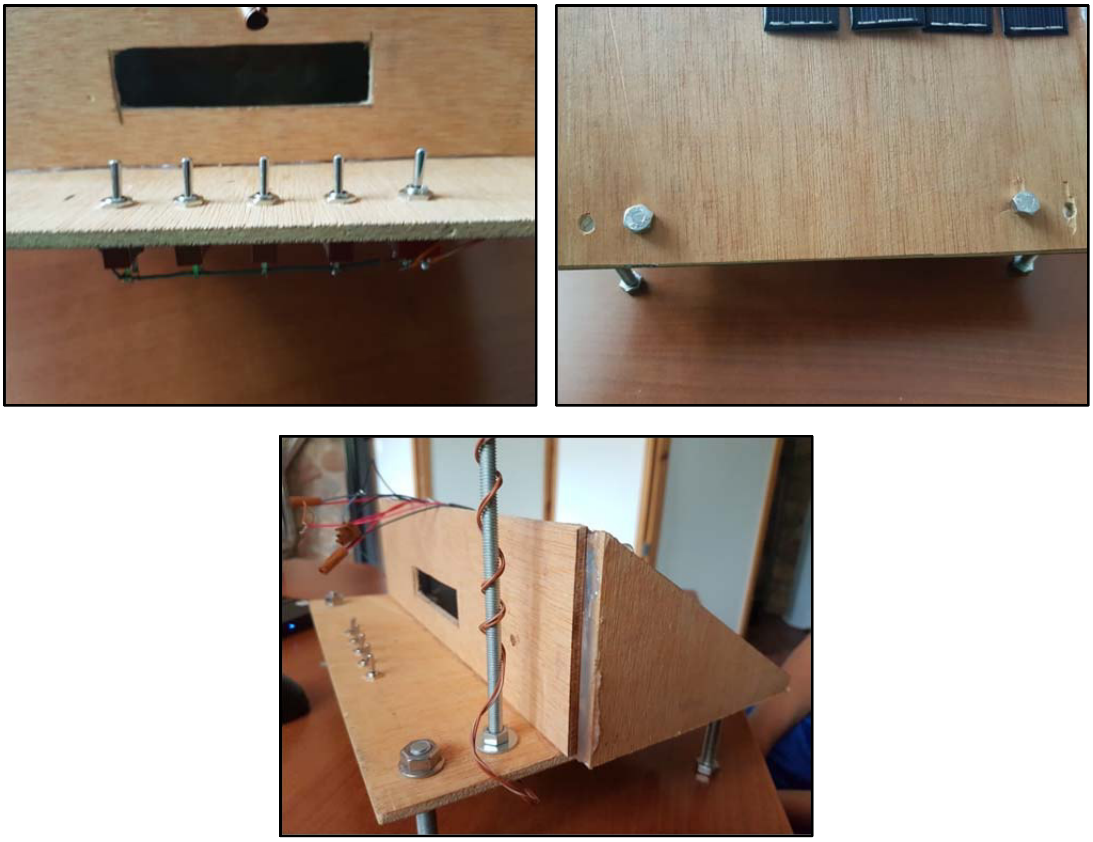
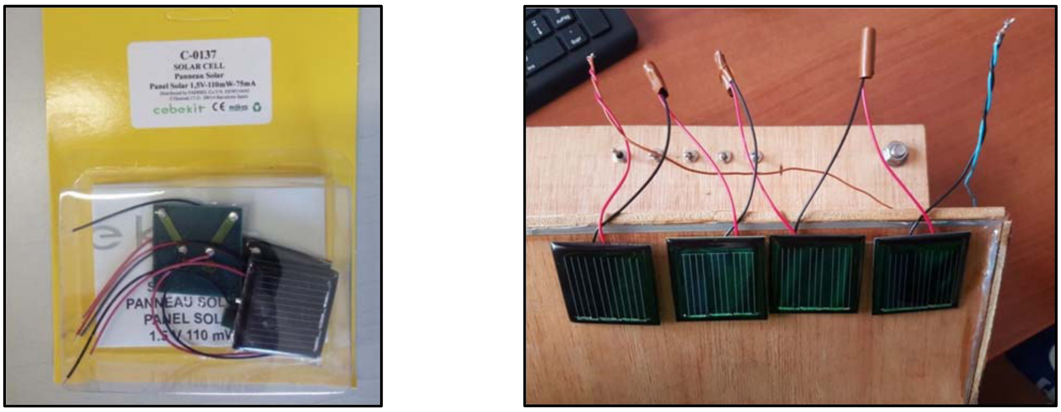


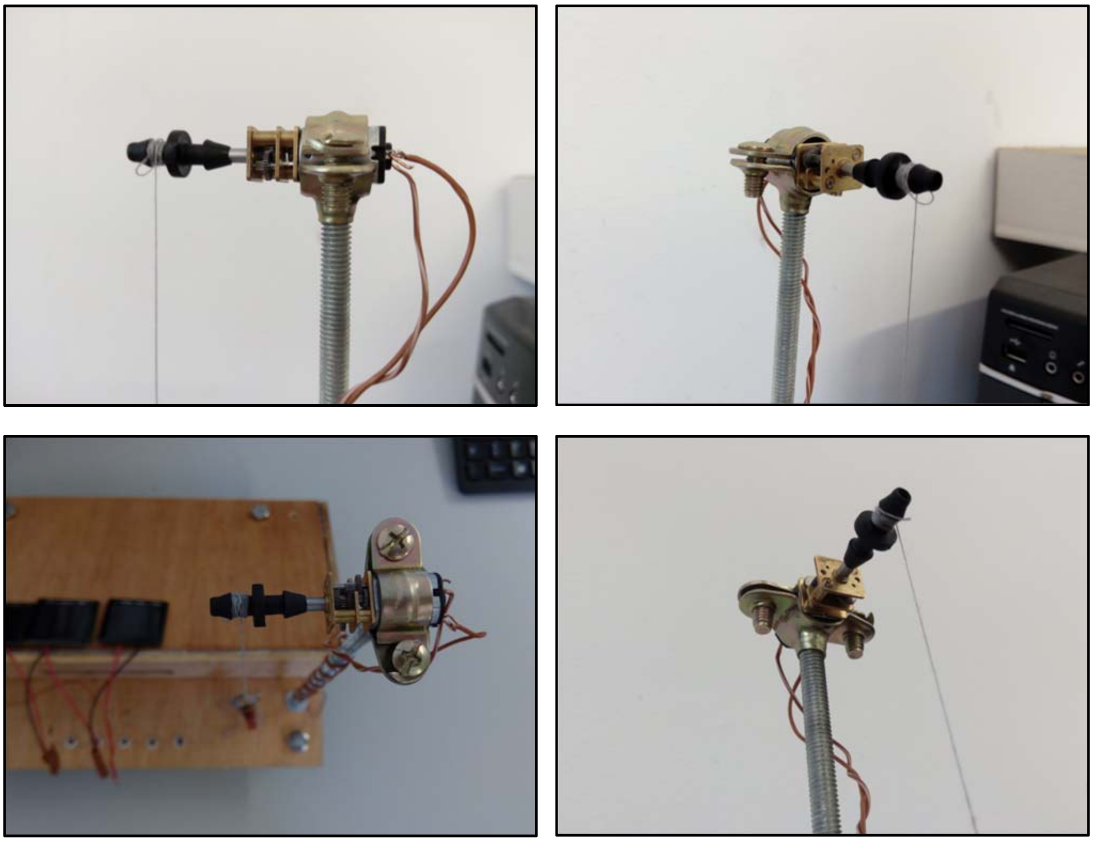
Figures 23



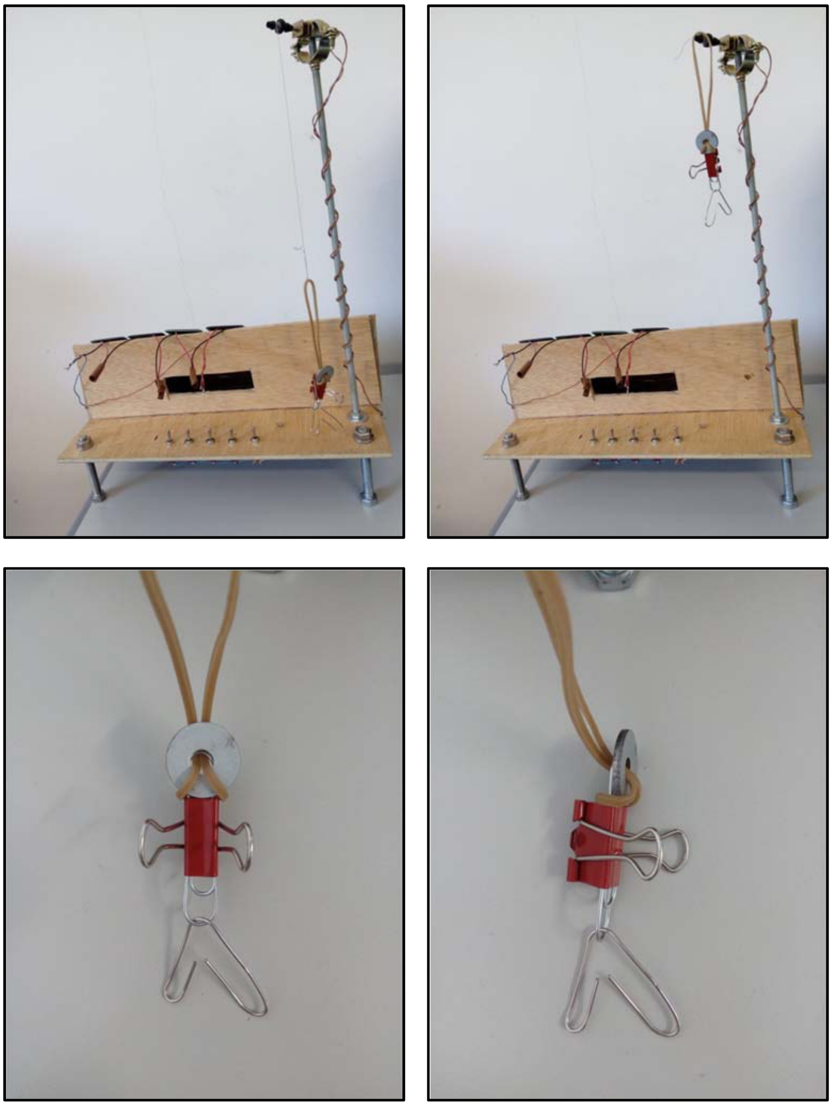
Figures 24

Figure 25

Figure 26



Figures 27



Figures 28

2.2.3. Aeroelevator

The workshop's goal is to experience the wind energy. As an output, a mock-up of a windmill (Figures 35) is going to be built. The turning axis is going to roll up the small piece to the "lookout".

- ***Required tools***

- Cutter
- Scissor
- Drill

- ***Required material***

Table 14. Required material for Aeroelevator

Required material	Suggested size	Pieces	Approximate price (for one unit)	Preferred characteristics	Where to get it from?
Plastic bottles	1.5 l 0.2 or 0.5 l	1 1	0 0		Household
Wooden sticks	minimum 5 cm longer than the height of the small bottle	1 piece	0 (1.2 € / package)	Or BBQ sticks	Household or supermarket
Paper		19x19 cm	0 (100 sheets / 2.7 €)	Decor or colored paper	Household or paper shop
Clip		1 piece	0 (0.25 € / box)		Household or paper shop
Stones		1 handful	0		Garden or park
Thread	30-40 cm	1	0 (1.5 € / spool of thread)		Household or haberdashery
Piece of LEGO	The lighter, the better is	1	0	Can be any kind of piece that is light	Household
Sellotape	3 cm	1	0 (0.65 € / roll)		Household or paper shop
Superglue		1	5 drops		Household or paper shop

- ***Construction step-by-step***

- Prepare all the materials and the tools listed above (Figure 29)
- Cut the neck of the big bottle, it is going to be the foundation of the windmill

- Cut a sort of holder out of the top so that it can hold the smaller plastic bottle when it is laid horizontally by cutting off two "sides" and leaving two "sides" (Figure 30-31).
- Fill the stones into the bottom of the bottle, this will guarantee the stability of the tower (Figure 31).
- Drill two holes into the small bottle: once into the bottom, second into the bottle tap a slightly larger diameter than the wooden stick. It is important to let the stick turning, the small bottle stands still (Figure 32).
- Ply the wings of a classical windmill, pin it through with the stick
- Glue the wings together and to the stick the closest possible to the end of the stick (Figure 33)
- Pin the stick through the tap of the bottle and the small bottle
- Open the outer stem of the clip
- Fix the clip to the end of the stick with sellotape
- Stitch the thread through the clip and knot it tight
- Knot the piece to the end of the thread (Figure 34)
- Try it out: start to move the wings by hand, the thread should be rolled up on the clip and the piece should be lifted up (Figures 35)
- If it works fine, try it by blowing the wings and if there is windy enough outside, bring the windmill model outside and try how the wind energy is turning into mechanical energy

- ***Illustration for construction***

Figure 29

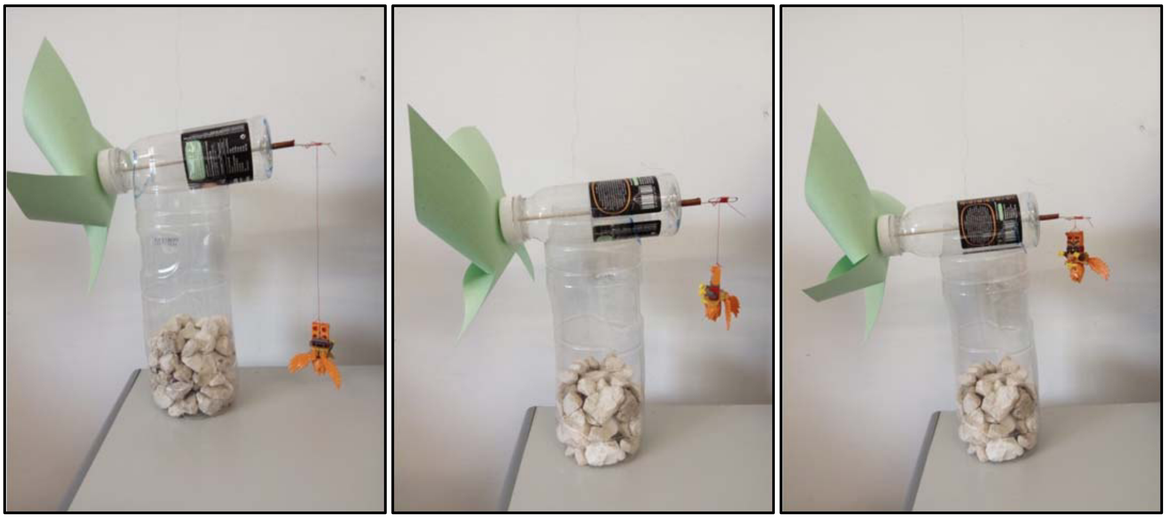
Figure 30

Figure 31

Figure 32

Figure 33

Figure 34



Figures 35

Budget and economic analysis

3. Economical aspects of the project.

In this chapter a hypothetical business case is presented. The business is about renewable energy education in rural schools. The economical study contains the financial calculation, viability of such classes and applicable for an individual entrepreneur or also for an existing business that would like to enlarge its scope.

3.0.Budget of the workshops

The concrete case starts with three topics (three different workshops) for schools in Castellón province, Spain. At the end of the present economical study three packages will be offered that vary in the cost, target age and all of them are in the topic of renewable energies.

The following table summarizes the costs of each workshop.

Table 15 – Price by workshop

EUR	Domestic Water Heater	Photovoltaic Energy in Domestic Lighting	Aeroelevator
personal	150	150	150
material	63	182	0*
travelling	46	46	46
indirect costs (20%)	52	76	39
benefit (15%)	39	57	29
TOTAL	**350**	**511**	**264**

In the three columns are represented the three topics of the different workshops.

The costs mean the followings one-by-one:

Personal: is the cost of one person who is preferably environmental educator, teacher or animator. The cost covers the class (preparation, travelling, the class itself and after work) and the administrative work (organizing the classes with schools). This person is self-employed or in cases of a functioning enterprise the person in charge of this task.

Material: Consists all the material that is listed in the *2.2 Construction guide*. The prices in the Construction guide are calculated to build one mock-up, therefore this is the cost of one group. Here, the quantities are calculated for a class that supposedly consists of 30 students that are brought under five groups (six students in one group). It has to be mentioned, that however, the most economical materials were chosen, for schools with limited budget there is a possibility to decrease the price by forming bigger groups, thus needing less material. It is described in details in the next subchapter.

*The material cost of the aeroelevator is indicated as 0 EUR because it can be built from waste material and materials that normally can be found in a household or in an office. In case, the business is started from the very zero, with 6.3 EUR "investment" numerous workshops can be hold. For its simplicity it can be a popular way to start the renewable energy class series in the rural areas of Castellón.

Travelling: an average is calculated. It is supposed, that the business is located in Castellón city. The average distance (return trip) is 185 km to the following locations (Morella, Vistabella, Montanejos and Losilla). They were chosen as possible destinations of the workshops. The average travelling time is 3 hours. The trip is organised by car that let the teacher carry the materials needed for the workshops. The average consumption of the car is 0.25 EUR/km, that includes fuel and maintenance costs.

The above listed three cost types are the **direct costs**.

The **indirect costs** are the 20% of it that includes the marketing, phone and office costs (like stationery, electricity bills, etc.) and unexpected costs.

The **benefit** of the business is defined in 15% of the direct cost that is going to be invested back to the business (see *4.4 Future plans*).

3.1.Price variations

In this subchapter a few opportunities are listed depending on the quantity of used material. However the suggested size of the group is 3-6 students, educators are free to establish bigger groups, thus making more economical the classes. It is considered as a good solution for schools with limited budget. For them, the table below shows the prices depending on the number of groups established in the class.

Table 16 – Price variations depending on number of groups (consequently group size)

EUR	Domestic Water Heater	Photovoltaic Energy in Domestic Lighting	Aeroelevator
5 groups	349	511	265
4 groups	332	461	265
3 groups	316	412	265
2 groups	299	363	265
1 group	282	314	265

3.2.Payback, IRR and NPV

These terms are hard to be interpreted in the context of the present case study, based on many reasons, just to mention one, is that there aren't important investments appearing in the business case. The most important things that are needed are the knowledge and experience in the field of environment, climate change and especially renewable energies, moreover pedagogical background, experience in education and with students. To start the business, the main investment is time and energy, supposedly that the person lives in an average household, optionally has his or her office or works from home.

Assuming the above mentioned conditions, an approximate calculation is attached below, based on hypothetical numbers.

3.3.Time management

Regarding how much personal commitment is needed, one day per class can be calculated, as on average 3 hours are spent on travelling, 2 hours on preparation and the workshops last 2 hours as well on average. This all together takes one working day.

Organising the workshops one-by-one, communicating with schools and administration would use up half a day per each session on average (by starting the business more, later evidently less).

Supposing that there are 10 workshops a month, and calculating with 4 weeks monthly, it results 10 complete working days per month and ten times half days of administration and organization, that sums 15 days of work a month in total (out of 20 more or less) that can be considered 75% intensity in time.

It has to be mentioned, that if we calculate only with the 9 months school period, the rest 2 months of the year are considered as holidays over the regular (20 days=) 1 month holidays. Therefore there are 9 months out of 11 months which results 82% intensity in time. However these two months extra can be considered either an opportunity to develop further the business and investigate into new materials and methods, or hold summer camps, summer activities with the same materials, it stays optional.

Concluding all the above, 75% monthly intensity and 82% “yearly” intensity results <u>62% working intensity in time at the end of the year.</u>

The business plan is sustainable in time, as in the next school year, the same workshops can be organised for the new classes in the same age range.

3.4.Salary calculations:

In internet databases 83 secondary schools can be found in the province of Castellón [11] and they have more classes in the school.

Putatively, not all of them will buy the most expensive package, but might do fewer groups in the class. The following table shows the calculations for the different packages and the possible number of clients. Due to the characteristics of the workshops, provisionally, the 50% will choose the Aeroelevator, 30% the Water heater system and 20% the Photovoltaic mock-up. The following table shows the calculated incomes depending on the number of groups.

Table 17 - Yearly income per workshop and number of groups

	Domestic Water Heater			Photovoltaic Energy in Domestic Lighting			Aeroelevator		
EUR	Price of ws.	Number of ws.	Price	Price of ws.	Number of ws.	Price	Price of ws.	Number of ws.	Price
5 groups	349	1	349	511	1	511	265	9	2.384
4 groups	332	2	665	461	2	923	265	9	2.384
3 groups	316	6	1.893	412	4	1.649	265	9	2.384
2 groups	299	10	2.987	363	6	2.179	265	9	2.384
1 group	282	8	2.255	314	5	1.570	265	9	2.384
TOTAL		**27**	**8.149**		**18**	**6.833**		**45**	**11.922**
							Yearly	**90**	**26.904**

In the next calculations you see summarized the incomes and expenses as per financial category.

Yearly costs	
personal	13.500
travelling	4.163
material	2.266
indirect costs	3.986
benefit	2.989
TOTAL (€)	**26.904**

3.5.Conclusions:

This business case is viable and profitable at least in two cases.

Once – as it has been mentioned already before – for an already existing company can be a new line of interest, with the dedication of one person as staff with 62% yearly intensity in time. This person would receive 1500 € salary during 9 months.

Second, for an individual entrepreneur, it is an opportunity for someone that cannot dedicate his or herself for a fulltime job – mothers with young children, university students or young people having temporary jobs for summer holidays (as occurs for example in tourism sector).

3.6.Future plans

However the business is feasible with these three workshops, depending on the motivation and vocation of the educator, also on the demand from customer side, more workshops can be developed and organised in different environmental topics (water, waste, biomass, etc.). This, for example can be financed from the benefit line of incomes.

There is a possibility to enlarge the area of Castellon to the provinces of Valencia, Teruel y Tarragona. In this case we might consider longer trips and more budget for travels.

In case of growing workload, demand and income, it is an option to enlarge the staff and establish a private school that provides educational services for schools, private persons or municipalities or even other businesses. Later the school might offer services in other topics, like languages, after-school activities, summer camps or excursions.

Project plans

4 . Project Plans

This chapter consists of the supporting documents to the *2.2 Construction guide*. In relation with *(2.2.2) Photovoltaic Energy in Domestic Lighting,* there are three construction schemes in order to understand better the necessary steps. Namely:

- General Layout of Photovoltaic Mock-up

That shows in details the whole "house" that is aimed to be built during the workshop.

- Basement layout of Photovoltaic Mock-up

That was designed especially to show with details where and how large holes are needed to be drilled on the basement.

- Electrical layout of Photovoltaic Mock-up

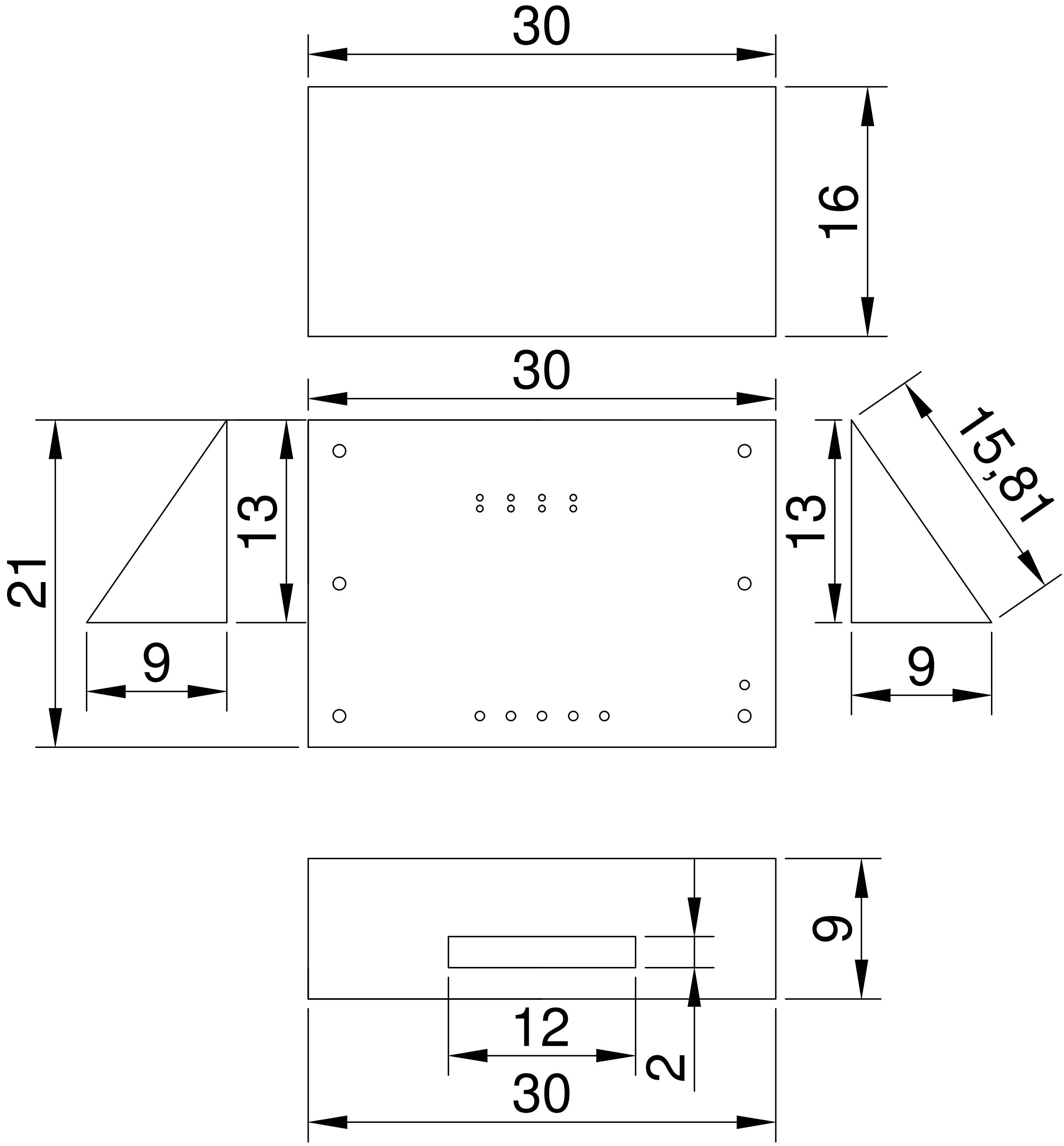
That serves to give guidance on the realization of the electric part of the mock-up.

- Solar cell technical information

That provides detailed technical description on the used solar cells.

- Motor technical information

That provides detailed technical description on the used motor.



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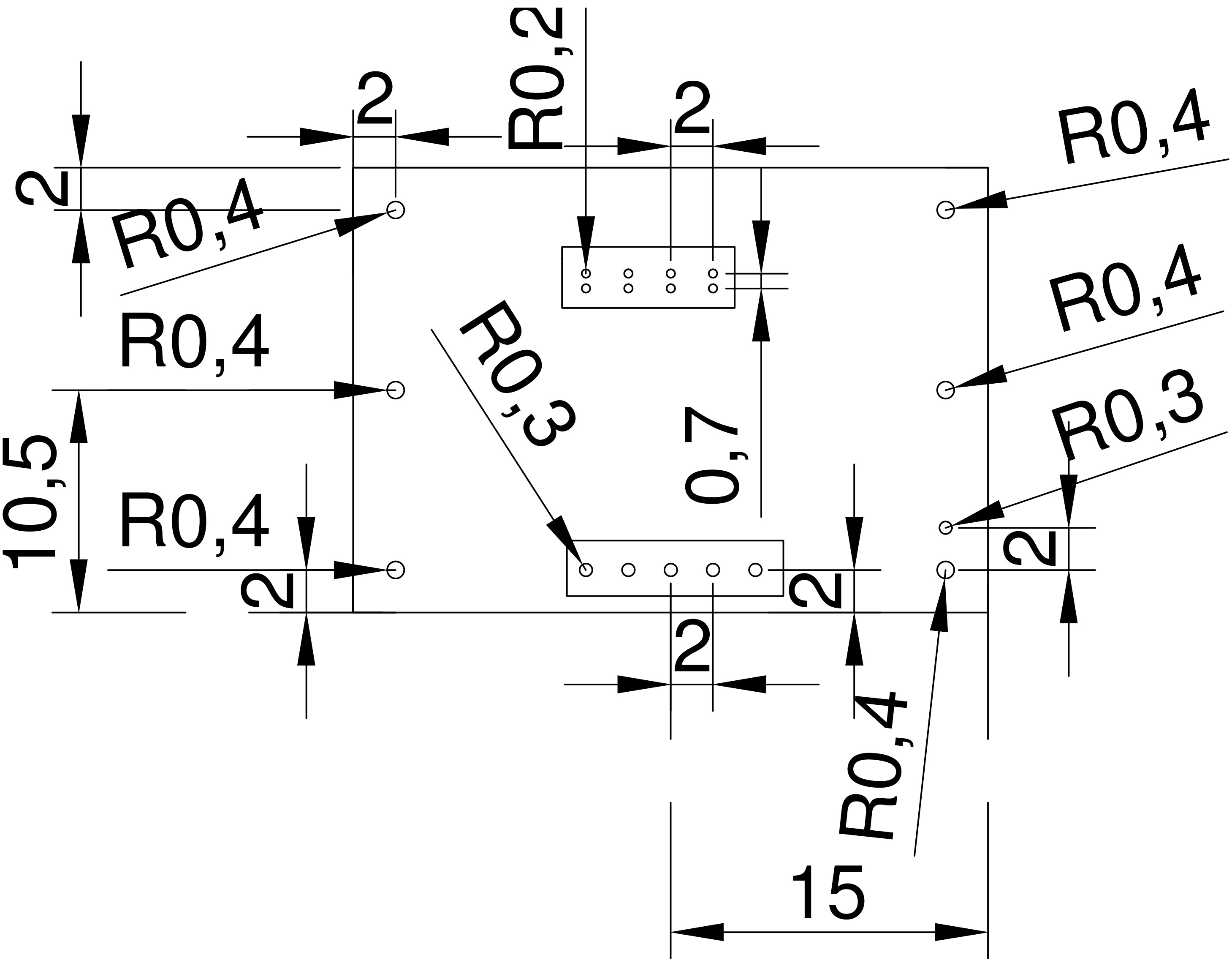

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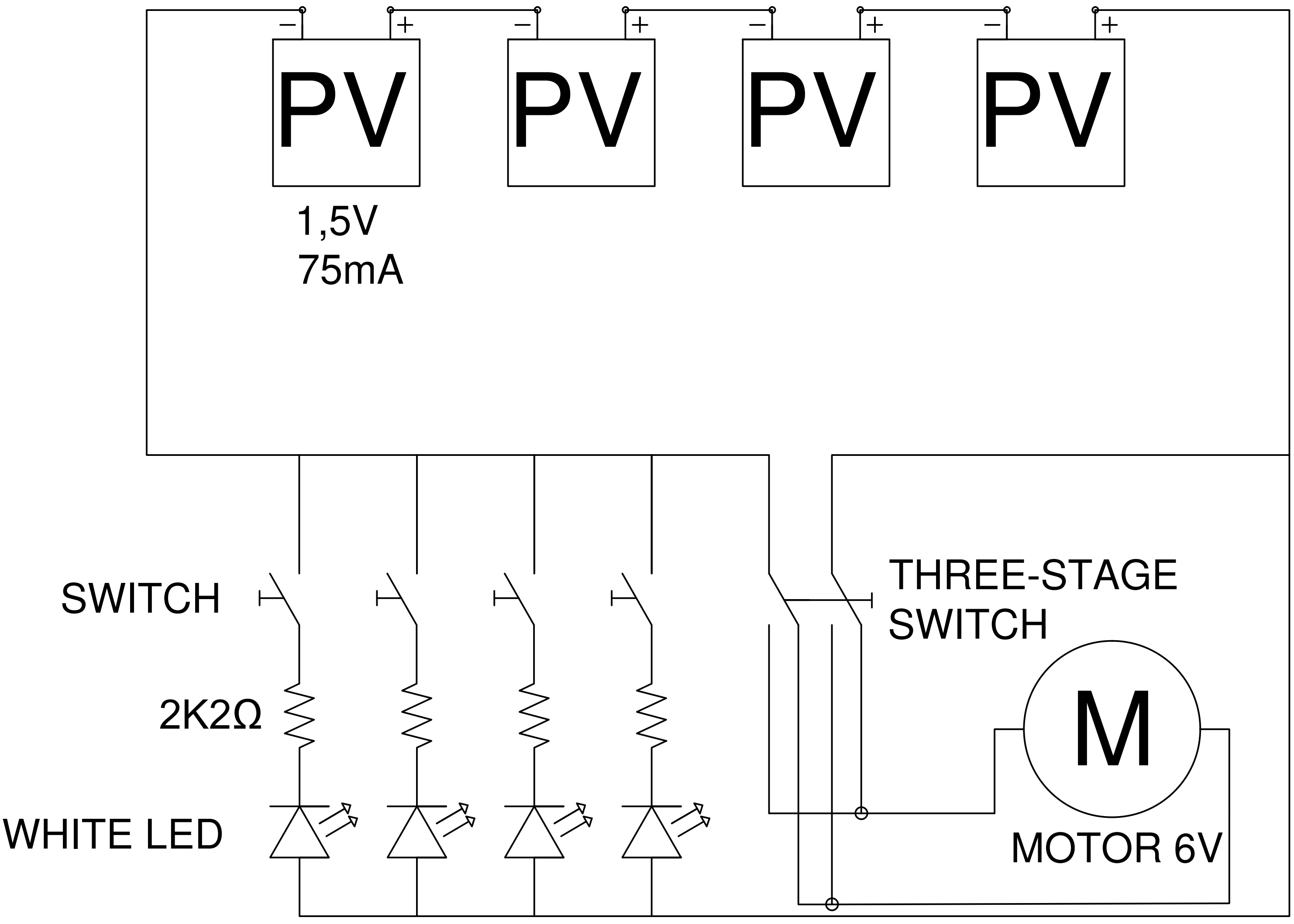
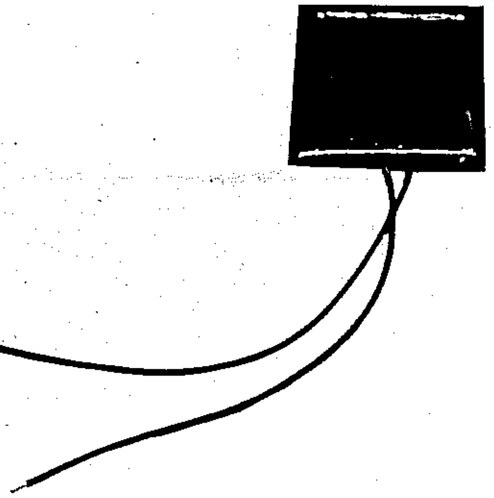

PV
PV
PV
PV
1,5V
75mA
SWITCH
2K2Ω
WHITE LED
THREE-STAGE
SWITCH
M
MOTOR 6V

SOLAR CELL
PANNEAU SOLAIRE
PANEL SOLAR
1.5 V 110 mW
C-0137



TECHNICAL CHARACTERISTICS

Power	110 mW
Voltage Voc	1,5 V. DC
Isc	75 mA.
Vm	1,0 V.
Im	56 mA.
Measures	40 x 40 mm
Connection	AWG26 13 cm.
Lot	4 units

Photovoltaic solar cells and high-performance miniaturized. They are ideal for classroom practices of technology, electricity, electronics, crafts, and robotics for any type of installation that requires a very small cell size and high performance. See our catalog the various special solar engine can be driven directly by these cells .

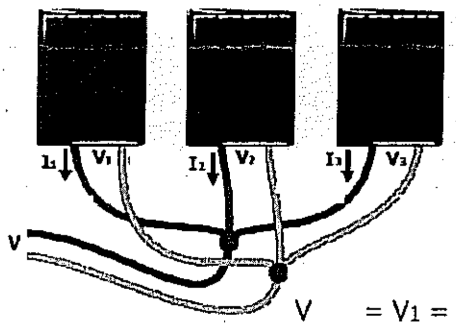
Mounting and installation. For cell fixation is recommended to use double sided tape on the back. Preferably a spongy base tape. The cell should stand we face the direct sunlight. Its performance depends on the light received. It can run on the inside, if the cell is illuminated with an incandescent lamp, preferably halogen. Not suitable for fluorescent lighting or compact fluorescent lamps .

Connection. Photovoltaic cells can be grouped into assemblies "series", "Parallel" and "mixed." When connecting two or more identical cells in series, the resulting voltage is the sum of all of them and the current intensity is the same for all. When connecting two or more identical cells in parallel, the voltage will be the same for all, with the resulting current intensity equal to the sum of all intensities. With serial, parallel or mixed is possible to obtain voltage and current we require. It is very important to respect the polarity shown in the diagrams .

Les panneaux solaires photovoltaïques de haute performance miniaturisés. Elles sont idéales pour les pratiques en classe de technologie, de l'électricité, l'électronique, de l'artisanat, la robotique et de montage pour tout type de cellule nécessaire par une très petite taille et haute performance. Voir nos spéciaux moteurs solaires en nôtre catalogue qui peuvent être entraîné directement par ces panneaux solaires.
Pour fixer le panneau recommandé d'utiliser un adhésif double face sur le dos. De préférence, une bande de base spongieux. Le panneau doit être placé adressée directement au soleil. Sa performance dépend de l'éclairement reçu. Vous pouvez travailler à l'intérieur, si le panneau les lumières une lampe à incandescence, halogènes de préférence. Ne convient pas pour l'éclairage fluorescent ou des lampes fluorescentes compactes.
Les panneaux photovoltaïques peuvent être regroupés en ensembles "de série", "parallèle" et "mixtes". Connexion de deux ou plusieurs panneaux, en nombre égal, la tension qui en résulte est la somme de tous et l'intensité du courant est la même pour tous. Connexion de deux ou plusieurs panneaux en parallèle égale, la tension sera la même pour tous, avec l'intensité de courant résultant égale à la somme de toutes les intensités. Avec série, parallèle ou mixte est possible d'obtenir la tension et le courant nous avons besoin. Il est très important de respecter la polarité indiquée dans les diagrammes .

Células solares fotovoltaicas miniaturizadas y de alto rendimiento. Son ideales para prácticas en el aula de tecnología, electricidad, electrónica, manualidades, robótica y para cualquier tipo de montaje que precise una célula de tamaño muy reducido y altas prestaciones.
Consulte en nuestro catálogo los diversos motores solares especiales que pueden ser accionados directamente por estas células.
Montaje e instalación. Para la fijación de la célula se recomienda usar cinta adhesiva de doble cara en el dorso.
Preferiblemente una cinta con base esponjosa.
La célula debe situarse encarada a los rayos solares directos. Su rendimiento depende de la iluminación recibida.

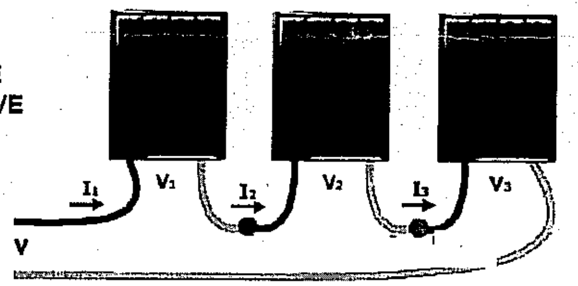
Puede funcionar en el interior, si se ilumina la célula con una lámpara de incandescencia, preferiblemente halógena. No es adecuada para iluminación de tubos fluorescentes o lámparas fluorescentes compactas.
Conexión. Las células fotovoltaicas pueden agruparse en montajes “serie”, “Paralelo” y “mixto”.
Al conectar dos o más células iguales en serie, la tensión resultante será la suma de todas ellas y la intensidad de la corriente será la misma para todas.
Al conectar dos o más células iguales en paralelo, la tensión será la misma para todas, siendo la intensidad de la corriente resultante igual a la suma de todas las intensidades.
Mediante conexiones serie, paralelo o mixtas es posible obtener las tensión y corriente que precisemos.
Es muy importante respectar la polaridad que se indica en los esquemas.



$V = V_1 = V_2 = V_3$

Parallel connection $I = I_1 + I_2 + I_3$

RED = POSITIVE
BLACK = NEGATIVE



$V = V_1 + V_2 + V_3$

Series connection $I = I_1 = I_2 = I_3$

Sourcingmap A12081300UX0999 - Motor micro DC

de Sourcingmap
4.5 de un m®ximo de 5 estrellas   2 opiniones de clientes

Precio: EUR 12,18
Elige envºos GRATIS m®s r®pidos con Amazon Prime o elige envºo GRATIS en 4-5 dºas en pedidos superiores a 29B
Precio final del producto
Vendido y enviado por Amazon. Se puede envolver para regalo.

¿ Nombre del producto: Motor Micro DC; Modelo nł: GB380-07285; Voltaje: DC 6V
¿ Corriente (sin carga): 1.3A; Velocidad (sin carga): 30RPM; Esfuerzo de torsiÆn: 2.5g.cm
¿ Tama¿o cuerpo: 12 x 15mm / Di®metro eje: 3mm/ Longitud total: 35mm
¿ Color principal: Plateado; Material: Metal
¿ Peso: 11g; Paquete: 1 x DC Micro Motor

InformaciÆn de producto

Detalles t¶cnicos

Identificador de producto del fabricante	a12081300ux0999
Peso del producto	9 g
Dimensiones del producto	3,5 x 1,2 x 1,5 cm
Nßmero de modelo del producto	a12081300ux0999
Nßmero de productos	1
Nßmero de piezas	1
Nßmero de empu¿aduras	1
Sistema de medida	Metric
Componentes incluidos	1 x DC Micro Motor
Incluye baterºas	No
Necesita baterºas	No
Peso	9.1 gramos

REPORT OF THE CASE STUDY ON RENEWABLE ENERGIES TO LOCAL DEVELOPMENT TRANSNATIONALLY IMPLEMENTED

Agricultural biomass production for bioenergy in integrated RE systems of small agricultural enterprises

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Case study tutor: Csaba Szűcs
Renewable energies tutor: Csaba Patkos - GEOLIN
Rural development tutor: Vicent Querol
English tutor: Csaba Szűcs
Professional supervisor: Sandor Nemethy/ Csaba Patkos
March-April 2017

Contents of the project

Memory of the project

1. Introduction

Humanity today is massively dependent on Energy. Imagine a day without any energy supply; the poor will be poorer and the rich would hit rock bottom in just one day. Humanity as we know it cannot produce or carry out its everyday activities without energy. The major source of energy that the population is highly dependent on is fossil fuels, mainly oil followed by natural gas and coal. Fossil fuels make modern life possible, they work to generate power transportation systems, electricity and steam, making the production of tens of thousands of commercial goods possible.

Fossil Fuels are easily transformed into energy at a low-cost which makes all countries contribute to the use of those fuels as their main source of energy. Although fossil fuels are somehow easily extracted in some regions around the globe and easily transformed into energy that fulfills our current energy supply needs, a lot of problematic questions arise; for how long are we going to benefit from these energy sources before them drying out?

Fossil Fuels are limited and non-renewable and soon will be depleted as the rate of energy demand will increase in the near future.

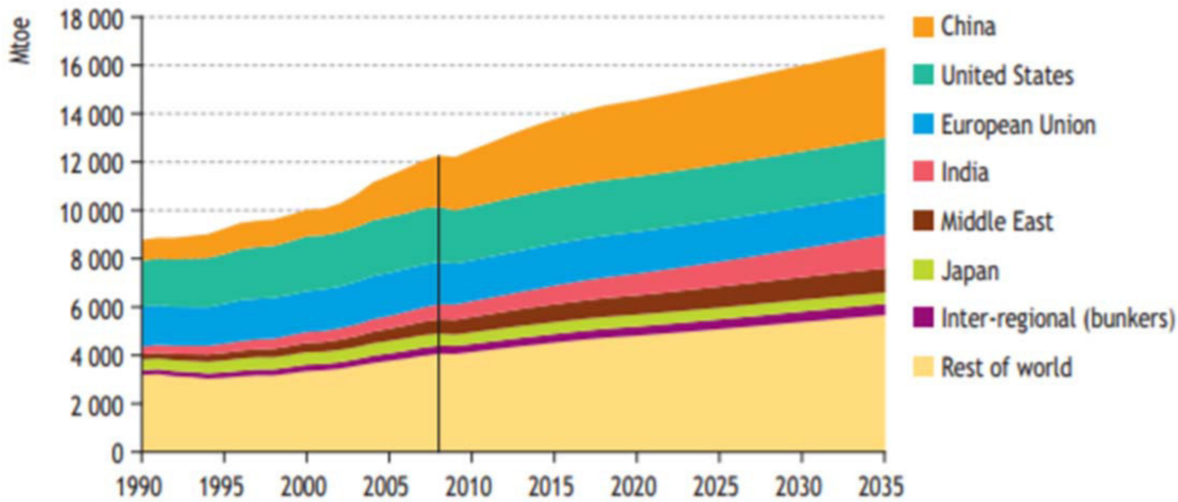

Figure 1. World Energy Demand [1]

(Source: IEA World Energy Outlook 2010)

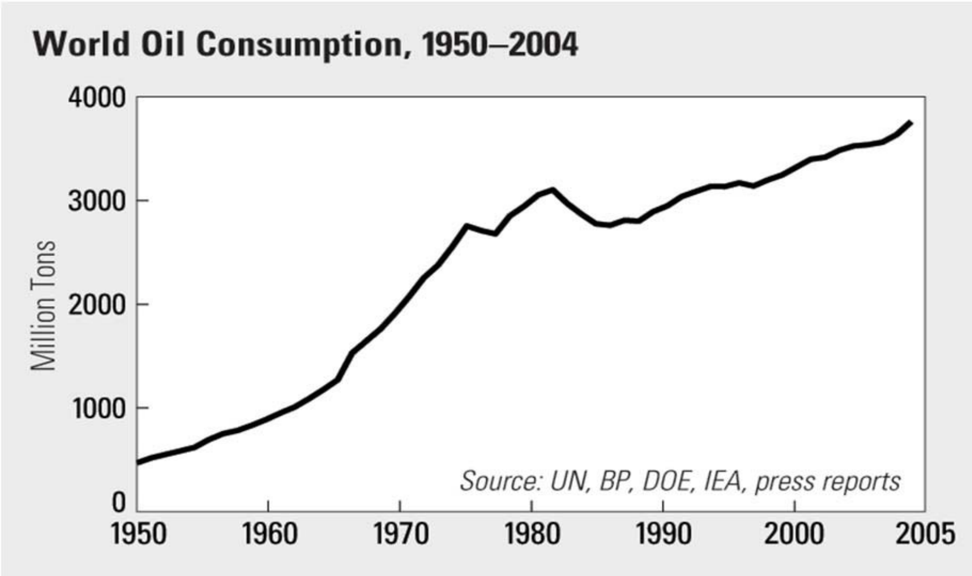

Figure 2. World Oil Consumption [2]
(Source: http://www.worldwatch.org/brain/images/press/news/vs05-world_oil.jpg)

According to IEA World Energy Outlook, the world's main energy supply has boosted up by 58% in 25 years, from about 7.2 billion TOE in 1980 hitting the value of 11.4 billion TOE in 2005.

Experts foresee an increase in the energy demand proportional to the increase of economic growth of emerging market countries such as China, India, and the Middle East. The increase is estimated to be about 48% over the next 25 years, reaching 17.0 billion TOE in 2030.

Table 1. Energy Outlook

Items		Energy	Demand	M($_{toe}$)	
	1980	2000	2005	2015	2030
Total primary energy demand	7,223	10,034	11,429	14,121	17,014
Petroleum Oil	3,107	3,649	4,000	4,525	5,109
Transport	1,245	1,936	2,011	2,637	3,171
Petroleum	1,187	1,844	1,895	2,450	2,915
Biofuels	2	10	19	74	118
Other fuels	57	82	96	113	137

(Source: IEA Energy Outlook 2007,2008) [3]

Co-funded by the Erasmus+ Programme of the European Union

1.1. Fossil Fuel vs. Renewable Energy

Fossil energy sources include oil, gas, and coal. They are non-renewable finite resources. The result product of millions of years of decayed prehistoric plants and animals that got gradually buried by layers of rock is what we call now fossil fuels. The type of fossil fuels depends on the nature of microorganisms, plants and animals (organic matter) that was present, for how long it was buried, temperature and pressure conditions along the years. These resources are collected by drilling and mining. Fossil Fuels are burnt to obtain electric energy and refined for heating and transportation fuel. [4]

Advantages of fossil fuels are:

a. Fossil fuels were used to power our world for decades therefore, the technology used to harness that energy is well-developed;
b. Fossil fuels are reliable sources of energy and are cheap too. They fulfill all our energy needs for a vast range of activities.

Those advantages might sound good enough, but the disadvantages of fossil fuel consumption are alarming:

a. Fossil fuels are not green sources of energy. They contribute highly to Global Warming because they contain high levels of carbon and when burnt, they increase the levels of greenhouse gases in our Earth's atmosphere.
b. It takes millions of years under favorable conditions for fossil fuels to regenerate in nonaerobic processes, which is why they are considered to be non-renewable sources of energy. Even though fossil fuel reserves around the globe might be considerable, humanity has been depending on these fuels to give an initial push into a technologically brighter future, which means that those energy sources, which are not replenishing will dry out sooner or later.

oil	between 2010-2020
coal	100 to 150 years from now
natural gas	from 120 to 150 years from now
235 uranium	100 to 120 years from now
238 uranium	10,000 to 60,000 years

Table 2. Traditional fossil fuel yield peaks are not distant [5]

(Source: International Atomic Energy Agency)

c. Fossil fuels are characterized by unsustainability which made people think about finding alternative sources to power our world's engines. Those alternative sources would be renewable and eco-friendly energies.
d. Many accidents could occur while these fuels are transported being highly flammable. Accidents in this case are not as serious as those related to nuclear power, but while transported – if accidents occur- they can produce spills that have been polluting our oceans and seas for the past century. [6]

Analyzing those disadvantages and noticing their obvious impacts on earth's vital signs, the world's interest for new sources of energy that cause less harm has awakened leading to the usage of renewable energies.

Renewable energies are sources of power that can never dry out and are abundant around the globe. They are easily replenished at a faster rate than that of their consumption. Using renewable energies serves to reduce the greenhouse gas emissions thus putting limits to the aggravating situation of global warming that we are currently facing.

These green energies come from diverse sources and have the potential to considerably reduce humanity's tremendous dependency on fossil fuels, and they can also stimulate employment through creating new job offers in new eco-friendly and green technologies.

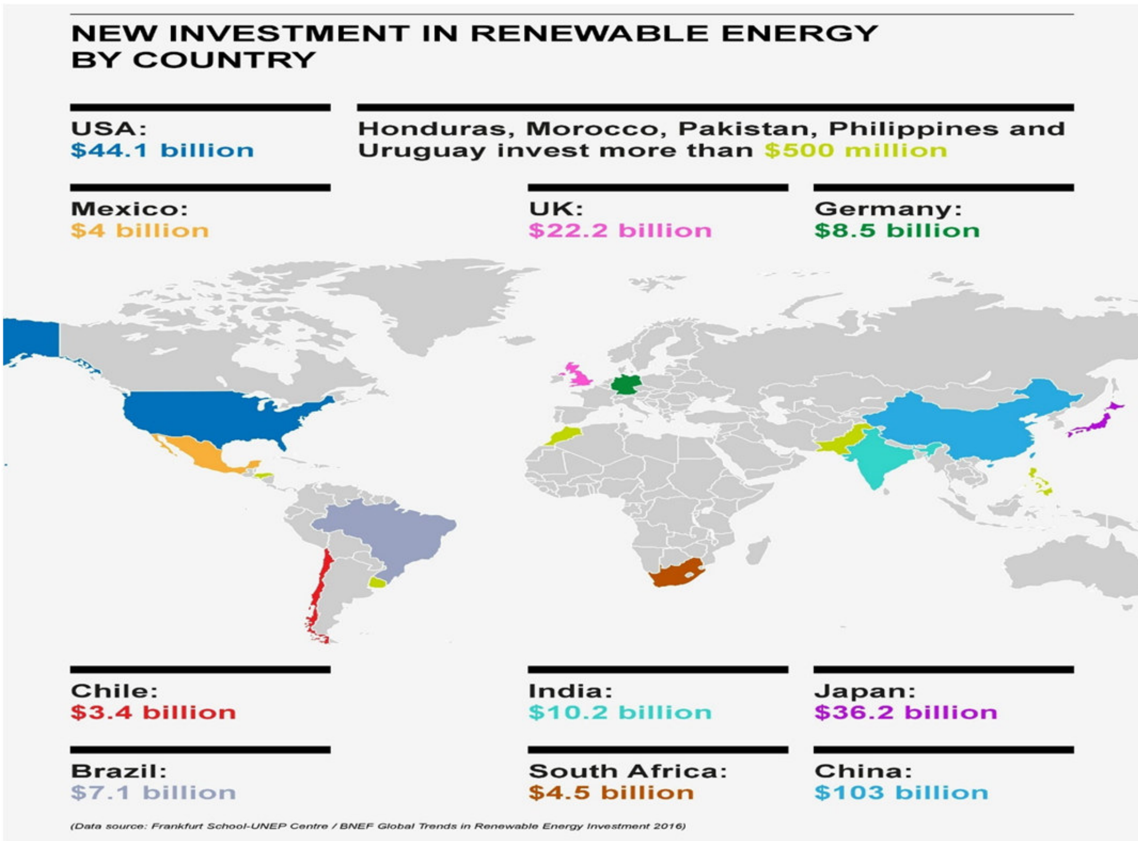

Figure 3. New Investment in Renewable Energy by Country [7]

(Source: https://www.weforum.org/agenda/2016/04/4-charts-that-show-the-rise-of-renewables/)

As we can see, countries worldwide have been largely investing in renewable energies in all forms. Moreover, we observe that the underdeveloped countries (e.g. India, South Africa, Chile, Honduras, Pakistan, Philippines) have been investing in green energies in a more evident matter than the developed countries (e.g. USA, and European Countries).

Renewable energies come in diverse forms but almost all of them depend partially or completely on sunlight. Wind and hydroelectric power depend in a complete matter on the differential heating of Earth's surface which leads to air moving creating what we call wind and the creation of precipitation as air is lifted, and that of course is thanks to sunlight. While wind and hydroelectric power are somehow created by sunlight, biomass is the stored solar energy in plants.

There are energy sources independent of solar energy, they are geothermal and tidal energies. [8]

1.2. Objective of the project

The main objective is the reduction of greenhouse gas emission through the introduction of innovative elements in the biomass processing and heat production.

- To replace the electric generator system already integrated for the greenhouse due to its low efficiency levels thus introducing a modern green wood-chip based heating system which is the boiler.
- Taking advantage of the availability of cost efficient wood and energy crops to be used as a renewable resource to power the boiler heating system.
- Taking into consideration multiple factors (moisture, wood quality, energy loss, pollution, labor cost, management and maintenance, transportation and harvesting fees, etc.)
- Encouraging the use of green energy systems in rural areas.
- Creating sustainability.
- Creating new job opportunities for locals in this rural area.
- Encouraging agriculture and paprika cultivation.

Co-funded by the Erasmus+ Programme of the European Union

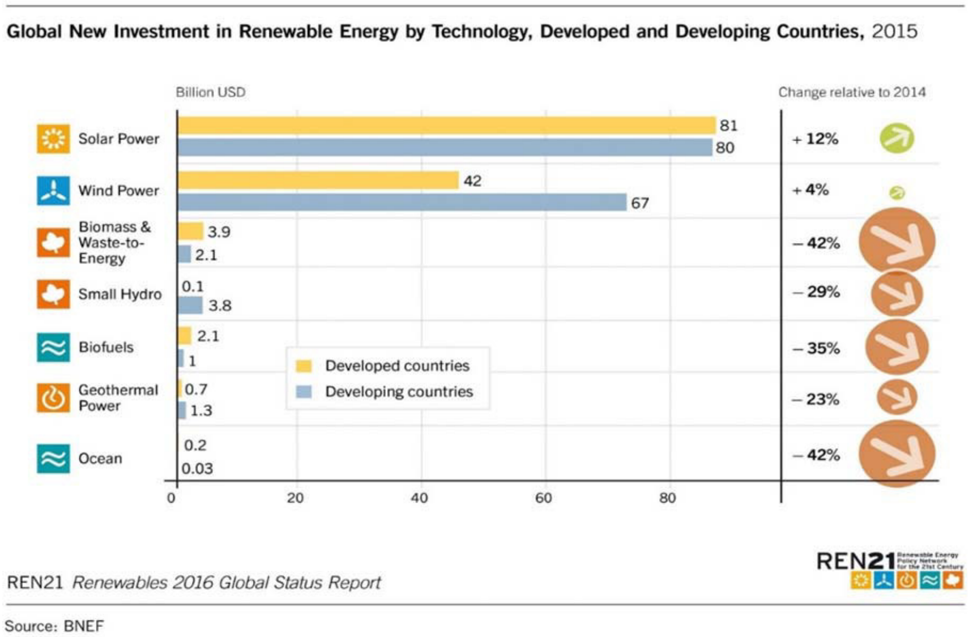

Fig. 4. Employment in RE [9]

(Source: http://www.se4all.org/sites/default/files/IRENA_RE_Jobs_Annual_Review_2016.pdf)

1.3. Location of the project

The project is located in Tass-puszta, Hungary.

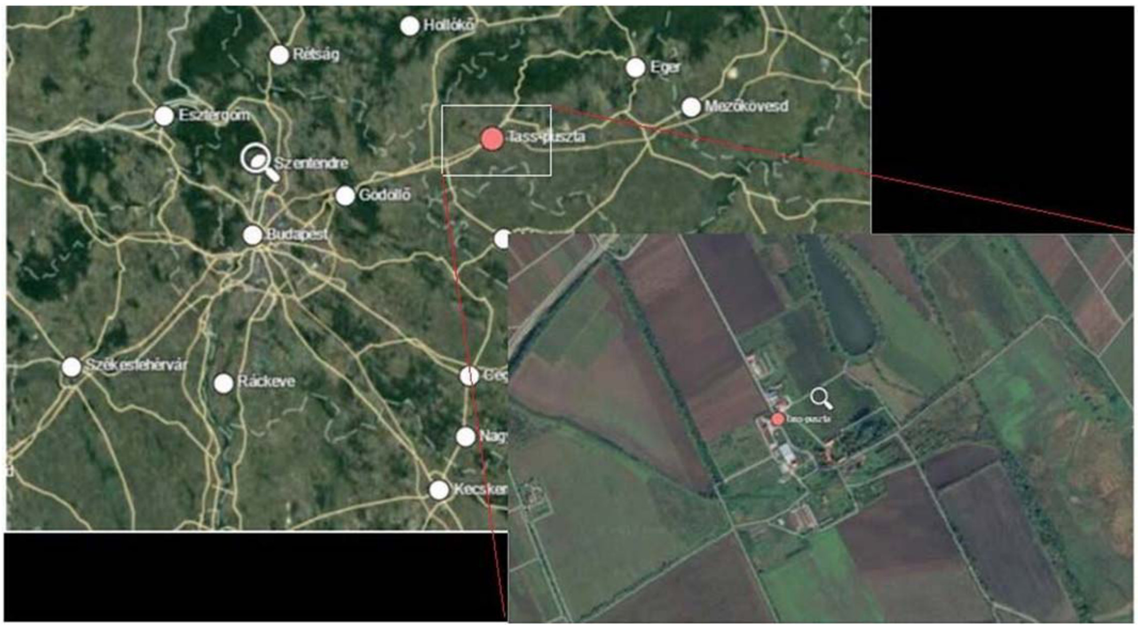

Fig. 5. Tass-puszta location [10]

(Source: https://mapcarta.com/18433856)

Location: Hungary, Central Europe, Europe

Latitude: 47° 44' 5.3" (47.7348°) north

Longitude: 19° 52' 40.4" (19.8779°) east

Elevation: 124 metres (407 feet)

Tazz Puzta is an experimental farm belonging to Karoly Robert University. It's main research center is Kompolt center where all the researches are made. Tazz Puszta Farm is basically made of two essential parts:

- The paprika greenhouse that produces approximately 3 tons of ready to sell paprika each year. The greenhouse is the ideal place for paprika to grow and be harvested because paprika can on grow in an average temperature of 25 degrees Celsius.
- The heating plant where an electric generator provides the necessary energy for the heating of the paprika greenhouse.

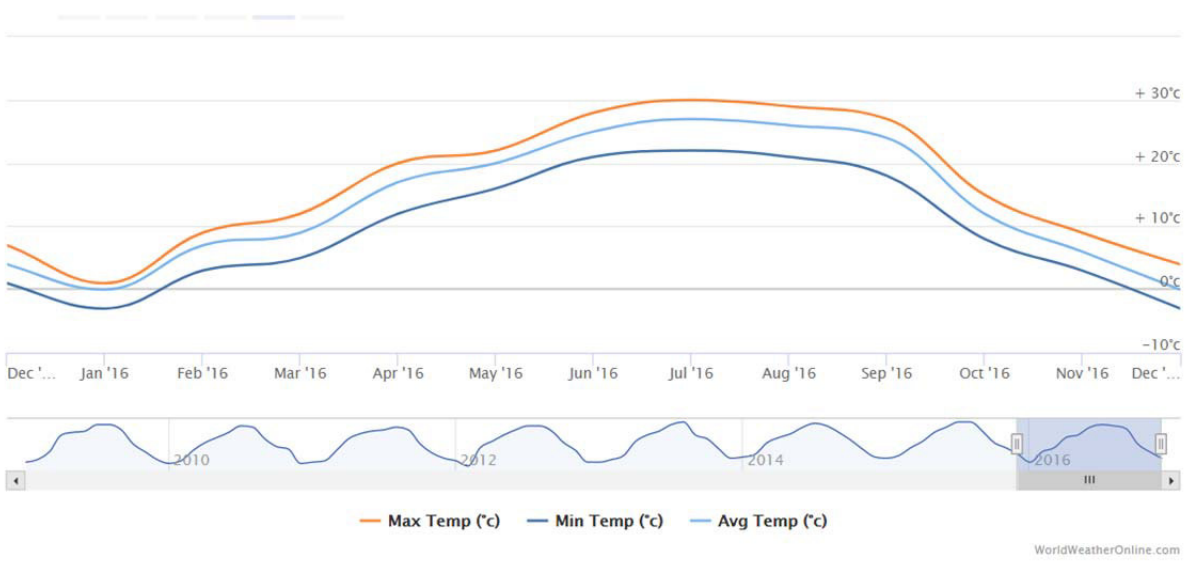

Fig. 6. Average temperature in Tass-puszta, Hungary. [11]

(Source: https://www.worldweatheronline.com/v2/weather-averages.aspx?locid=971022&root_id=954533&wc=local_weather&map=~/tas-puszta-weather-averages/heves/hu.aspx)

1.4. Precedents

Biomass based boilers are used to provide heating for several facilities:

- Schools
- Hospitals
- Public buildings
- Hotels
- Commercial buildings
- Greenhouses
- Large-scale agricultural operations
- Manufacturing plants

Most biomass energy plants utilize some kind of wood to address their facilities' needs for space heating or local boiling hot water.

Biomass systems are often capable of giving higher levels of comfort at a lower energy cost. Because biomass fuels are very inexpensive, many building owners can afford comfortable temperatures for various uses especially in winter.

Biomass systems are relatively easy to convert into other types of fuel and offer high flexibility for a green energy future.

Therefore, all these make good enough reasons to replace the old heating system present in Tass-puszta study farm with a modern biomass-based boiler.

1.5. State-of-art in the problem domain

Biomass

Photosynthesis is the process in which plants store solar energy to produce an organic material called starch. This captured energy that plants store is what we now call biomass. Biomass is used widely to produce electricity and heating. It is obtained from plants, animal wastes and other organic materials. It is a renewable and sustainable source of energy because it is a totally natural resource and is abundantly found and replenished. Types of biomass can be summed up in 5 main categories: Wood, garbage, crops, landfill gas and alcohol fuel.

The only way to release its energy, biomass is burnt. The energy release is in the form of heat energy. But biomass can also be converted in biofuels and biogases through multiple processes like fermentation. Those converted products can thus be burnt to produce electric and heat energy. For example, obtained methane gas is obtained from the decomposition of agricultural wastes and garbage in landfills in special containers called digesters and can be used to produce electricity, heating or power garbage trucks. Other examples are biofuels and ethanol that are obtained from sugar canes, vegetable oil and animal fats, and their main usage is to power vehicles.

Fig.7. Biomass Energy [12]
(Source: http://www.nationalgeographic.org/encyclopedia/biomass-energy/)

Bioenergy is basically the energy derived from converting biomass which can be used directly as a fuel by burning it, or converting this biomass into biofuel and biogas.

Nowadays, the most challenging requirement for humankind is finding a reliable and most importantly sustainable source of energy to address climate change and global warming. Currently, biomass is the largest global contributor of renewable energy and has the potential to significantly meet our needs of energy in the near and far future.

If managed in the proper ways, biomass can present the following advantages:

- Larger contribution to the total energy production around the globe;
- Economic and social development possibilities in rural areas;
- Reduction of municipal wastes and residues;
- Substitution of fossil fuels and thus assuring a healthier environment and significant greenhouse gas emissions;
- Creation of energy security.

Currently, bioenergy accounts for 10% of global energy consumption, mostly used in traditional ways like burning biomass for heat and cooking.

1.6. Sources of biomass – Classification of biomass feedstocks

Biomass feedstocks are classified into 8 major groups:

- Dedicated Energy Crops

Dedicated energy crops can be grown on marginal land due to being non-food substances that can withstand the raw and unhospitable nature of these lands. These energy crops are divided into two categories, one pertaining to herbaceous energy crops and the other to short-rotation woody crops.

Herbaceous energy crops that are perennials that have the ability to live in such raw nature are harvested annually after blossoming to their full productivity at a 2 to 3-year interval.

These include such grasses as switchgrass, miscanthus (also known as elephant grass or e-grass), bamboo, sweet sorghum, tall fescue, kochia, wheatgrass, and others.

Short-rotation woody crops on the other hand are fast growing hardwood trees that have a 5 to 8-year interval of waiting before being harvested at full potential. These include hybrid poplar, hybrid willow, silver maple, eastern cottonwood, green ash, black walnut, sweetgum, and sycamore.

Theoretical consideration of solar capture by plants reveals C4 perennial energy crops to be as efficient as photovoltaic devices to the point of charge separation in photosynthesis. Any subsequent large energy losses occur in the synthesis of stored energy (carbohydrate) and in building and maintaining the system, something man-made photovoltaic devices are unable to do.

The annual yield of a plant with a given genotype at a given location is the product of the total solar radiation and the efficiencies with which the crop first, intercepts that radiation; second, converts it into chemical energy in the form of plant biomass; and third, partitions it into the harvested component. [13]

- Agricultural Crops

These include commodity products such as cornstarch and corn oil, soybean oil and meal, wheat starch, and vegetable oils. Processing these crops into sugar and other extractives can also help in producing plastic as well as other chemical products.

- Agriculture Crop Residues

They include crop wastes that are not usually harvested and left in an agricultural field or the residues left after crops have been harvested like leaves, stalks, stubble, cobs, etc.

- Forestry Residues

Residues often are obtained from precommercial thinning in young stands or removing old stands, non-harvested biomass in logging sites in commercial hardwood and softwood stands. [14]

- Aquatic Plants

Aquatic plants from the seaweed and marine microflora pay a role in biomass production. Some of these latter organisms are algae and giant kelp.

As an aquatic organism, algae grow in diverse watery media from freshwaters to seawaters and damp oil; in a fast manner that allows its adaptation in these media, whilst taking in carbon dioxide out of the atmosphere, serving as a great potentially home-grown source of renewable, sustainable fuel; for example, Algenol, has some algae strain that can produce ethanol directly, and the system can then convert remaining biomass into hydrocarbon fuels such as biodiesel, gasoline, and jet fuel. The biorefinery has helped Algenol exceed its milestone of 9,000 gallons of ethanol per acre per year at peak productivity, with an additional 1,100 gallons per acre per year of hydrocarbon fuels.

Land plants currently used to produce biodiesel and other fuels include soy, canola, and palm trees. For the sake of comparison, soy beans produce about 50 gallons of oil per acre per year; canola produces about 160 gallons per acre per year, and palms about 600 gallons per acre per year.

But unlike the plants above, some types of algae can produce at least 2,000 gallons of oil per acre per year, due to its production of fatty lipid cells that contain fuel alongside its photosynthesis process which gives oxygen as a by-product, removes carbon dioxide from the atmosphere, and uses phosphates, nitrogen, and trace elements to grow and flourish. [15,16]

- <u>Biomass Processing Residues</u>

In the use of biomass feedstocks such as wood, residues linger after the process ends. But in return these residues can be used again as a source of energy with minimal cost and high effectiveness as such unused branches and sawdust for heat and fire as an example.

Due to the non-ceasing increase of urbanization, industrialization and population growth around the globe, the amount of food wastes is instantly escalating. So, due to the process of HTL discussed above they consequently represent a widely available resource in the form of biomass, and their use as a raw material in decreasing the environmental cost accompanied with their disposal.

Due to their high moisture content, a solution such as dry valorization is highly unfavorable due to its relative excessive cost. Hence, its alternative, HTL, which converts wet biomass into a crude-like oil with higher heating values up to 40 MJ/kg using subcritical water (T=250–370 °C, P=10–30 MPa) [17]

- <u>Municipal Waste</u>

Municipal waste, once a recurring Eco devastative issue for extreme environmentalists, has now become a somewhat rejuvenating subject since it has become one of the important sources of biomass production after its treatment and cultivation. Examples of the latter range from organic matter as sewage to the industrial and commercial wastes, but excluding wood and agriculture waste residues.

For the transformation of wet solid wastes into biocrude or bioenergy a process such as hydrothermal liquefaction must be used. This process is a viable thermochemical process that gives out biocrude which is hydro processed to liquid transportation fuel blend stocks. A feasible percentage of biogenic feed carbons ranging from 20-50% should be installed for the enhancement of this process on an industrial scale.

One of the interesting alternatives in biofuel coming from several conversion processes o solid wastes is Bioethanol (C_2H_5OH), one of its properties is that its oxygenated (35%) with a bio base, providing an ability to reduce particulate and NOx emissions in compression ignition engines for example.

According to the diagram below, a process done on municipal waste or its transformation into bioenergy or bioethanol in this case is shown.

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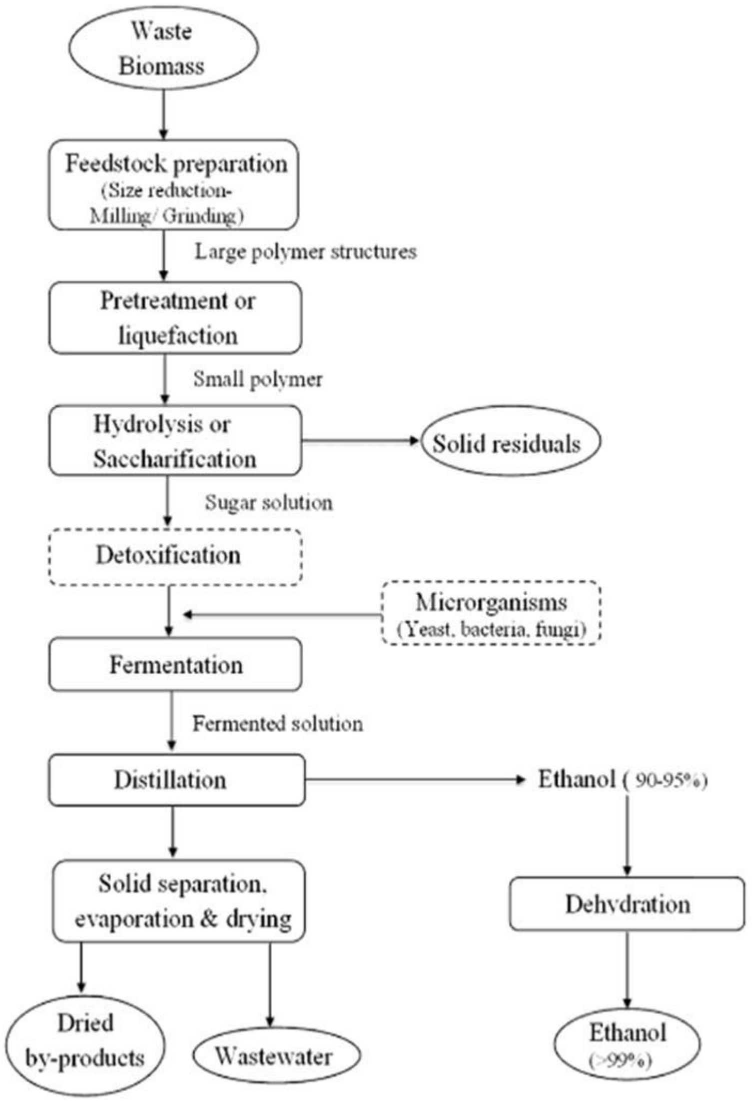


FIGURE 8.1 General block flow diagram of bioethanol production from waste biomass. *Modified from M.J. Taherzadeh, P.R. Lennartsson, O. Teichert, H. Nordholm, Bioethanol production processes, in: Biofuels Production, John Wiley & Sons, Inc., Hoboken, NJ, USA, 2013, pp. 211–253.*

Fig.8. Bioethanol Production from Agricultural and Municipal Wastes [18]
(Source: Current Developments in Biotechnology and Bioengineering Solid Waste Management)

- <u>Animal Waste</u>

Animal wastes are obtained from farms and animal-processing operations. They are a complex mixture of organic materials, if left unprocessed, they can significantly pollute the surrounding environment. Through anaerobic digestion, which are basically a series of biological reactions where certain type of bacteria break down biodegradable material in the absence of air. These wastes can be used to make many products, including energy.

1.6.1. Wood

Fig.9. Wood [19]
(Source: https://www.google.hu/search?q=wood+biomass&rlz)

Wood has been used by humanity for decades as a main source of heat for cooking and for light. Wood continues to be an essential fuel for various ways of consumption especially in developing countries.

In Europe, wood is still used highly in the renewable energy domain. The chart below shows wood and wood product in gross inland energy consumption for various European countries in 2014.

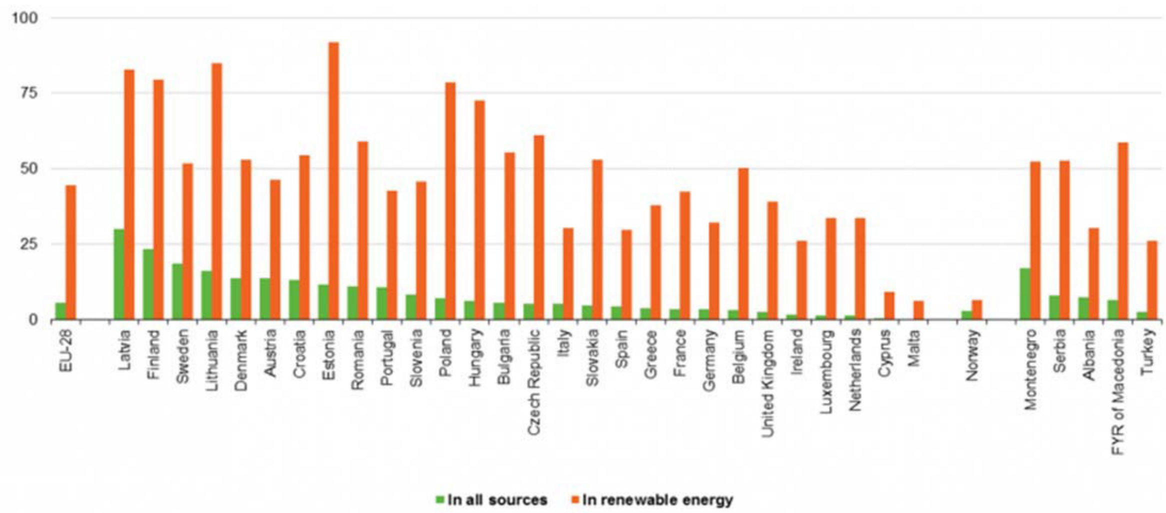


Fig.10. Wood as a source of energy [20]
(Source:http://ec.europa.eu/eurostat/statistics-explained/index.php/Wood_as_a_source_of_energy)

Wood is a composite of cellulose, lignin and hemicellulose (43%, 36% and 22%, respectively). A typical analysis of dry wood yields carbon (52%), hydrogen (6.3%), oxygen (40.5%) and nitrogen (0.4%). The proximate analysis of wood shows the following components:

1. wood: volatile matter (80%), fixed carbon (19.4%) and ash (0.6%);
2. bark: volatile matter (74.7%), fixed carbon (24%) and ash (1.3%).

1. Forestry and waste of forestry related industries

Forestry residues that are used for advanced biofuel production can be summed up in two types:

- Harvest residues that are left in the forests after logging such as stems, roots, branches, foliage, etc.
- Complimentary fillings, which describe the difference between the maximum need for consumption and the actual harvest needed to satisfy round wood demand.

2. Energy forests

Energy forests are getting major interest nowadays when talking about renewable energy resources and for meeting the increasing global energy demand. Energy forests are described as a new type of forestry that's main goal is containing fast-growing trees that provide a higher level of energy when converted to fuel. The main aim of these forests is to produce biomass for energy production purposes. There are two types of energy forestry, short rotation coppice - includes tree crops like willow, Eucalyptus, and many others which can be harvested and cut after 2-5 years - and short rotation forestry.

3. Processing wooden biomass

Logs and chips are the two main forms of forestry-derived wooden biomass. Wood pellets are produced from sawmill or wood product processing plant residues and are made in large scale pellet mills. They are unlikely to be appropriate for community scale production. Each wood heating system will have particular fuel requirements e.g. some boilers are designed for larger woodchip sizes than others.

Processes involved:

a. **Logs** - Once harvested, wood needs to be cut to uniform lengths, stacked off the floor, in the woodland for drying and ultimately chopped into logs and transported off site for use in boilers or stoves.

Fig.11. Wooden Logs [21]
(Source: http://cooroyoutdoor.com/our-products/chainsaws/wooden-logs/)

b. **Woodchips** - once harvested wood needs to be cut to uniform lengths, stacked for drying, transported to a processing site if outside the woodlands, chipped using a chipper and screen and transported to the woodchip boiler.

Fig.12. Wood chips [22]
(Source: http://www.photos-public-domain.com/2010/10/03/red-wood-chips/)

c. **Wood pellets** - wood pellets are produced on a factory scale by forcing dried sawdust and clean wood by-products (from sawmill or forestry activities) through holes in a rotating dye to form tight pellets. [23]

Fig.13. Pellets [24]
(Source: http://www.framfuels.com/)

1.6.2. Energy grasses

Conventionally, most solid biomass heating fuels—woodchips, wood pellets, and cordwood—came from forests and the forest products industry. Over the past 15 years, however, growing crops (both herbaceous and woody) specifically for energy has gained widespread appeal, and perennial grasses such as Switchgrass, Miscanthus, and Reed Canary grass present exciting new renewable energy options.

Perennial grasses are now being used as a solid fuel in co-fired coal power plants as well as targeted as a choice feedstock for such advanced biofuels as cellulosic ethanol. Despite this focus on generating electricity and producing liquid fuels, perennial grasses can also be pressed into pellets, briquettes, and cubes and used as a heating fuel to replace or complement fuels made from wood fibers. Including a thermal component in the use of solid biomass for energy increases a combustion system's efficiency more than threefold. [25]

1.6.3. Agricultural organic residues

Organic waste or materials obtained from biomass remain at least partly un-degraded for longer times, this effectively removes carbon from the atmosphere. This is the case, for example, when compost that has been spread on agricultural land is only slowly mineralized and increases the soil organic matter, or when organic material in landfills decays only over many years.

Disposal and treatment of organic waste represents a major challenge for the waste industry. Anaerobic digestion is an alternative to composting for a wide range of organic substances including livestock manure, municipal wastewater solids, food waste, industrial wastewater and residuals, fats, oils and grease, and other organic waste streams. Diverting organic waste to facilities that contain anaerobic digestion technology could lower greenhouse gas emissions, specifically methane released from landfills as waste breaks down. In addition to waste management, anaerobic digestion provides a renewable source of biogas, which can be burnt to generate heat or electricity or upgraded to be used as a vehicle fuel.

Such organic wastes alongside energy crops can be put under microbial conversion to be transformed into biogas widely used in energy production, resource recovery and waste treatment. As well as its role, In the reduction of greenhouse gas emissions and its improvement of the manure and organic waste management system since it can replace mineral fertilizers. [26]

1.7. Design of the Biomass Boiler

What Does a Wood-Chip System Look Like?

Switching from an electric generator to a biomass based heating system can be challenging.

Biomass warming plants are comparable in their practical parts to warming plants that keep running on traditional powers. They incorporate substantial volume fuel stockpiling ability, a means for moving the fuel from the capacity canister to the burner, a burner and heater to consume the fuel also, extract the useable heat from combustion, and association with a chimney that scatters the burning gases. Engine compartments or heater houses for biomass frameworks are normally bigger than regular boiler rooms, since wood boilers are bigger and the fuel handling gear consumes up additional space. The chimney of a biomass framework is typically taller than that for an oil or, on the other hand gas framework.

All things considered, a biomass framework looks much like a regular heater room, with the exception of its fuel chimney. While oil and fluid propane (LP) gas are ordinarily put away in covered tanks (petroleum gas requires no on-location capacity), wood-chip containers might be above or beneath the ground.

If the wood-chip container is subterranean, which is the regular case, just its chimney is noticeable. Over the ground containers may look simply like homestead storehouses: they are round concrete or metal storehouses of different structures and heights. As a rule, biomass energy frameworks in the 1-10 MMBtu size range don't adjust the external appearance of the facility. They fit into the look of the current structures and the encompassing region.

If operated appropriately, they don't create obvious smoke. In light of the fact that the biomass fuel generally consumed is green, or near one-half water, in chilly climate the chimney may demonstrate a plume of consolidated water vapor. Interviews with many framework administrators bolster the conclusion that scent produced by the fuel or the smoke is never an issue.

The components of a biomass boiler system include:

1. The fuel storage facility
2. Boiler room to house the equipment
3. Fuel handling equipment to move the fuel from storage to the boiler
4. A chimney to exhaust the gases
5. Exhaust gas cleaning devices
6. Ash disposal equipment

The person operating the plant is also essential to the success of the system.

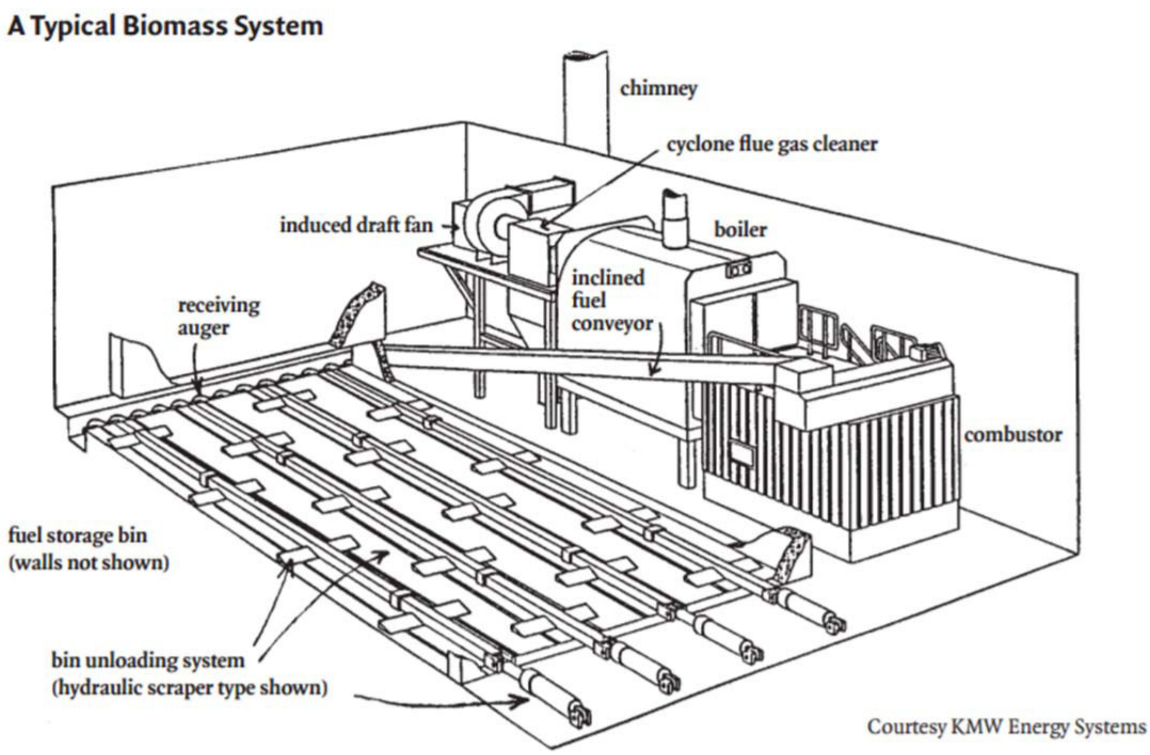


Fig.14. Typical biomass system [27]
(Source: http://www.biomasscenter.org/pdfs/Wood-Chip-Heating-Guide.pdf)

Factors to be considered:

1. The characteristics of the fuel to be used

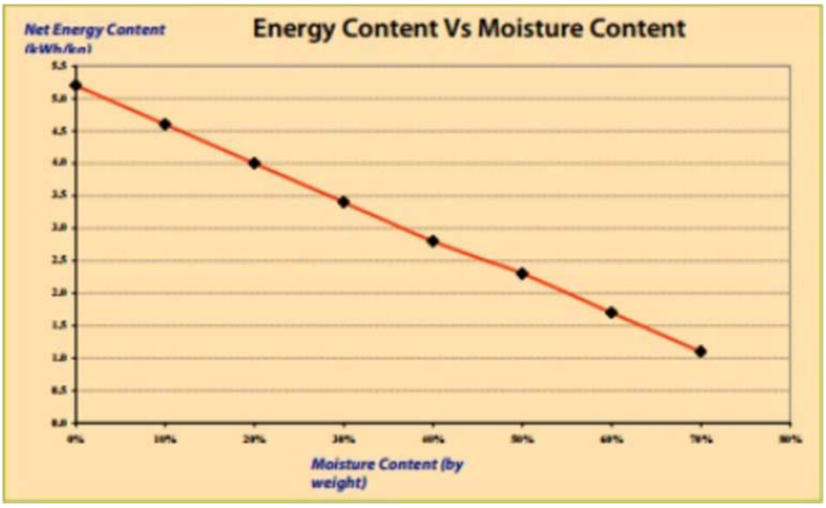


Fig.15. Energy Content Vs Moisture Content [28]
(Source: https://www.slideshare.net/ConorDorman/improving-the-energy-efficiency-of-fota-wildlife-park)

All biomass fuels are made up halfway of water. Fuel dampness is usually expressed on a wet premise: a fuel that is half water by weight would have a 50% wet basis moisture content. Fuels are likewise once in a while described on a dry premise. A similar fuel would have a 100% dry premise dampness content, in light of the fact that the heaviness of water is equivalent to the weight of dry wood. Most purchased biomass fuel is green or undried, with 30-55% of the conveyed weight being water. All references to fuel moisture are on a wet premise.

Fuel ought to dependably be shielded from precipitation to counteract solidifying and clustering, treating the soil, and warm development. Biomass fuel that has dependably been kept under cover will dry out if left after some time. In most systems, however, the fuel does not remain in the capacity container sufficiently long to dry significantly, or to start treating the soil on the off chance that it has been rained on. High fuel dampness levels diminish consuming efficiency in light of the fact that the significant of the fuel that is water is not burnable. Efficiency is likewise lessened since an expansive piece of the vitality accessible in the wood itself is utilized to warm up and dissipate this dampness. One approach to increment efficiency is drying the fuel on location. Be that as it may, the cost of hardware to do this is high. Hence, fuel driers are never found in offices measured underneath 10 MMBtu.

Fuel	Net Calorific Value kWh/kg	Bulk density kg/m^3	Volumetric energy density kWh/m^3
Wood (solid, oven dry, 0% mc)	5.3	400-600	2,100 - 3,200
Wood pellets (~8% mc)	4.8	650	3,100
Log wood (stacked, 20% mc)	4.1	350-500	1,400 - 2,000
Wood chips (30% mc)	3.5	250	870
Miscanthus (bale, 25% mc)	3.6	140-180	500 - 650
Heating oil	11.8	845	10,000
Anthracite	9.2	1,100	10,100
House coal	7.5-8.6	850	6,400 - 7,300
Natural gas (NTP)	10.6	0.9	9.8
LPG	12.9	510	6,600

Table 3. Heating values for different types of fuels [29]
(Source:https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/forest_guide_for_designers_and_architects_en)

Moisture Content (MC)	Gross Heating Value (GHV-AF)
oven-dry	8500
25%	6375
30%	5950
35%	5525
40%	5100
45%	4675
50%	4250
55%	3825
60%	3400

Table 4. Moisture content and energy output [30]
(Source: http://www.biomasscenter.org/pdfs/Wood-Chip-Heating-Guide.pdf)

Efficiency can be defined by the amount of useful heat output from combustion, divided by the heat input of the fuel. For efficiency calculations, the input fuel's energy content can be characterized either by its as-fired gross heating value (GHV-AF) or by its net heating value (NHV). For obvious reasons, there is a need to be consistent in the way in which efficiency is calculated.

Green wood combusts with relatively low efficiency because it contains a large amount of moisture. GHV based efficiency calculations look at the total heating potential of the wood, including the energy that is "wasted" in vaporizing water and in not condensing water vapor in the flue gases. When efficiency calculations are based on NHV, which removes fuel moisture from the equation, efficiencies increase significantly compared to efficiencies calculated on a GHV basis. Some European manufacturers (or manufacturers with product lines based on European technology) report their efficiencies based on NHV. Prospective buyers must be sure that they know what heating value basis is being used when they evaluate the efficiency of different combustion systems.

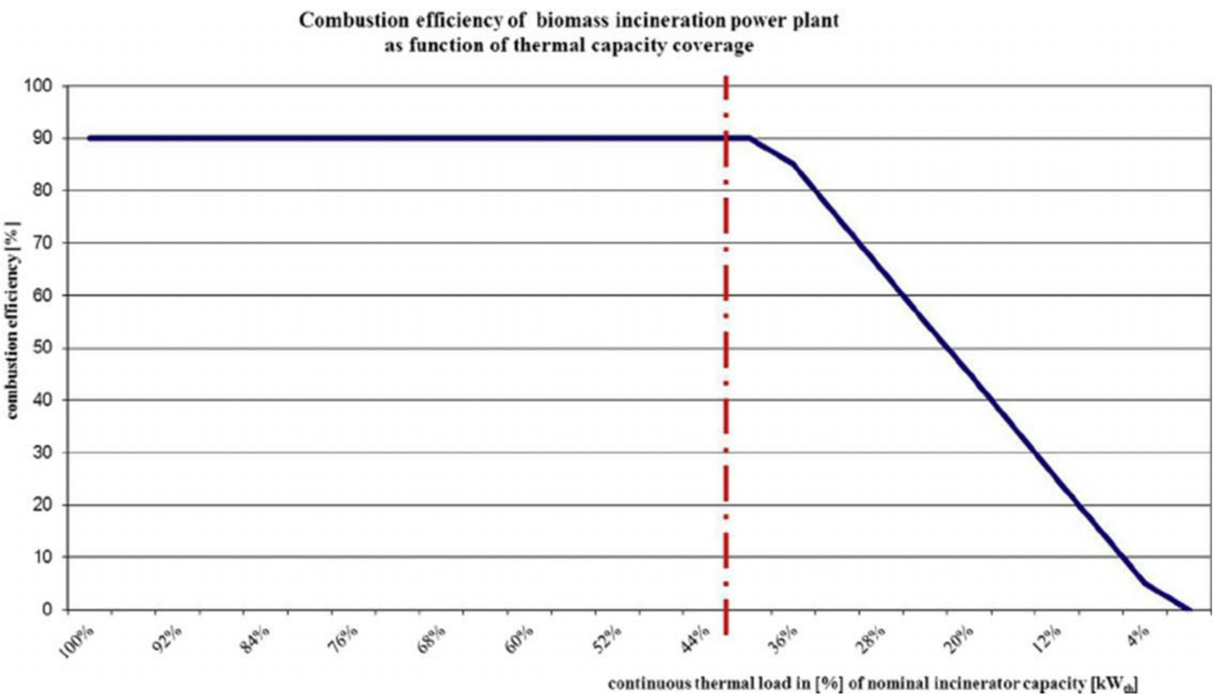


Fig.16. Combustion efficiency. [31]

(Source: https://www.researchgate.net/figure/270398042_fig4_Fig-7-Combustion-ef-fi-ciency-characteristics-of-a-typical-woodchip-furnaceboiler)

2. The energy capacity and pattern of demand to be met

How big should the biomass system be?
How to decide the adequate Btu yield and by what method should the backup system be sized.
These will be discussed in the following points depending on the objectives to be carried.
Regardless of the target, net oversizing of the biomass plant should be deliberately avoided, due to the natural tendency of designing oversized biomass plants which will ultimately affect the efficiency of the plant, thus consuming too much fuel and the possibility of generating too much smoke in low load scenarios.
The primary objective here is to minimize backup fuel use. In our case the system should be sized to cover the full heating load of the greenhouse in use. In cold weather (period of high peak load) the system will be running almost constantly at full potential output.
The backup fuel system would not be needed to meet the load except for short periods.
Most of the time the system will be running less efficiently due to the fact that high peak load conditions are less frequent.

In this case, poplar tree woodchips are going to be used a fuel for the heating system, being harvested from the energy forest nearby the study farm.

3. The cost and the performance of the equipment

Semi-automated greenhouse heating systems usually cost less than those fully automated systems found in schools or hospitals. There are 3 main reasons for this difference in system costs.

Firstly, tractor based semi-automated systems that use tractors to transport the wood chips from the storage bin to the daily bin are inexpensive to be built. The construction variations also affect the differences in the total cost of building a greenhouse heating system, being cheaper when less expensive construction material is used and vice versa in case the higher end products are used. Further savings come from already owning some handling equipment and controls.

Secondly, due to this installation system being used for a greenhouse heating purpose, most of the resources to be used are already available on site and the greenhouse staff can also be used to install the biomass system, thus evading the high costs of hiring architects/engineers and labor forces.

Thirdly, sophistication and additional features heavily affect the payload of the project because while using a less complicated system with no exhaust gas cleaning equipment may reduce cost levels, it would not offer the comfort of the higher end micro-processor fully automated self-cleaning equipment but would considerably decrease the total price tag of the greenhouse project.

4. Local legislations relating to buildings and the environment. [27]

1.8. Design of the biomass heating system

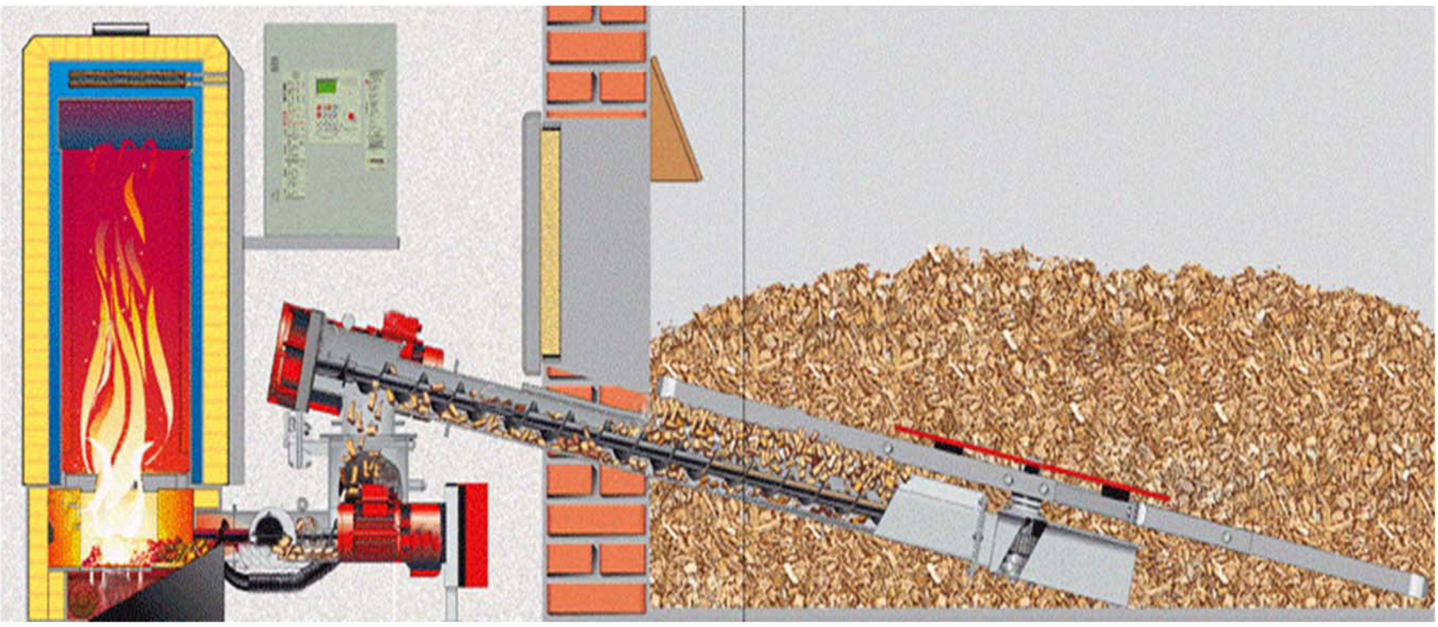


Fig.17. Wood chip heating system [32]

(Source: http://www.williamsrenewables.co.uk/biomass/woodchip-boilers/)

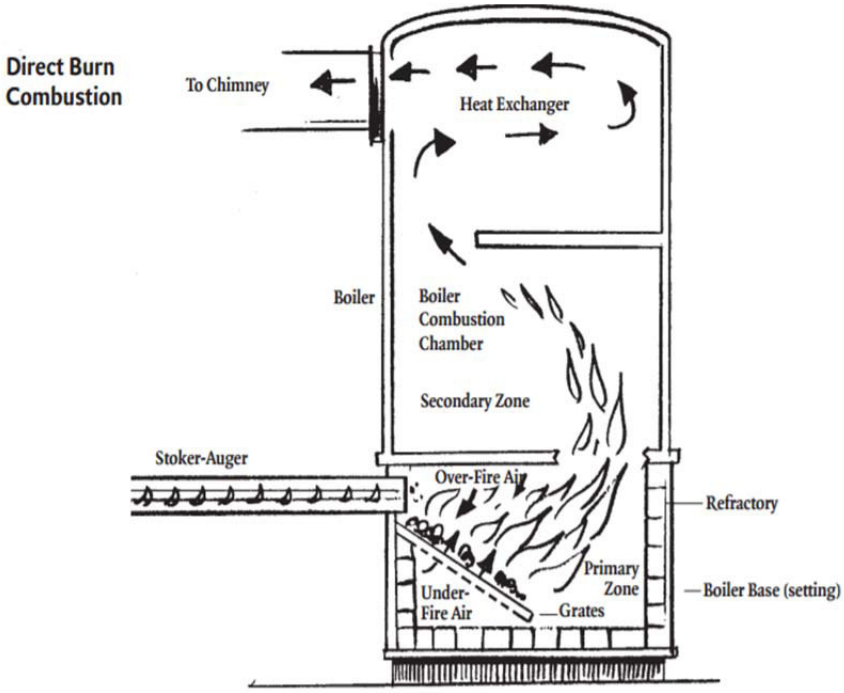


Fig.18. Biomass Boiler [27]

(Source: http://www.biomasscenter.org/pdfs/Wood-Chip-Heating-Guide.pdf)

The fuel storage system

In this case a below-ground concrete bin is chosen, having the following advantages:

- In cold weather conditions the underground bins prevent the chips from freezing due to the bottom layers of chips, which are below frost levels.
- No mechanical equipment must be used to discharge the chips into the bin because self-unloading trucks can use gravity for ease of discharge.
- The underground position of the bin aids in the visual aspect of the compound, not obstructing or deterring as those built above ground.

Fig.19. Storage bin and fuel handling system

The fuel handling system

Biomass is conveyed using automated equipment, from the storage facility into the boiler room and eventually the combustion chamber.

Beginning with the fuel removal from the storage bin, which is done using hydraulic scrapers (with a back-forth motion) at the base of the bin, discharging fuel form the bin and feeding a horizontal receiving auger that runs along one of the bin's sides which transports the fuel towards the combustion chamber.

This system profits of a small metering bin located between the storage bin and combustion chamber which separates the rapid flow of wood chips being transported from the bin carefully controlling the feed rate of the fuel that goes through to the combustion chamber.

Co-funded by the Erasmus+ Programme of the European Union

Combustion Chamber

In this case, a single combustion chamber is being used which is located directly under the boiler, set on a base supporting the boiler.

The grates and fuel feed systems are in the refractory lined setting where air is injected into it, both below and above the grates.

In this design, the furnace volume of the setting is open to the combustion chamber of the boiler above it, where the hot gases will rise up from the grate area into the combustion chamber of the boiler where the combustion of the hot gases and solid particles is completed.

Properly designed with effective combustion controls, direct burn systems are capable of highly efficient combustion with low emissions.

This boiler is chosen to be of 160 kW power.

Fig. 20 . Combustion Chamber.

1.8.1. Other Equipment

For this installation it is necessary to size a proper pump, a reservoir, an expansion vessel and an adequate length of steel pipes to heat the greenhouse.

1.9. Impact of the project for the rural development

The concept of 'sustainability' has been enhancing considerably in the last three decades, but only a few people have been concerned about this matter before. Development was considered to have infinite possibilities and the concept of scarcity was never taken into consideration on the way towards a better life. The main scope was believed to be the defeat of nature, and not the twisting and shaping of the world with nature towards a "wealthy society" with respect to nature's rules. All of these thoughts came from the idea that natural resources are endless – no one could be bothered in the case of exhaustion of old shafts and wells, because new mine-shafts and oil wells were discovered. In the Articles of Agreement of the International Monetary Fund and the World Bank of 1944 is mentioned that the resources of our planet are infinitely rich and global welfare can be guaranteed for all. Those Articles were writing about Earth's huge reserves that could be enough for even 50 billion people. Regarding the downfall of raw materials, the human insight was without a question believed to be able to solve the emerging problems by finding substitute resources, while an energy crisis was considered to be impossible.

Sustainable development is described as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It links two main key concepts, the concept of needs and the concept of limitations.

The decline of polluting activities could greatly boost the implementation of the principles of sustainability. Despite the decline of industrial activities and the relative backwardness of a region the existing production is only partly sustainable. Sustainability can be measured against the following criteria:

- Management of natural resources
- Biological and operational structure harmonized with its environment, degree of intensity
- Minimized use of chemicals and artificial inputs
- Retained biodiversity
- The responsibility of sustainable development at a global scale [34].

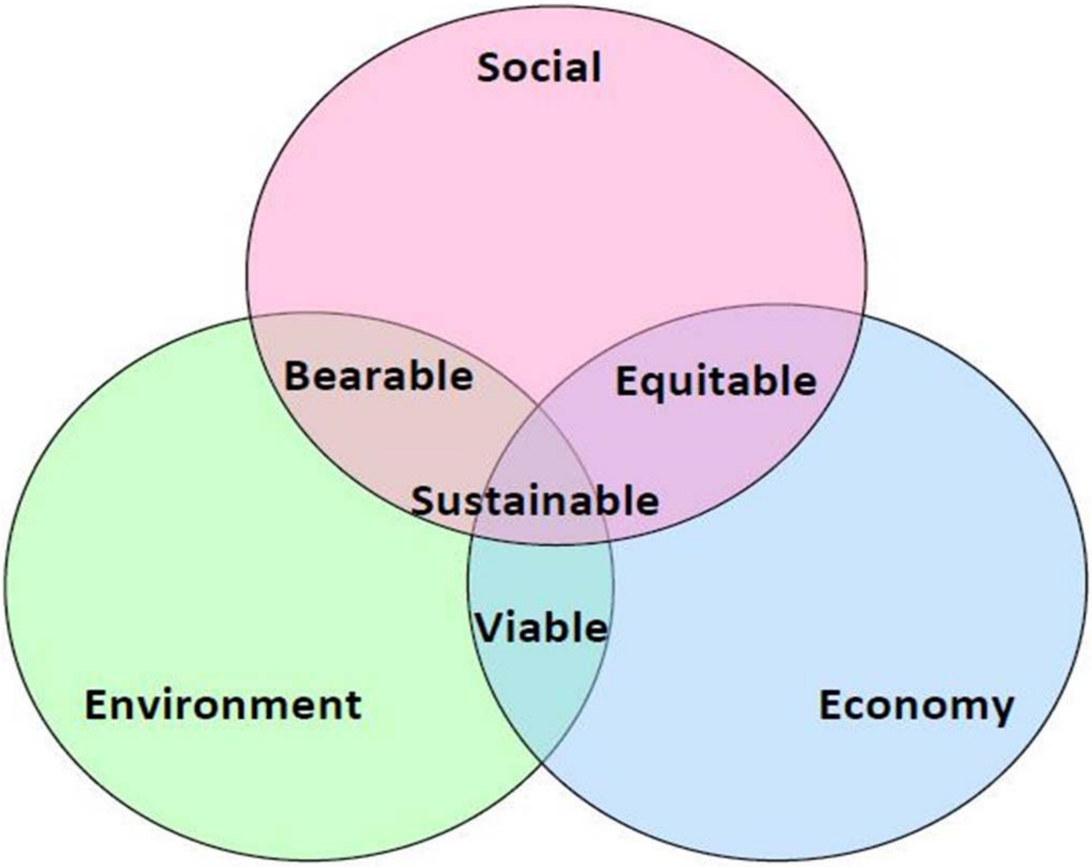


Figure 21. Sustainable development main basis. [33]

(Source:

https://www.google.hu/search?q=sustainable+development&rlz=1C1CHZL_enRO733RO733&source=lnms&tbm=isch&sa=X&ved=0ahUKEwj9hqTFmMPTAhXGJZoKHeYYAa4Q_AUICigB&biw=1536&bih=735#imgdii=8DWwk6VE79YLNM:&imgrc=ZmuRVt3bf1FUtM:)

Environmental impact

As shown in the introduction above, fossil fuels are highly pollutant while renewable energies – in this case biomass- are clean energies that help our environment somehow regain its vital signs. The most obvious environmental impacts that using biomass for energy production are:

- Biomass can produce a considerable amount of energy beside the fact that it can have almost zero carbon footprint if used in a proper way. For example, even burning biomass can be clean low on pollution if burnt at a specific temperature.
- Forest residues, animal wastes and municipal wastes would be used for a good cause instead of dumping them and polluting the soil and water.

- Greenhouse gas emissions would be kept under control, minimizing the carbon dioxide and other toxic gases from our Earth's atmosphere.

Social and Rural Impact

Consumption of renewable energies in rural areas specifically has a positive direct impact on social and rural development in those areas.

The use of biomass for energy production can present the following impacts in rural areas:

- Minimizing unemployment by creating job offers in many fields like farming, installation of boilers, and power plants where electric energy from biomass is produced.
- Low energy bills since biomass is way cheaper than any fossil fuel used nowadays.
- Attraction of investments in the field of energy production improving the economic status of the rural area.
- Touristic attractions.
- Encouraging the investments in new farms and the production of energy crops and energy forests.
- Minimizing migration of the habitants and the youth by creating the favorable conditions of job offers and proper livelihood.
- Educating people and informing them about their strong impact upon the environment and the steps that should be taken in order to live at peace with our surrounding.
- Starting educational courses at schools about farming, agriculture and renewable energies.
- Creating extra money for land owners that would sell their share of energy crops and biomass to energy producing units.
- Innovating and rejuvenating the area with numerous projects knowing that the economic status would be considerably blooming.
- Raising the family incomes in rural areas by producing their own energies, would give them the ability to invest in other projects that lead to rural development.
- Sustaining the farm's stability and evolution towards future expansions that lead to a larger paprika production.

1.10. Conclusion

Shifting from an electric heating system to a wood chip based heating system can be beneficial in various fields; economic, environmental and social.

- Wood fuel is cost effective being economically competitive with other fuels used for heating also woodchips are often stable, not depending on exogenous factors such as fossil fuels.
- Wood chips are small in size and boilers can be fed through an automated system, being easy to store and producing a minimal amount of ash
- Wood chips are easily obtainable and available if properly used due to the fact that they are green, renewable resource and a sustainable fuel which does not produce carbon dioxide emissions which harm the environment. The amount of dioxide emitted through burning is roughly equivalent to the amount absorbed during the growth of trees.
- This wood chip boiler heating system is energy-efficient requiring minimal user input and easy cleaning labour as well as affordable maintenance and supervision.
- This wood chip heating system will be able to support local economies because the wood chips are locally produced providing more jobs for local people and businesses such as wood chip machine operators as well as transport companies, that can lead to energy independence.

The financial side for Tass-puszta to pursue the installation of a woodchip heating system are very good, favourable economics are driven by substituting an electric generator high-cost low-efficiency system for the more advantageous low-cost high-efficient heating system that runs on locally produced woodchips.

From an economic point of view, the investment and project costs, however, will be recovered in time through fuel cost savings.

1.11. References

[1]. http://www.worldenergyoutlook.org/media/weo2010.pdf

[2]. http://www.worldwatch.org/brain/images/press/news/vs05-world_oil.jpg

[3]. http://www.eria.org/Energy%20Situation%20in%20the%20World.pdf

[4]. https://energy.gov/science-innovation/energy-sources/fossil

[5]. International Atomic Energy Agency

[6]. http://energyinformative.org/fossil-fuels-pros-and-cons/

[7]. https://www.weforum.org/agenda/2016/04/4-charts-that-show-the-rise-of-renewables/

[8]. http://www.altenergy.org/renewables/renewables.html

[9]. http://www.se4all.org/sites/default/files/IRENA_RE_Jobs_Annual_Review_2016.pdf

[10]. https://mapcarta.com/18433856

[11]. https://www.worldweatheronline.com/v2/weather-averages.aspx?locid=971022&root_id=954533&wc=local_weather&map=~/tas-puszta-weather-averages/heves/hu.aspx

[12]. http://www.nationalgeographic.org/encyclopedia/biomass-energy/

[13]. http://www.sciencedirect.com/science/article/pii/S0958166908000542

[14]. http://www.altenergy.org/renewables/biomass-feedstocks.html

[15]. https://www.nasa.gov/centers/ames/news/features/2009/clean_energy_042209.html

[16]. https://energy.gov/eere/articles/making-algal-biofuel-production-more-efficient-less-expensive

[17]. ***Maxime Deniel, Geert Haarlemmer, Anne Roubaud, Elsa W.H., Jacques Fages, (2016). Energy valorisation of food processing residues and model compounds by hydrothermal liquefaction Book retrieved from URL.

[18]. *** Jonathan Wong, R. Tyagi, Ashok Pandey (2016). Current Developments in Biotechnology and Bioengineering: Solid Waste Management Book, retrieved from URL.

[19]. https://www.google.hu/search?q=wood+biomass&rlz

[20]. http://ec.europa.eu/eurostat/statistics-explained/index.php/Wood_as_a_source_of_energy

[21]. http://cooroyoutdoor.com/our-products/chainsaws/wooden-logs/

[22]. http://www.photos-public-domain.com/2010/10/03/red-wood-chips/

[23]. https://www.forestry.gov.uk/forestry/infd-9qqln7

[24]. http://www.framfuels.com/

[25]. http://www.biomasscenter.org/resource-library/fact-sheets/grass-energy-basics

[26]. http://onlinelibrary.wiley.com/doi/10.1002/elsc.200620128/full

http://ftp.jrc.es/EURdoc/JRC87124.pdf

https://energy.gov/eere/energybasics/articles/anaerobic-digestion-basics

[27]. http://www.biomasscenter.org/pdfs/Wood-Chip-Heating-Guide.pdf

[28]. https://www.slideshare.net/ConorDorman/improving-the-energy-efficiency-of-fota-wildlife-park

[29]. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/forest_guide_for_designers_and_architects_en

[30]. http://www.biomasscenter.org/pdfs/Wood-Chip-Heating-Guide.pdf

[31]. https://www.researchgate.net/figure/270398042_fig4_Fig-7-Combustion-ef-fi-ciency-characteristics-of-a-typical-woodchip-furnaceboiler

[32]. http://www.williamsrenewables.co.uk/biomass/woodchip-boilers/

[33]. https://www.google.hu/search?q=sustainable+development&rlz=1C1CHZL_enRO733RO733&source=lnms&tbm=isch&sa=X&ved=0ahUKEwj9hqTFmMPTAhXGJZoKHeYYAa4Q_AUICigB&biw=1536&bih=735#imgdii=8DWwk6VE79YLNM:&imgrc=ZmuRVt3bf1FUtM:

[34]. ***Dr. Robert Magda, Dr. Norbert Bozsik, Dr. Tamas Erdelyi, (2015). Sustainable Green Innovation. Gyongyos, Hungary: Vareg Hungary Commercial and Service Ltd.

Calculation and Design

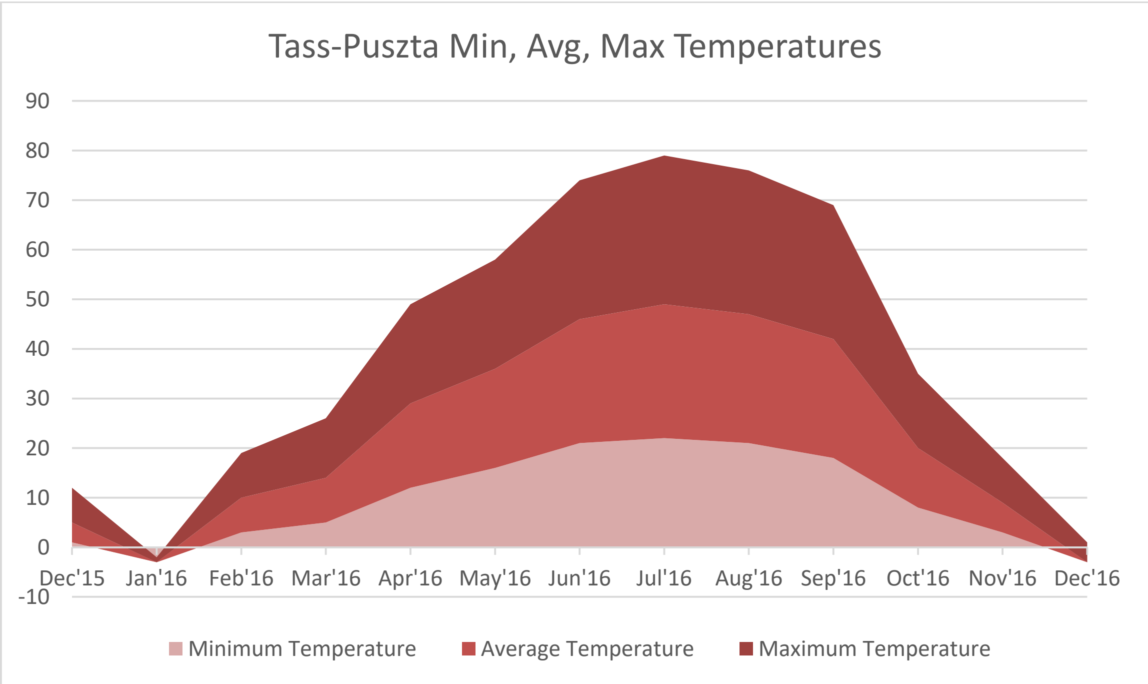
2. Calculations

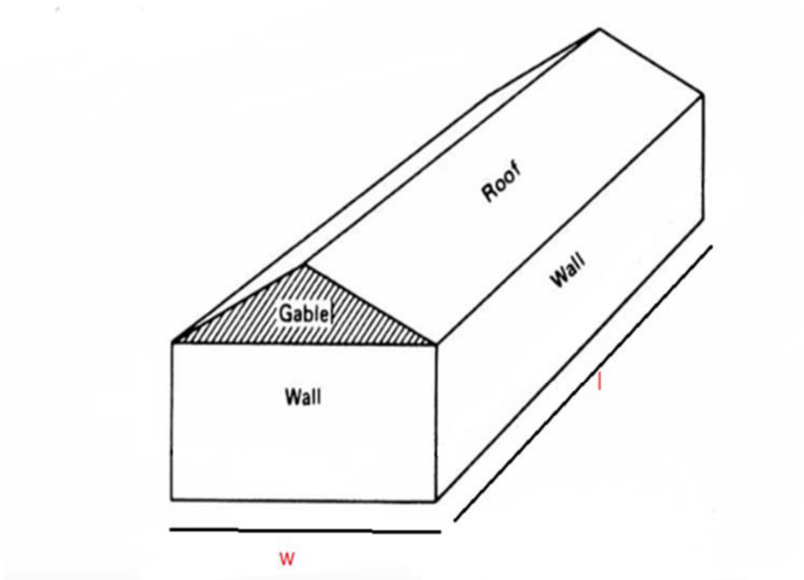
2.1. Temperature in Tass-puszta, Hungary

The following table and graph show an archive of temperatures recorded in Tass-puszta in year 2016. [x]

Month	Minimum Temperature	Average Temperature	Maximum Temperature
Dec'15	1	4	7
Jan'16	-3	0	1
Feb'16	3	7	9
Mar'16	5	9	12
Apr'16	12	17	20
May'16	16	20	22
Jun'16	21	25	28
Jul'16	22	27	30
Aug'16	21	26	29
Sep'16	18	24	27
Oct'16	8	12	15
Nov'16	3	6	9
Dec'16	-3	0	4

Table 5. Minimum, average and maximum temperatures in Tass-puszta 2016.





In order to calculate the heat demand of the greenhouse, it is essential to define the basic parameters of the latter. These parameters are defined as in the figure above.

Where:

l is the length of the greenhouse = 80 m

w is the width of the greenhouse = 10 m

H is the height of the wall = 4 m

h is the height of the gable = 1 m

2.2. Heat loss

Heat loss in this case can be calculated according to the results of three energy losses which include:

1. Structural heat loss
2. Thermal loss due to ventilation

2.2.1. Structural heat loss

Type of covering material	U Value (BTU/sq.ftºFhr)	U Value (W/sq.mK)
Glass single layer	1.1	6.2414
Glass double layer	0.7	3.9718
Glass triple layer	0.5	2.837
Polyethelene single layer	1.1	6.2414
Polyethelene double layer	0.7	3.9718
Double acrylic or polycarbonate	0.6	3.4044
Corrugated polycarbonate	1.2	6.808
Concrete block	0.5	2.837
Plywood	0.7	3.9718
Concrete poured	0.8	4.5392
Greenhouse with thin thermal curtain	0.3-0.7	1.7022-3.9718
Uninsulated perimeter	0.8	4.5392
Insulated perimeter	0.4	2.2696

Table 6. U value for structural through conduction.

The following considerations are taken into account:

- The roof and gable are made of a double glass layer
- The walls are made of double polyethylene layer
- The floor is made of poured concrete

In this case, the minimal outside temperature is considered to be $-3^0 C$

To calculate the structural thermal loss, the following relation is given:

$$Q = U \cdot A \cdot \Delta T$$

Where:

- Q is the heat loss measured in Watts
- U is the thermal loss coefficient $^{W}/_{(m^2 K)}$
- A is the area measured in m^2
- ΔT is the temperature difference; T_{inside}-$T_{outside}$ measured in Kelvin

Element	U (W/m^2K)	A (m^2)	ΔT (K)	Q (W)
Roof	2.409	800	25	48,180
Gable	2.409	10	25	602.25
Walls	2.049	720	25	43,362
Floor	2.38	800	18.85	35,890
Total Thermal Loss/ Energy demand				128,034.25

Table 7. Total thermal loss.

2.2.2. Thermal loss due to ventilation

Considering that the index of minimum renovation inside the greenhouse has a value of 1(1/h), we can calculate the minimum flow of air renovation and respectively the coefficient of thermal loss due to ventilation using the following relations:

$$V_i' = V_i \cdot n_{min}$$

$$H_{v,i} = 0.34 \cdot Vi \cdot n_{min}$$

Where Vi is the volume of the greenhouse under study.

Thermal power loss due to ventilation is calculated using the following relation:

$$Q_v = H_{i,v} \cdot \Delta T$$

Co-funded by the Erasmus+ Programme of the European Union

Interior Volume $[m^3]$	3,600
Outside Temperature [K]	270
Inside Temperature [K]	295
Minimum Index of air renovation [1/h]	1
Minimum air flow $V'min$ $[m^3/h]$	3,600
Thermal loss coefficient $H_{v,i}$ $[w\ /\ k]$	1,224
Thermal power loss due to ventilation [W]	30,600

Table 8. Thermal power loss through ventilation.

$$Q_{total} = Q_{structural} + Q_{ventilation} = 158{,}634.25\ W$$

2.2.3. Annual Heat Demand

Base temperature is defined as the temperature at which a building or any other type of construction does not need heating or cooling. It is also called comfort temperature. In this case of a greenhouse, base temperature is different from the normal base temperature of the city or location, because a greenhouse has to maintain a certain temperature at which the agricultural output remains intact. In our case of a paprika growing greenhouse, the base temperature is 18 degrees Celsius. The heat degree days is calculated utilizing the following relation:

$$HDD_{18} = (18 - T_{avg}) \times \text{Number of days}$$

For the calculation of HDD, during summer months, the boiler is not used due to the hot weather.

Month	Number of days	Average Temperature (°C)	HDD_{18}
January	31	0	558
February	28	7	308
March	31	9	279
April	20	17	20
May	-	20	-
June	-	25	-
July	-	27	-
August	-	26	-
September	-	24	-
October	31	12	186
November	30	6	360
December	31	4	343
Total HDD_{18}			2,054

Table 9. Total HDD

The annual energy demand can be calculated using the total HDD_{18} calculated above and the total heat loss Q_{total} as in the following relation:

$$E = \frac{HDD_{18} \cdot Q \cdot hours/day}{Tcomfort - Toutside}$$

Where,

- Q is the total heat loss expressed in kW

- Hours/day is the total heating hours per day, 24 hours in this case.

  Therefore, the annual energy demand is equal to 278,170 *kWh*

2.3. Pipe heating system

In order to calculate the necessary pipe length needed for the greenhouse, heat dissipated by 1m^3 of a steel pipe must be calculated.

Given:

$$\overline{q_l} = \frac{T_i - T_e}{\frac{1}{\pi d_i \alpha_i} + \frac{1}{2\pi\lambda_{st}} ln\frac{de}{d_i} + \frac{1}{\pi d_e \alpha_e}}$$

Where,

- $\overline{q_l}$ is the linear heat transfer.
- T_i is the water temperature.
- T_e is the exterior temperature, i.e. ambient temperature.
- D_i is the interior diameter of the pipe.
- D_e is the exterior diameter of the pipe.
- λ_{st} is the thermal conductivity of steel of which the pipe is made of.
- α_i, α_e are the heat convection coefficients.

α_i and α_e are calculated using the following relation:

$$\alpha = \frac{Nu \cdot \lambda}{l}$$

Where:

- Nu is the Nusselts number.
- λ is the thermal conductivity coefficient.
- L is the length of the pipe.

Nu can be calculated using the following equation:

$$Nu=0.135(Gr\times Pr)^{0.33}$$

Where:

- Gr is Grashof number
- Pr is Prandt number

Where Gr is calculated as follows:

$$G_r = \frac{g \cdot l^3 \cdot \beta(t_1 - t_2)}{\upsilon^2}$$

Where:

- g is the gravitational acceleration.
- L is the length of the pipe.
- β is the inverse of the average temperature in K.
- υ is the cinematic viscosity.

$$\beta = \frac{1}{T_m + 273.15} \; ; T_m = \frac{t_1 + t_2}{2}$$

Given,

Term	Symbol	Value	Unit
Exterior diameter	d_e	0.16	m
Interior diameter	d_i	0.14	m
Ambient temperature	T_e	25	°C
Water temperature	T_i	70	°C
Interior wall pipe temperature	T_{pi}	67	°C
External wall pipe temperature	T_{pe}	60	°C
Thermal conductivity of steel	λ_{st}	53	W/mK
Thermal conductivity of water at 70°C	λ_{water}	0.65	W/mK
Thermal conductivity of air at 25°C	λ_{air}	0.025	W/mK
Kinematic viscosity of air at 25°C	υ_{air}	15.5×10^{-6}	m^2/s
Kinematic viscosity of water at 70°C	υ_{water}	0.47×10^{-6}	m^2/s
Prandt's number for air at 25°C	Pr	0.69	-
Prandt's number for water at 70°C	Pr	2.99	-

Table 10. Given Values.

First case:

Convective heat transfer between the water and the interior pipe wall.

$$Tm = \frac{70 + 67}{2} = 68.5$$

$$\beta = \frac{1}{Tm + 273.15} = \frac{1}{68.5 + 273.15} = 0.002$$

$$G_r = \frac{9.8 \cdot 0.14^3 \cdot 0.002(70-67)}{(0.47\times10^{-6})^2} = 7\times10^8$$

$$Nu = 0.135(7 \times 10^8 \cdot 2.99)^{1/3} = 84.4$$

$$\alpha_i = \frac{Nu \cdot \lambda}{l} = \frac{84.4 \cdot 0.65}{0.14} = 391.8\ W/m^2K$$

Second case:

Convective heat transfer between the exterior pipe wall and the air.

$$Tm = \frac{60 + 25}{2} = 42.5$$

$$\beta = \frac{1}{Tm + 273.15} = \frac{1}{42.5 + 273.15} = 0.003$$

$$G_r = \frac{9.8 \cdot 0.16^3 \cdot 0.003(60-25)}{(15.5\times10^{-6})^2} = 2.1\times10^7$$

$$Nu = 0.135(2.1 \times 10^7 \cdot 0.69)^{1/3} = 18.99$$

$$\alpha_i = \frac{Nu \cdot \lambda}{l} = \frac{18.99 \cdot 0.025}{0.16} = 2.96\ W/m^2K$$

Then, $\bar{q}_l$ can be calculated as follows:

$$\bar{q}_l = \frac{70 - 25}{\frac{1}{\pi \cdot 0.14 \cdot 391.8} + \frac{1}{2\pi \cdot 53} ln \frac{0.16}{0.14} + \frac{1}{\pi \cdot 0.16 \cdot 2.96}} = 60\ W/m$$

Knowing the value of $\bar{q}_l$, we can calculate the total length of steel pipes needed using the following relation:

$$Q = \bar{q}_l \cdot l$$

Thus, $l = \frac{Q}{\bar{q}_l} = \frac{158{,}634}{60} = 2{,}643\ m$

2.4. Pressure loss

Pressure losses or drops of fluids passing through pipes usually occur for various reasons. Sometimes the fluid loses pressure throughout the installation and sometimes it gains pressure due to differences in elevation between the end and the start of the pipe.

Some of the reasons behind pressure loss are mentioned below:

- Friction between the fluid passing and the pipe wall.
- Friction between the layers of the fluid itself.
- Elevation differences.
- Existence of pipe fittings, bends, narrowing, and elbows.

It is essential to calculate the pressure loss throughout the system because the size of the chosen pump should be able to cover the pressure losses along the installation.

Flow Rate

The flow rate is calculated using the following relation:

$$\text{Flow rate} = \frac{1}{4} \cdot \pi \cdot d^2 \cdot V = 0.01\ \text{m}^3/\text{s}$$

where:

- D is the inner diameter of the pipe.
- V is the velocity of the fluid passing through the pipe, in this case the velocity of hot water is estimated to be around 1 m/s.

Reynold's number

$$R_e = \frac{V \cdot d}{\nu}$$

Where:

- V is the velocity of the fluid, 1 m/s.
- D is the internal diameter.
- υ is kinematic viscosity of water at 70°C.

R_e= 0.29×10^6 > 2,300; which indicates that in this case we have a turbulent flow.

To determine the friction coefficient λ, we have to use the calculation relation for turbulent flow considering the case of a smooth pipe as follows:

According to Filonenko's formula[x],

$$\lambda = (1.82\, log\, Re - 1.64)^{-2}$$
$$= (1.82 \log (0.29\times10^{6}) \text{- } 1.64)^{-2}$$
$$= 0.014$$

<u>Linear pressure loss or head loss</u>

$$h_l = \lambda \frac{l}{d} \cdot \frac{v^2}{2g}$$

Where:

- λ is the friction coefficient calculated above.
- l is the length of the pipe.
- d is the internal diameter of the pipe.
- v is the velocity of the fluid, in this case water, passing through the pipe.
- g is the gravitational acceleration.

$$h_l = 0.014 \cdot \frac{2{,}400}{0.14} \cdot \frac{1^2}{2 \cdot 9.8}$$
$$= 12.2 \text{ m} = 1.196 \text{ bar}$$

<u>Local pressure loss</u>

$$h_s = \Sigma\xi \frac{v^2}{2g}$$

Where:

- ξ is the local pressure loss chosen to be equal to 0.138. [x]
- v is the fluid velocity.
- g is the gravitational acceleration.

$$h_s = 1000 \cdot 0.138 \cdot \frac{1^2}{2 \cdot 9.8}$$
$$= 7 \text{ m} = 0.68 \text{ bar}$$

Total pressure loss = linear pressure loss + local pressure loss
= 1.196 + 0.68
= 1.876 bar

Which implies that the adequate pump pressure to recover the pressure losses in the system is that of 2 bar.

2.5. Sizing the buffer tank

The buffer or reservoir is considered to have (3…5) times the debit of the pump, which means that the reservoir should be able to feed the pump with fluid independently up to almost 4-5 minutes until it dries out.

In this case:

Flow rate= 0.01 m^3/s = 600 l/min

So, the buffer tank should be 5 times the flow rate = 5 × 600 = 3,000 l

2.6. Yearly amount of wood chips

The yearly amount of wood chips is based on 3 important factors:

- The yearly head demand measured in kwh/year
- The heating value of woodchips measured in kwh/kg, in this case, the woodchips are considered to be of 30% moisture [x]
- The efficiency of the boiler %

$$\text{Wood chips (kg/year)} = \frac{E/year}{H'(M)30 \cdot Ef\%}$$
$$= \frac{278{,}170}{3.4 \cdot 80\%}$$
$$= 102{,}268 \text{ kg/year} = 102 \text{ tons/year}$$

Budget and Economic Analysis

Denomination	Units	Cost (€)	Total Cost (€)
Boiler GILLES HPK-RA 160 kW	1	€ 20,000.00	€ 20,000.00
Steel pipes (1 meter)	2,400	€ 8.28	€ 19,875.00
Expansion vessel (400 l)	1	€ 680.00	€ 680.00
Buffer tank (3000 l)	1	€ 2,300.00	€ 2,300.00
Accessories	NA	€ 1,500.00	€ 1,500.00
Installation	NA	€ 1,000.00	€ 1,000.00
Maintenance	1	€ 200.00	€ 200.00
Check valve	3	€ 150.00	€ 450.00
Water pump (4 bar)	1	€ 230.00	€ 230.00
Transport fees	NA	€ 620.00	€ 620.00
Auger	1	€ 2,440.00	€ 2,440.00
		TOTAL GREENHOUSE HEATING	€ 49,295.00
		MATERIAL EXECUTION BUDGET	€ 49,295.00
		13% OF GENERAL EXPENSES	€ 6,408.35
		6% OF INDUSTRIAL BENEFITS	€ 2,957.70
		SUBTOTAL	€ 58,661.05
		21% TVA	€ 12,318.82
		TOTAL BUDGET	**€ 70,979.87**

Considerations	
Capital cost	€ 70,979.87
Estimated energy production	797,440 kW
Annual energy loss	0,5%
Pellet cost	0,04€/kW
Gasoil cost	0,059€/kW
Wood chip annual increase	0,4%
Gasoil annual increase	3,5%
Discount rate	4,02%
O&M cost	€ 456
Investment period	20 years
Grant	35%

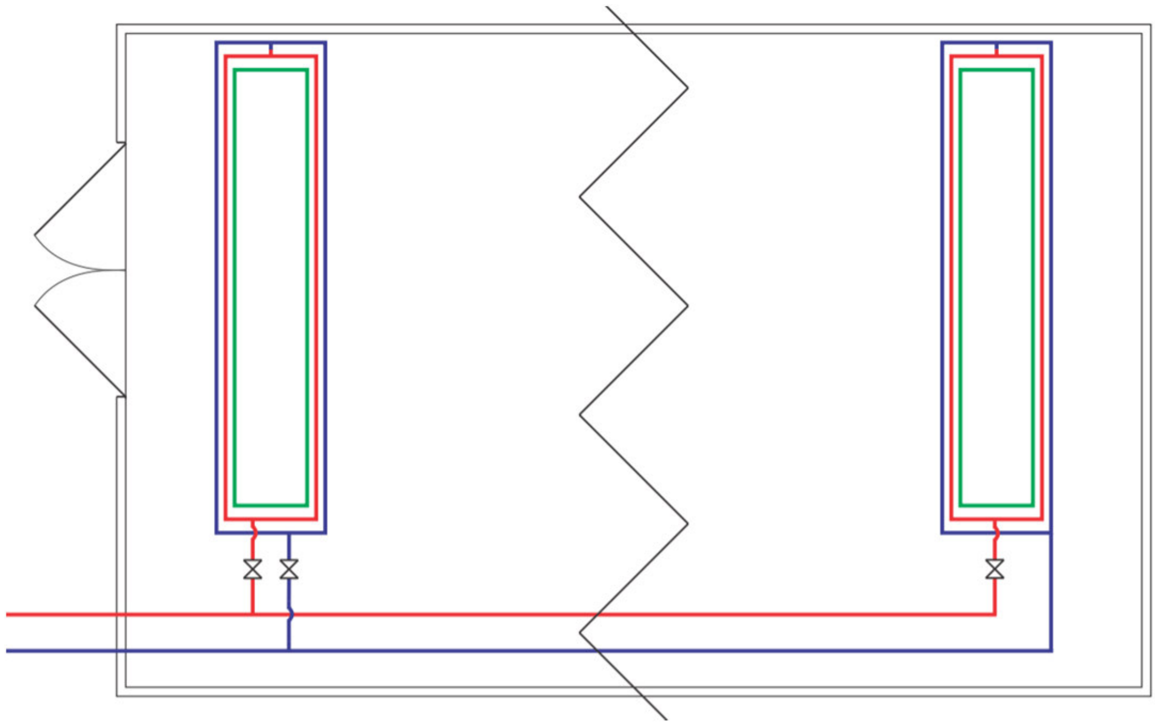
Year	Energy Production (kWh/year)	Wood chip cost (€/yea	Gasoil cost (€/year)	Estimated savings (€/year	O&M cost (€)	Cash flow (€)	Cumulative cash flow (€)
0							
1	€ 797,440.00	€ 31,897.60	€ 47,048.96	€ 15,151.36	€ 456.00	€ 14,695.36	€ 14,695.36
2	€ 793,452.80	€ 31,865.62	€ 48,452.19	€ 16,587.13	€ 456.00	€ 16,131.13	€ 30,826.49
3	€ 789,485.50	€ 31,832.05	€ 51,316.55	€ 19,484.50	€ 456.00	€ 19,028.50	€ 49,854.99
4	€ 785,538.00	€ 31,798.50	€ 52,631.05	€ 20,832.50	€ 456.00	€ 20,376.50	€ 70,231.49
5	€ 781,610.30	€ 31,764.60	€ 53,931.10	€ 22,166.50	€ 456.00	€ 21,710.50	€ 91,941.99
6	€ 777,702.20	€ 31,730.24	€ 55,216.80	€ 23,486.56	€ 456.00	€ 23,030.56	€ 114,972.55
7	€ 773,813.68	€ 31,695.40	€ 56,488.39	€ 24,792.99	€ 456.00	€ 24,336.99	€ 139,309.54
8	€ 769,944.60	€ 31,660.12	€ 57,745.80	€ 26,085.68	€ 456.00	€ 25,629.68	€ 164,939.22
9	€ 766,094.87	€ 31,624.39	€ 58,989.30	€ 27,364.91	€ 456.00	€ 26,908.91	€ 191,848.13
10	€ 762,264.39	€ 31,588.20	€ 60,218.80	€ 28,630.60	€ 456.00	€ 28,174.60	€ 220,022.73
11	€ 758,453.06	€ 31,551.64	€ 61,434.69	€ 29,883.05	€ 456.00	€ 29,467.05	€ 249,489.78
12	€ 754,660.79	€ 31,514.60	€ 62,636.80	€ 31,122.20	€ 456.00	€ 30,666.20	€ 280,155.98
13	€ 750,887.48	€ 31,477.20	€ 63,825.40	€ 32,348.20	€ 456.00	€ 31,892.20	€ 312,048.18
14	€ 747,133.04	€ 31,439.30	€ 65,000.00	€ 33,560.70	€ 456.00	€ 33,104.70	€ 345,152.88
15	€ 743,397.37	€ 31,401.10	€ 66,162.30	€ 34,761.20	€ 456.00	€ 34,305.20	€ 379,458.08
16	€ 739,677.38	€ 31,362.30	€ 67,310.60	€ 35,948.30	€ 456.00	€ 35,492.30	€ 414,950.38
17	€ 735,978.90	€ 31,323.26	€ 68,446.03	€ 37,122.70	€ 456.00	€ 36,666.70	€ 451,617.08
18	€ 732,299.00	€ 31,283.81	€ 69,568.40	€ 38,284.59	€ 456.00	€ 37,828.59	€ 489,445.67
19	€ 728,637.50	€ 31,243.97	€ 70,677.83	€ 39,433.86	€ 456.00	€ 38,977.86	€ 528,423.53
20	€ 724,994.30	€ 31,203.75	€ 71,774.40	€ 40,570.65	€ 456.00	€ 40,114.65	€ 568,538.18

Year	Payback (€)	Payback with grant (€)	NPV (€)	NPV with grant (€)
0				
1	€ (56,284.51)	€ (31,441.56)	€ (56,852.43)	€ (32,009.40)
2	€ (40,152.38)	€ (15,310.43)	€ (41,943.80)	€ (17,100.70)
3	€ (21,124.88)	€ 3,718.07	€ (25,029.57)	€ (186.47)
4	€ (748.38)	€ 24,094.57	€ (7,613.75)	€ 17,229.34
5	€ 20,962.12	€ 45,805.07	€ 10,225.60	€ 35,068.60
6	€ 43,992.68	€ 68,835.63	€ 28,417.19	€ 53,260.10
7	€ 68,329.67	€ 93,172.62	€ 46,896.30	€ 71,739.20
8	€ 93,959.35	€ 118,802.30	€ 65,604.00	€ 90,446.20
9	€ 120,868.26	€ 145,711.21	€ 84,487.40	€ 109,330.20
10	€ 149,042.86	€ 173,885.81	€ 103,485.70	€ 128,328.60
11	€ 178,469.91	€ 203,312.86	€ 122,569.39	€ 147,412.20
12	€ 209,136.11	€ 233,979.06	€ 141,687.96	€ 166,530.70
13	€ 241,028.31	€ 265,871.26	€ 160,796.52	€ 185,639.20
14	€ 274,133.01	€ 298,975.96	€ 179,866.04	€ 204,708.70
15	€ 308,438.21	€ 333,281.16	€ 198,861.16	€ 223,703.80
16	€ 343,930.51	€ 368,773.46	€ 217,760.14	€ 242,602.70
17	€ 380,597.21	€ 405,440.16	€ 236,525.08	€ 261,367.60
18	€ 418,425.80	€ 443,268.75	€ 255,141.51	€ 279,984.00
19	€ 457,403.66	€ 482,246.61	€ 273,579.47	€ 298,421.90
20	€ 497,518.31	€ 522,361.26	€ 291,821.69	€ 316,664.10

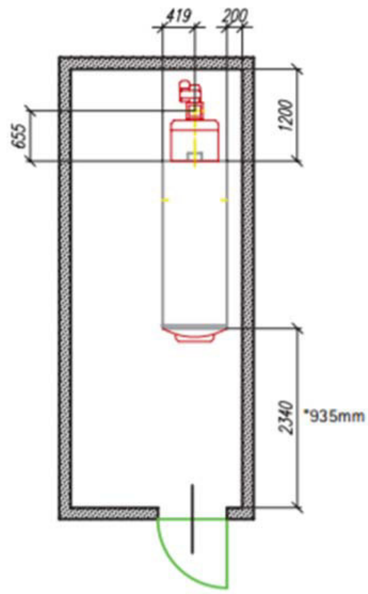
Payback	4 years
Payback with grant	2 years
NPV	4 years
NPV with grant	3 years
IRR	4 years
IRR with grant	3 years

Project Plans

I. Greenhouse



II. Boiler



Co-funded by the Erasmus+ Programme of the European Union

REPORT OF THE CASE STUDY ON RENEWABLE ENERGIES TO LOCAL

DEVELOPMENT TRANSNATIONALLY IMPLEMENTED

Differences between 2 PV systems in irrigation

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UMANS – Urbanisme i Medi Ambient Nebot i Segarra

La Vall d'Uixó, March-April 2017

Contents of the project

Memory of the project

1. Introduction to the Project

For centuries people have looked for ways to improve their life starting with the fundamental needs. Agriculture, then as now, is the biggest provider of our food and raw materials for industries. However, agriculture depends on many factors such as the quality of the seeds, mineral in the soil, geographical position, as well as the quantity of water and climate. The last two are interdependent because water can be provided from rivers (Figure 1) in the area as well as from precipitation.

Another option to provide water for irrigation is to install a special pump in the soil through the groundwater powered by photovoltaic panels (Figure 2). This system can be used as the main system of irrigation as well as a backup system. Although renewable energy (RE) makes a low impact on the environment, a farmer or a company may benefits from other important advantages of it like: energy independence, sustainability or low cost of energy.

Figure 1. Irrigation from river [1]

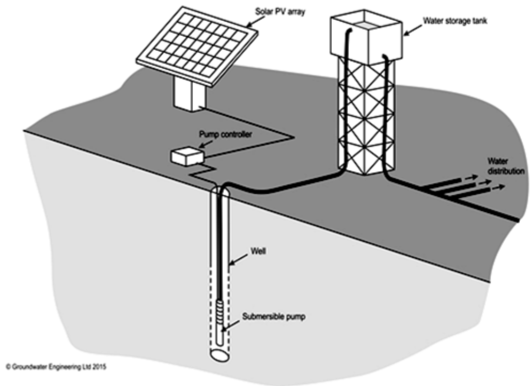

Figure 2. Off-grid irrigation system [2]

Renewable energy has a great impact on rural areas. Besides maintaining the energy requirements for private contractors, RE can fulfil the need of an entire rural society:

- Low-price energy – even though the initial price is substantial, in the medium and long time terms, the price of renewable energy is low and sustainable.
- Economic growth – by decreasing the price of energy, people and companies have more capital for spending on their needs, which can lead to a better economic cycle.
- Energy independence – RE can be installed in places were connection to the grid represents technological difficulties or high construction costs.
- Job opportunities – this can happen directly by creating jobs in the field or indirectly by decreasing the cost of energy of the companies resulting in more capital for human resources
- Modern design – equipment of renewable energy sources has a futuristic design and gives a modern touch to rural environment.
- Young people – with the benefits of increased job opportunities and life stability, young people tend less to move in different locations.
- Variety for personal/ industrial use – it depends on the technology, the profile of the customer can change depending on the need.

Even more, the benefits of RE can be noticed on a worldwide scale. For example, in 2015 the International Renewable Energy Agency (IRENA) has recorded that "8.1 million people were hired in renewable energy industry from which almost 2.8 million jobs were in solar energy (Figures 3 and 4) all around the globe with an increasing trend."[3]

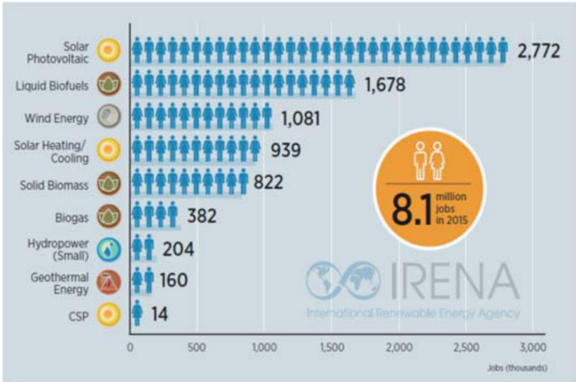

Figure 3. Renewable Energy Employment by Technology[3]

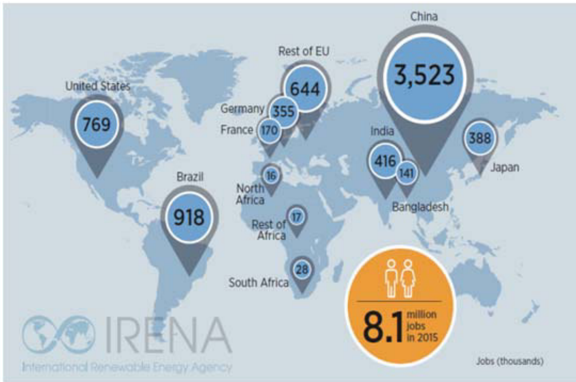

Figure 4. Renewable Energy Employment in Selected Countries and Regions[3]

Another important factor that awakes the interest for alternative energy sources is given by limited fossil fuel resources. Therefore, sustainability has become a big part of research for the new technologies. The emergence of these technologies is built on principles gained over time. In consequence we start harvesting energy from endless sources of natural energy. The interest in sustainable energy can be seen in international statistics. For example, from 2014 to 2015 it has registered in amount of +3.5 % of RE power (Figure 5 and 6). [5]

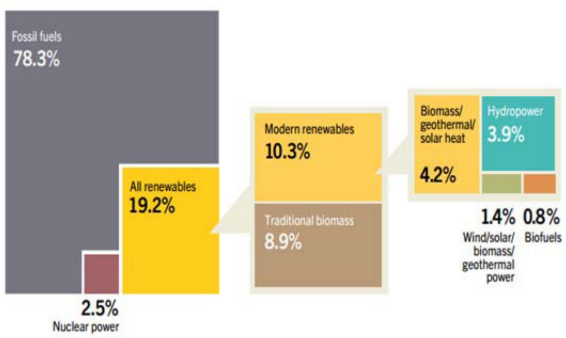

Figure 5. Estimated Renewable Energy Share of Global Final Energy Consumption, 2014[5]

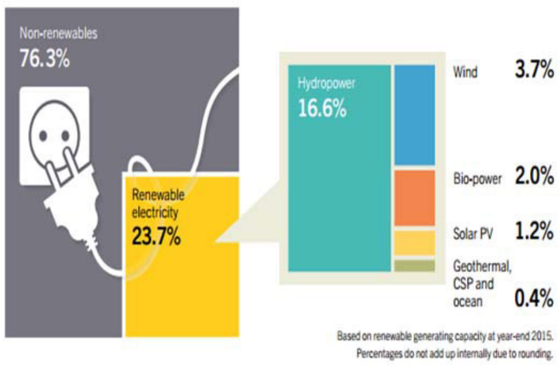

Figure 6. Estimated Renewable Energy Share of Global Electricity Production, End–2015[5]

To define the RE industry, governments have set up laws and directives in order to facilitate growth. The legislation is different in each country but they are align with the International Conferences on Environment and Renewable Energy (ICERE), World Future Energy Summit (WFES), EU Directives (e.g. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC).[4]

1.1. Objectives of the project

One of the objectives of the project is to ensure the information needed to design a photovoltaic system that will produce enough energy for an underground pump. The pump has to irrigate 75.660 m^2 of agriculture land as shown in Table 1. The calculation will be related to the summer month being the main demand.

Month	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Hours	3	4	4	5	5	5	4	3	2

Table 1. Irrigation hours per day

On the other hand, the social impact has to be taken into account. The introduction of any new technologies in the rural environment has to protect and preserve the ecosystems of the areas as well as the traditions and habits. In the context of the modern lifestyle and the evolution of the society, RE can fulfil the socio-economic aspects.

1.2. Scope

According to a European Union (EU) report from 2012, "More than half (51.3 %) of the EU's land area is within regions classified as being predominantly rural". However, the population located in those areas represent just 22.3 % of EU-27 population with 112.1 million people" [6]. In data registered in 2015, after Croatia's accession to the EU (2013), the distribution of urban-rural population has changed as shown in Figure 7 and Figure 8.

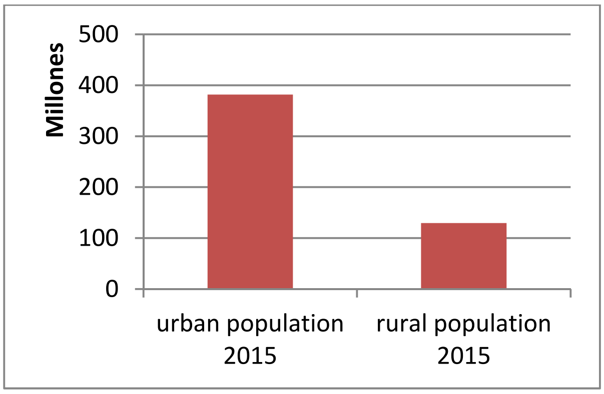

Figure 7. Urban – Rural population [7]

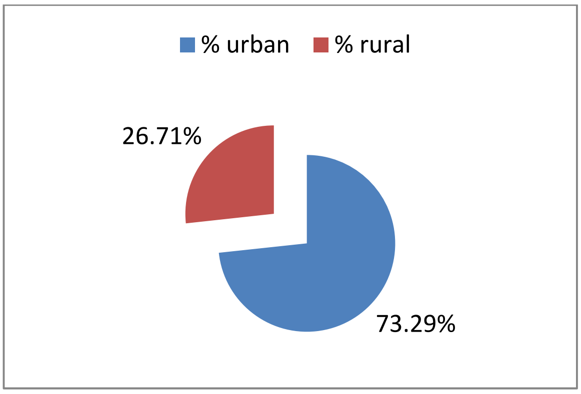

Figure 8. Urban – Rural percentage [7]

Within this context were rural areas which represent half of EU surface and include just one fourth of the population, this project aims to design one type of system that may improve life conditions for the habitants. This initiative came as a result of many researches that showed the benefits of a well-developed province.

According to the Renewable Energy to Rural Development Summary (Brief for Policy Makers), RE offers to rural areas:

- Affordable and sustainable energy that triggers the economy;
- Development of new income sources as a result of innovation of new products;
- Expansion of businesses thanks to technological advancement leading to new jobs for entire population;

- Strengthened tax base that comes with improvement of public services within the possibility of a development plan of the area;
- Growing population as a result of better life condition and determination of young people not to migrate to big cities. [8]

1.3. Location of the project

The location of the project is situated near to a town named Jérica (in Valencian Xèrica) in Castellón province of Valencian Community, Spain. (39°54′ N 00°34′ W) presented in Figure 9. In the 2009 census, Jérica registered 1703 habitants. The official language spoken by the citizens is Spanish and also the language spoken by most of the people in the region,"Valencià". [9]

Figure 9. The location of Jérica [10]

The municipality has an area of 78.30 km². It is crossed by the river Palancia, and an area in the south is part of the Calderona mountain range. The town centre is located at a height of 523 m, on a rocky promontory along the Palancia river channel. The precipice valley is very difficult to access and therefore, the population has settled in the opposite direction, along the slope of the hill. [9]

The first proves of actual settlements originate from the XI century in period of Muslims but also there are evidences of human activities from Neolithic period. Iberians and Romans have left proves of their presence in Jérica's history.

One of the challenges of the project is to introduce modern technologies in a traditional environment without disturbing the landscape, the culture and the social life of the habitants.

The climate of Jérica is classified as "warm-temperate subtropical climate" or after Köppen-Geiger system as Csa. With an average temperature of 14,5 °C this climate behaviour is given by the presence of the mountains and the Mediterranean Sea within the influences of geographical position. It also offers an average of 2689 hours of sunshine with 75 clear days/ year. The evolution of the sun during the year can be seen in the in following figures.

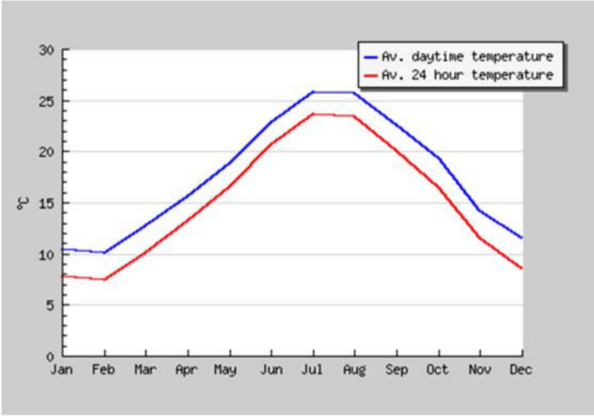

Figure 10. Average daytime temperatures in location of the project [11]

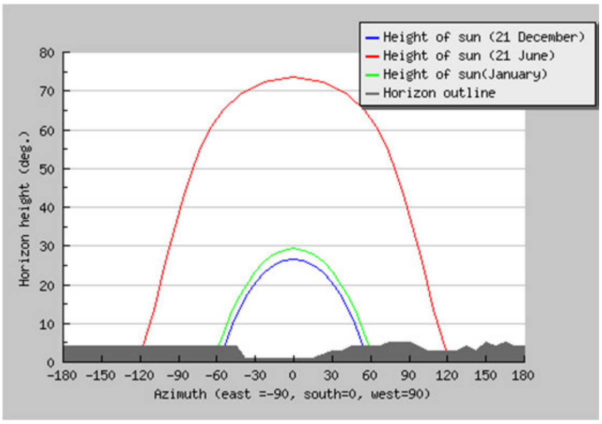

Figure 11. Height of the sun on the horizon outline [12]

For the particular case, the months evaluated are June, July and August. For these months, the official monthly average values of temperature, clear/ cloudy/ rainy/ stormy days and hours of sunshine are presented in Table 2.

Month	T	TM	Tm	R	H	DR	DT	DD	I
June	22.5	27.3	17.6	19	63	2.8	2.7	8.4	296
July	25.3	30	20.6	9	64	1.4	2.1	11.7	329
August	25.6	30.3	20.9	24	66	2.4	3.9	7.9	290

Table 2. Monthly average weather values [13]

T	Monthly average temperatures (°C)
TM	Monthly average of maximum daily temperatures (°C)
Tm	Monthly average of minimum daily temperatures (°C)
R	Monthly average rainfall (mm)
H	Average relative humidity (%)
DR	Monthly average number of rainfall days equal or greater to 1mm
DT	Monthly average number of stormy days
DD	Monthly average number of cloudless days
I	Monthly average number of hours of sunshine

This characteristic offers good conditions for the primary section of the economy (direct use of natural resources; e.g.: agriculture, forestry, fishing, and mining).

Traditionally, the primary sector has been of great importance in the Jericano economy. The agriculture of arid land has been important, producing *olive*, *carob* and *almond* crops. Recently, rural tourism has been an important sector relying on the medieval market. [14]

The placement of the installation is designed to be situated at a distance of 5-6 km away from the city, in an agricultural area of 75.660 m^2 designated to harvest 30 ha almond and 3 ha lavender for commercial purpose (selling the raw and derived products such as oil and essence).

1.4. Precedents

Photovoltaic panels are used to provide energy in rural environment for irrigation systems in many types of installations but all of them follow the principles (Figure 12: A & B). Mainly, the differences are made by the water sources, requirements needed by the water pump (power, flow, pressure) and the way of distribution of the power. Often, a generator is used as a back-up system in case of bad weather condition or during the maintenance of the PV-system.

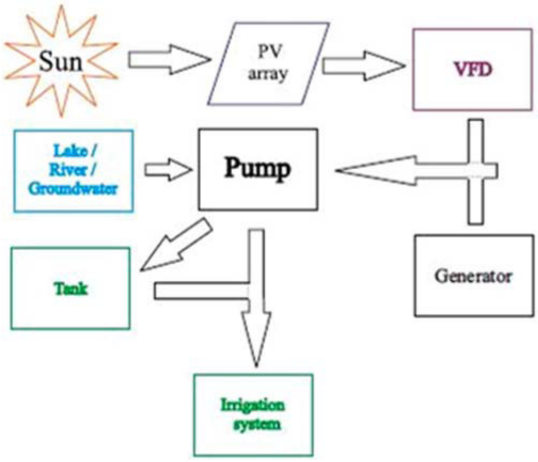

Figure 12-A. Irrigation system with VFD

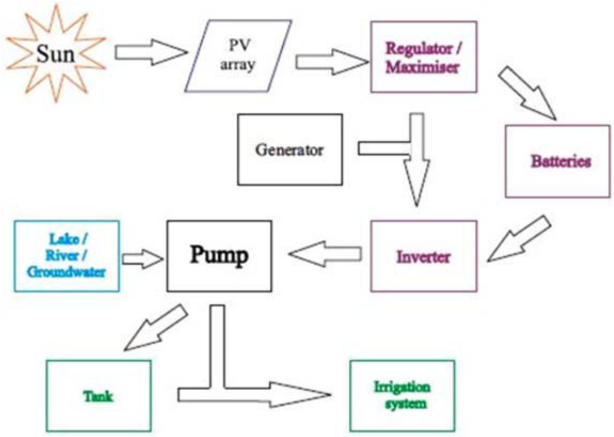

Figure 12-B. Irrigation system with batteries

To choose the most efficient system of irrigation, a technological and an environmental analysis is required. Starting from the amount of water (flow and pressure) needed, a water pump is chosen as in the following case (project made by Heliotec 2006 S.L. a Spanish SME from Castellón province). [15]

A project situated in Quargla (Argelia) had to provide 1.000 m^3 of water each day during the months of June, July and August froma depth of 120 m. The selection of the pump was made according to these requirements. As a result, a hydraulic pump of 125 CV – 92 kW, 380-415 V / 50 Hz; 460 V / 60 Hz was chosen. [15]

Analysing monthly radiation levels for 2 different angles (a – 0^o and b – 30^o ,Figure 13), average hours of radiation per month (Figure 14) and production curve for one kW system (Figure 15), the company designed a PV array for 27 kW compound by 90 modules with peak of 300 Wp organized in 6 parallel lines compound in series of 16’th PV panels. [15]

	Daily radiation [kWh/m²/day]	Days in month	Monthly radiation [kW/m²/month]
January	3,61	31,00	112
February	4,66	28,00	131
March	6,11	31,00	189
April	6,75	30,00	202
May	7,33	31,00	227
June	7,89	30,00	237
July	7,78	31,00	241
August	7,14	31,00	221
September	5,74	30,00	172
October	4,91	31,00	152
November	3,97	30,00	119
December	3,28	31,00	102
ANNUAL	5,77	365,00	2.110

a

	Daily radiation [KWh/m²/day]	Days in month	Monthly radiation [kW/m²/month]
January	5,61	31	174
February	6,45	28	181
March	7,23	31	224
April	6,99	30	210
May	6,88	31	213
June	7,05	30	211
July	7,11	31	220
August	7,11	31	220
September	6,42	30	193
October	6,33	31	196
November	5,94	30	178
December	5,27	31	163
ANNUAL	6,53	365	2384

b

Figure 13. Radiation per month on angle [15]

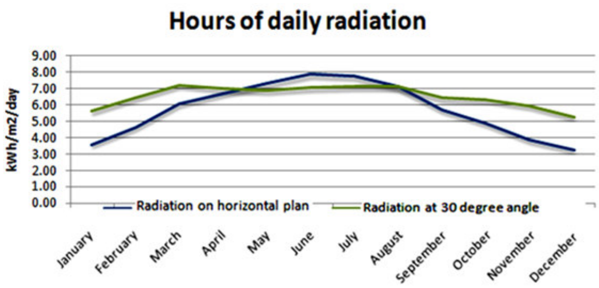

Figure 14. Hours of daily radiation [15]

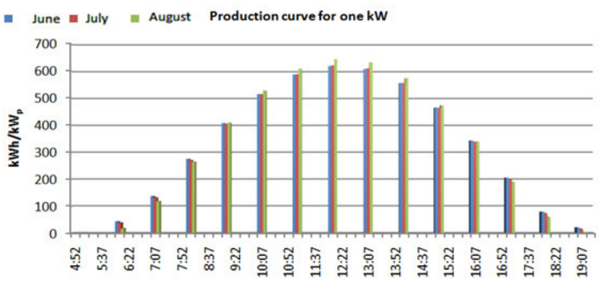

Figure 15. Production curve for one kW system [15]

This system is design to work through a variable frequency driver (VFD – check 1.5 E) that provides the capacity of running at different speeds of the engine offering accurate control. [15]

1.5. State-of-art in the problem domain

The challenging part of the project is to provide a more efficient system to provide energy for the existing irrigation system. The existing installation consists of a generator (Figure 16 - CTM-60 L, Carod) as source of energy for the pumps that execute the irrigation as shown in Figure 17.

Figure 16. Generator CTM-60 L, Carod [16]

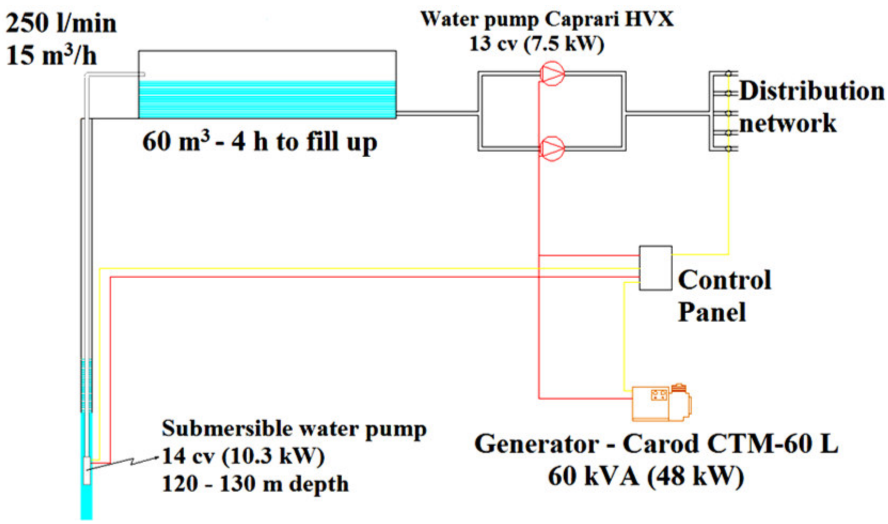

Figure 17. Previous Irrigation system [17]

The new system is design to replace the 3 pump with a more efficient pump regarding flow and consumption. The pump will be powered by the photovoltaic system that fits the best in demands of the contractor.

Starting from the power source, the system is a compound of the following:

A. Solar Radiation
B. PV panels : PV cells + designated structure
C. Charge controller : Regulator / MPPT
D. Battery
E. PV inverters or Variable frequency driver (VFD)
F. Loads
G. Other aspects

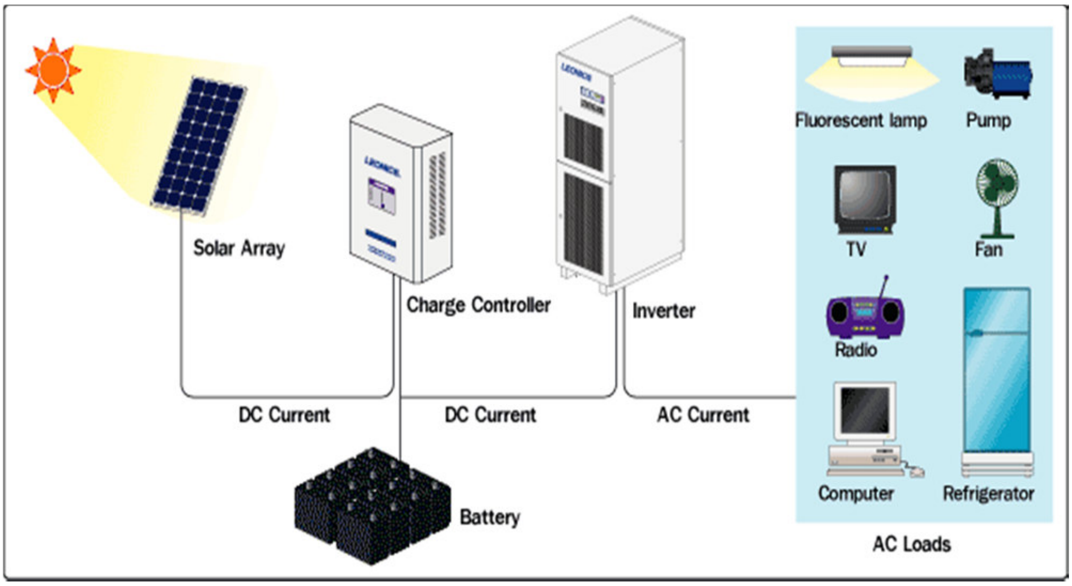

Figure 18. Components of Off-Grid PV System [18]

A. Solar Radiation.

Solar radiation is the main source of energy that turns into electricity inside photovoltaic cells via photovoltaic effect. This phenomenon occurs when solar radiation photons impact on a semiconductor surface. If the photon hits the semiconductor surface with enough energy, it releases an electron that leaves enough space for the electrons to move and generate an electric current as a consequence. [19]

Factors that influence the level of radiation over the PV-panel :

a. Radiation;
b. Inclination;
c. Losses due to shades;
d. Losses due to dirt;

a. Radiation.

Solar radiation is made up of groups of electromagnetic waves with different frequencies and, therefore, different energies. The representation of the energy of radiation according to the wavelength, or the frequency, is known as the spectrum. [19]

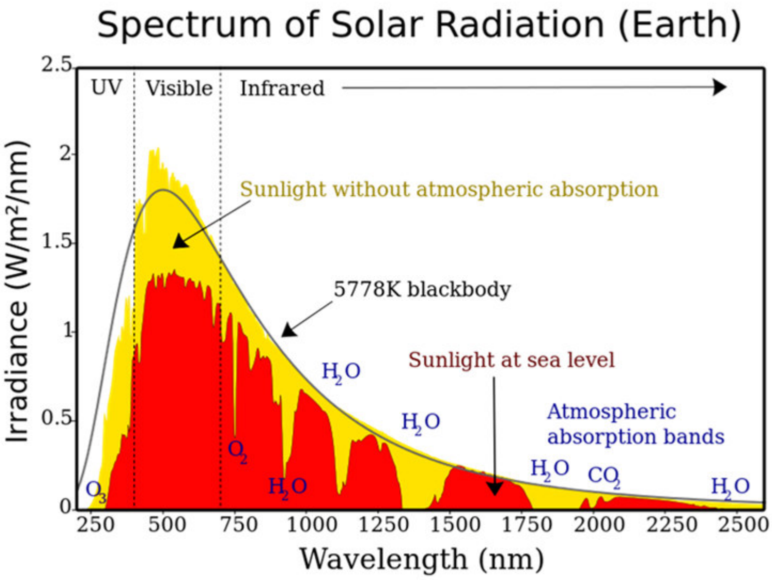

Figure 19. Solar Radiation Spectrum, by Robert A. Rohde [20]

From all the spectrum, the radiation that contributes for producing energy within PV panels have values between 390 nm and 750 nm is named as visible range. This type of radiation has the power to interact with materials used in the manufacturing of photovoltaic cells. [19]

The quantity of radiation can be different depending on the way of its distribution. Therefore, we have Direct Radiation, Diffuse Radiation and Reflected Radiation **(**Figure 20).

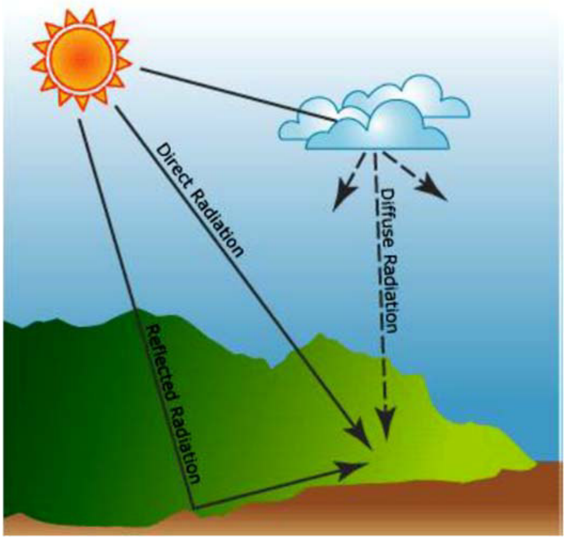

Figure 20. Radiation types World map by SolarGIS[21]

Incoming radiation provided by the sun from 1983 to 2005 - in Spain had in average values between 3 and 5 kWh (Figure 21) with a direct radiation between 1.5 and 4.2 kWh (Figure 22).

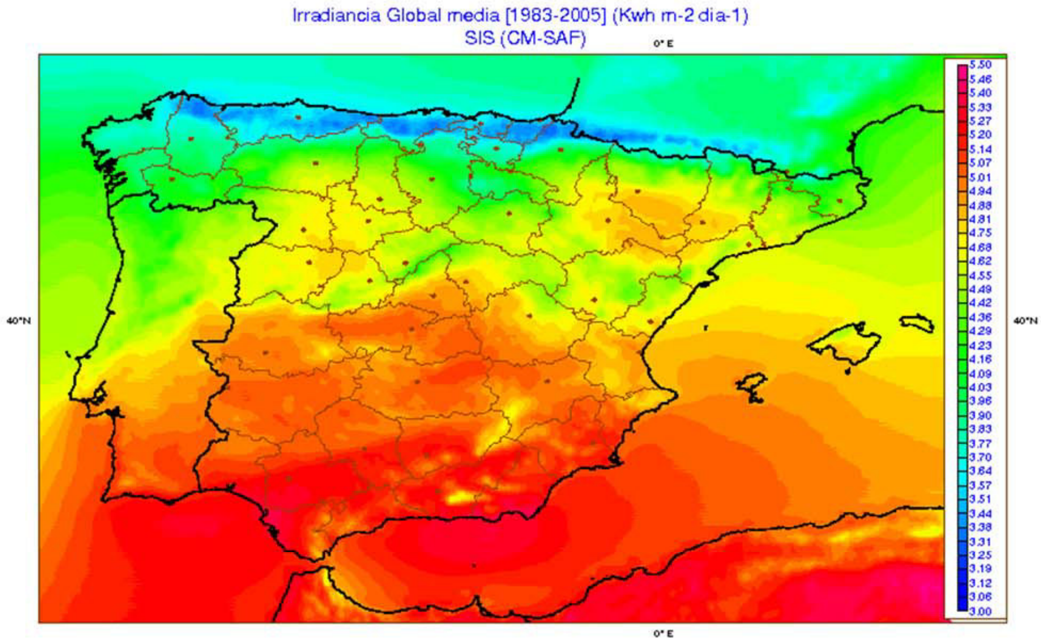

Figure 21. Incoming Radiation – Spain [22]

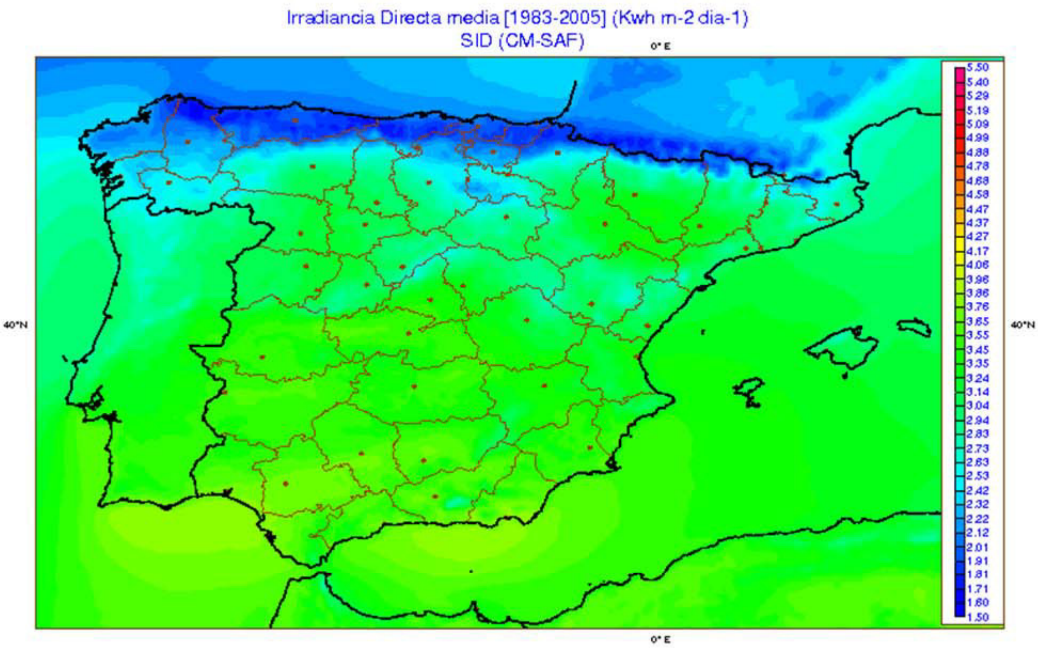

Figure 22. Direct Radiation – Spain [22]

Another important factor for radiation level is the "variation of solar energy flow" that includes [19]:

- *Geographical sunlight variation* (each surface gets a distinguished quantity of radiation depending on the geographical position);
- *Diurnal light variation*: caused by the rotation of the Earth around its own axis and its trajectory around the Sun. This daily variation produces changes in the solar radiation on a surface throughout the day and the months of the year (Figure 23)."

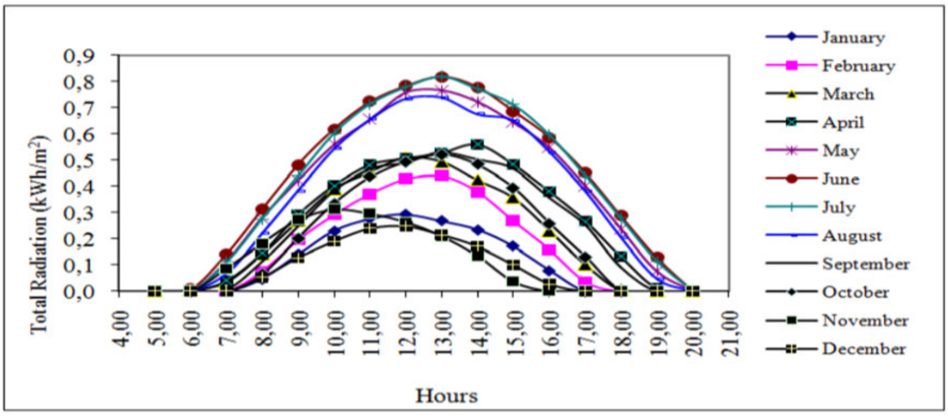

Figure 23. Diurnal Light Variation [19]

- *Elevation or altitude*. Surfaces situated at higher altitude above the sea level get a higher quantity of solar radiation because of thinner atmosphere and a shorter distance from the sun.

b. Inclination

Different angles between the surface and the sun can increase or decrease the efficiency of the PV-panels. The proper angle is variable during the day and year because of the continuous movement of the Earth and the Sun. To calculate the angle of the PV modules, there are three different situations that need to be taken into account:

Annual demand: $\alpha = \phi - 10$ Eq. (1) [19]

Summer demand: $\alpha = \phi - 20$ Eq. (2) [19]

Winter demand: $\alpha = \phi + 10$ Eq. (3) [19]

$\alpha = \phi - 20° = 39° - 20° = 19°$ Eq. (4)

α – angle; ϕ – latitude of the location

From practical consideration, the chosen angle is $\alpha = 20^o$ (Figure 24).

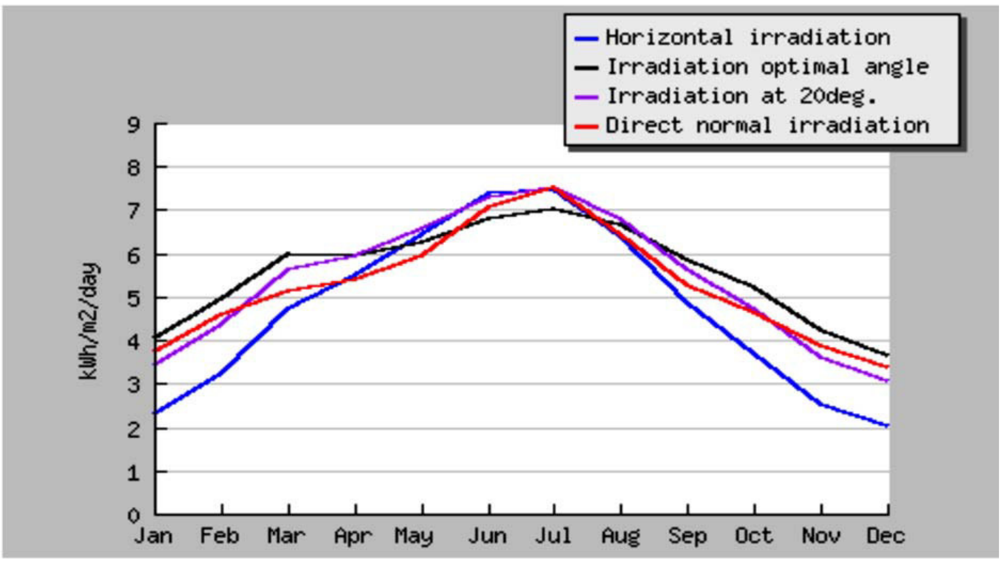

Figure 24. Irradiation by angle for PV Panel - PVGIS-CMSAF

c. Losses caused by shadow

Anything that comes between the Sun and the PV-panel can contribute to decrease the quantity of solar radiation leading to less efficiency. Shades on PV-panels can come from natural sources as clouds and trees but also from artificial sources as buildings, columns and other PV-panels situated too close to one to another.

d. Losses caused by dirt and dust

Photovoltaic systems are affected by dirt and dust because of the weather condition (wind) and placement of the systems (rural or heavy industry areas). Estimated losses in a normal environment are considered to be 5%.

B. PV panels : PV cells + designated structure

Advancement of technologies lead the companies to provide a wide range of photovoltaic cells made with different types of semiconductors:

Name	Material	Efficiency	Observation
Monocrystalline silicon	Same time of silicon crystals	Up to14-18 %	▪ highest efficiency ▪ high cost to produce the monocrystals
Polycrystalline silicon	Different types of silicon crystals	Up to 12-14 %	▪ High efficiency for a lower price
Amorphous silicon / Thin film panel	Non-crystal silicon	≈ 10%	▪ cheapest ▪ flexible ▪ used in curved and irregular surfaces
CIS and CISG	Copper, indium, selenide and gallium (CISG)	≈ 10%	▪ used in thin film modules
CdTe	Cadmium telluride	≈ 10%	▪ used in thin film modules
Others	Researchers are continuing to develop new technologies that produce electricity using photovoltaic cells.		

Table 3. PV Cells materials

PV cells are assembled on Solar Panels with different sizes and shapes. Most of the traditional PV panels are configured for fixed or mobile (with sun tracking systems) structures.

Fixed structures can be used as coplanar (parallel) structures or with inclination. Depending on the need (solar radiation, placement, costs and governmental regulation), engineers choose the proper structure. Coplanar structures are usually mounted on the roofs with a proper distance to ventilate the structure.


Figure 25. Coplanar PV Panels[23]


Figure 26. Inclined PV Panels[24]

To raise the efficiency, PV-cells can be assembled on PV panels with a sun tracking system. By changing the angle between the Sun and the surface (Figure 27), the cells can absorb more solar radiation intensifying the productivity by up to 40 %.

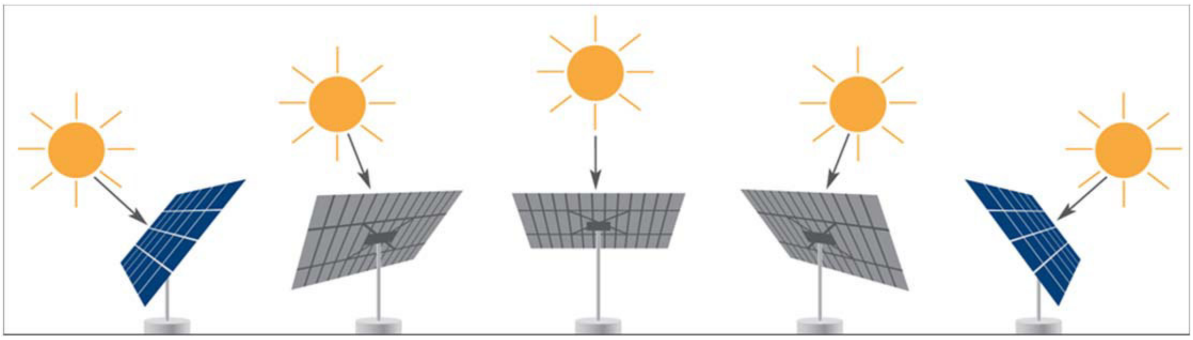
Figure 27. Sun tracking system [25]

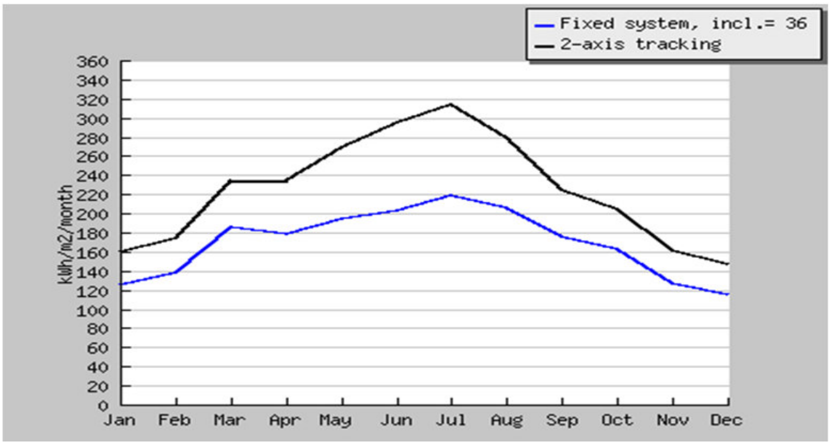

Figure 28. Fixed system vs. 2-axis Sun tracking system - PVGIS-CMSAF

C. Charge controller: Regulator / MPPT:

Regulator – It is an electrical component that controls the flow of DC from the PV panels to the battery to prevent overcharging or over-discharging. As a result, a regulator is a life optimizer for the batteries. They tend to have input voltages of 12 or 24 V, which limits their use with certain types of panels. [26]

MPPT (Maximum Power Point Tracking) – are an evolution from traditional charge controllers. These power converters analyse the energy flow of the photovoltaic panels and compare it with their internal algorithm to make the best use available. They enable the use of panels usually employed in grid connecting installations without problems, and they can even reach an input voltage of 150 Vcc. [26]

D. Batteries

A battery or a battery cell is a device that converts chemical energy into electric energy by moving electrons from a negative pole to a positive pole through a medium environment named electrolyte. It can be exploited for one cycle named dischargeable battery or for more named rechargeable battery by changing the poles. Batteries come in high diversity in electric power, sizes, number of cycles, dischargeable rate and purposes. The most common batteries used in PV installations are:

<table>
<tr><td>Name of the Battery</td><td colspan="4">Performance – Lifetime</td><td>Specifications</td></tr>
<tr><td>Monobloc Battery</td><td colspan="4">400 cycles to 75% of discharge</td><td>Recommended for vacation houses, caravans or ships as a result of low maintenance making it an economical battery.</td></tr>
<tr><td rowspan="5">GEL and AGM monobloc batteries [27]</td><td rowspan="2">Average Temp.</td><td>AGM ‘Deep Cycle’</td><td>Gel ‘Deep Cycle’</td><td>Gel ‘Long Life’</td><td rowspan="5">Low self-discharge (keep full charged for up to 6 months with no important charge losses).
Free gas emission during operation makes it optimal for solar installation, caravans and ships.</td></tr>
<tr><td colspan="3">Years</td></tr>
<tr><td>20°C</td><td>7-10</td><td>12</td><td>20</td></tr>
<tr><td>30°C</td><td>4</td><td>6</td><td>10</td></tr>
<tr><td>40°C</td><td>2</td><td>6</td><td>5</td></tr>
<tr><td rowspan="2">Semi-stationary monobloc batteries [28]</td><td colspan="4">Flat plate : 50-1000 cycles within 15-18 years at 80% discharge</td><td rowspan="2">Tubular batteries have the highest efficiency with low electrolyte pollution.</td></tr>
<tr><td colspan="4">Tube plate : 1100 – 1800 cycles in 20 years at 80% discharge</td></tr>
<tr><td>CPZS</td><td colspan="4">1500 cycles at 80% of discharge</td><td>Optimized for intensive use within a high rate of discharge Commercialized in 2V cells.</td></tr>
<tr><td>OPZS</td><td colspan="4">1500 cycles at 80% of discharge</td><td>With the option to see the electrolyte level and with low-maintenance, OPZS batteries are commonly used in PV installations.</td></tr>
</table>

Table 4. Batteries commonly used for PV installations

E. PV inverters and Variable frequency driver

Inverters have the ability to transform direct current (DC) into alternating current (AC). The process transforms the electricity stored in batteries or generated by PV panels (12V, 24V or 48V) into electricity required for appliances or the grid (voltage and frequency). Depending on the needs, an installation can use different types of inverters:

<table>
<tr><td>Grid-tie inverters (GTI)</td><td colspan="2">▪ to inject power in the grid, a GTI must have the same phase and the same voltage.
▪ the highest efficiency recorded for GTI goes up to 94-96%.</td></tr>
<tr><td rowspan="4">Stand-alone inverter (Figure 29)</td><td colspan="2">▪ frequently used for off-grid power systems .
▪ drains the power from the batteries and convert it to required characteristic of energy for the appliances.
▪ their efficiency depends on the type of the wave emitted:</td></tr>
<tr><td>Square wave inverter</td><td>▪ low price;
▪ noise made by harmonic interferences;
▪ recommended for small appliances.</td></tr>
<tr><td>Modified sine wave inverter</td><td>▪ best quality-price;
▪ the waves are similar to the sine waves;
▪ recommended for variable frequencies</td></tr>
<tr><td>Pure sine wave inverters</td><td>▪ the most efficient
▪ high cost in account of high technology required.
▪ generates pure sine waves.</td></tr>
</table>

Table 5. Inverters

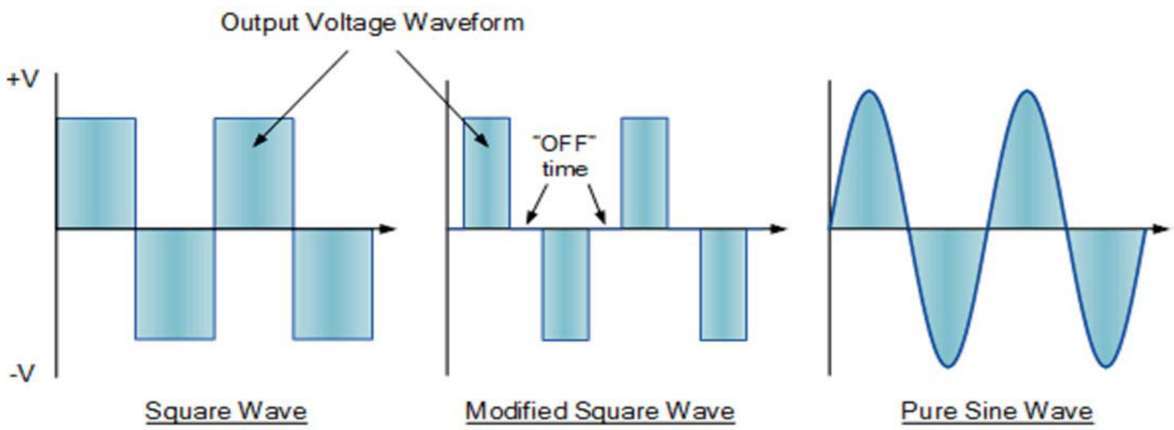

Figure 29. Stand alone inverter waves[29]

The variable frequency driver (VFD) or adjustable speed driver (ASD) has the ability to transform DC into AC through 6 isolated gate bipolar transistors (IGBT) that control the voltage and the frequency.

F. AC loads

AC loads represent the last link from the electric chain, shortly, the consumer of electricity. There are different for each chain, depending on the purpose of it. In Figure 18 a wide range loads are presented.

G. Other aspects

- Cell temperatures.

By warming the temperature of PV-cells, the semiconductor material is losing its properties to become a conductor. Depending on the technology and the material a PV module loses an average of 4% for every 10^{o}C.

- Losses made by wires

Wiring losses are due to their resistance to electrons movement named as "Joule Effect" ($P = R \times I^2$). DC losses may be as high as 1.5 % and AC losses can reach 3 %. [19]

Per total, by combining the elements we can find the following type of systems:

a) PV + VFD + Pump ± Tank → Consumption (Con.);	b) PV + Regulator/ MPPT + Batteries + Inverter + Pump ± Tank → Consumption (Con.)
▪ better control on the system: On/OFF ▪ multiple speed giving accuracy of flow and pressure; ▪ most frequently used for irrigation because of good grades for quality-price; ▪ recommended to be used with the tank; ▪ costs are compensated in time; ▪ difficult to use in changeable weather condition.	▪ the system can be used to provide energy for a variety of energy consumers; ▪ can be used in places with changeable weather; ▪ higher cost supplied by the extra equipment; ▪ costs are compensated in time.
* Efficiency of the PV system can be increased by using sun tracking system	

Table 6. Differences between systems

1.6. Design systems to be compared

For making the complete comparison of the systems, it is necessary to know initially, the equipment used for the installations. Both assemblies are designed to produce energy for the same load. Furthermore, the PV array will contain the same type of PV modules for making a fair comparison. The selection of the equipment is based on the cost-effective rate as well as the competence of devices in favour of high yield.

The final power consumer is a submersible water pump made from stainless steel produced by HN Bombas S.L. The pump model that coincides with the needs is GJ012-25 (Figure 30). In Figure 30 it is shown that at 130m depth, the pump provides 260 l/min. To do so, the three phase engine of the pump requires 11kW of energy.

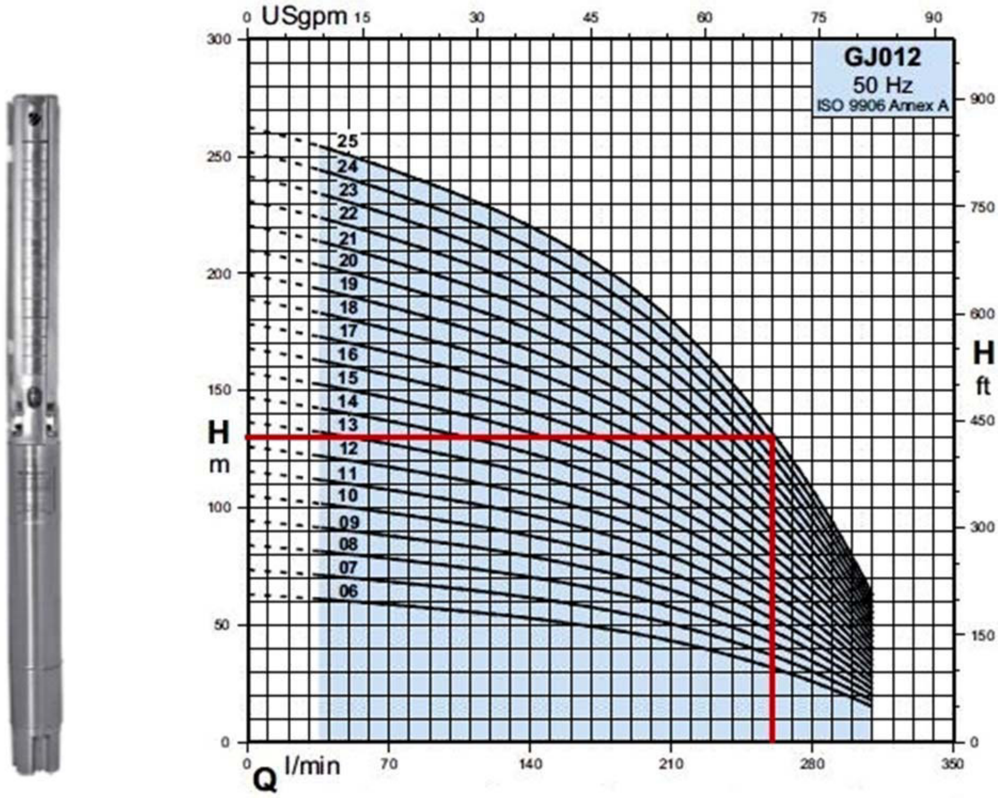

Figure 30. GJ012-25 Pump and flow graphic[30]

The energy required to feed the pump will be produced by PV modules AS-6P-310 (Figure 31) manufactured by Amerisolar Co. with a performance of 310 W per module at 17.01 % efficiency of conversion. The company assures a linear power warranty of 91.2 % of the nominal power after 12 years and furthermore 80.6 % of the nominal power after 30 years. This specification can encourage the payback while keeping high performance. The module is made from 72 polycrystalline cells (156x156 mm) distributed 6 x 12. Moreover, the frame of the module is design to support up to 5400 Pa. [31]

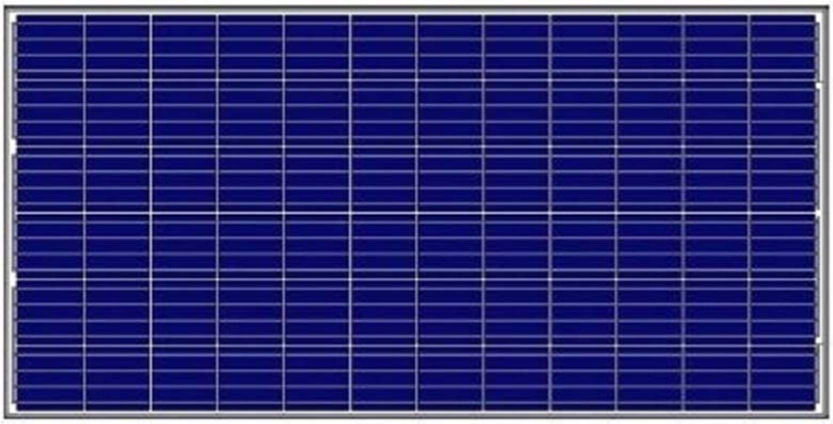

Figure 31. PV module AS-6p-310 [31]

To make the PV array, the modules will be placed on a structure provided by Turbo Energy Private Limited company that produces a variety of structures at different angles. Because the location of the project is in an agricultural area, the structure has to assure enough height to the modules for a good ventilation and also stability.

To complete the circuit and to connect the PV Array with the pump, it is designed to use one of the 2 ways described in the previous subchapters. As mentioned, the variable frequency driver (VFD) replaced by regulator/ MPPT, batteries and inverter. Each system has different influence over the system with different assets.

The VFD equipment (Figure 32) is selected to be in line with the pump demands as well as with the power of the PV array. As a consequence, the Iksut Solar 425 manufactured by Baico S.L. is preferred because it is able to transform the DC into AC at 11 kW. In addition, it is specially designed to drive a submersible pump for different activities, including irrigation. The body is light (8.5 kg) made from aluminium that helps the two fans from inside to cool down the mechanism. [32]

Figure 32. VFD Iskut Solar [32]

Even of presenting a lot of advantages including the replacement of Regulator/MPPT, batteries and inverter, the installations that include VFD cannot store the energy for being used in further time.

The regulator and the MPPT are used for the same purpose but there are some differences given by the efficiency of the system and the cost.

Regulator	MPPT
Harvesting the voltage from the PV panels while charging the batteries or giving energy to the inverter	
More like a connector between PV panels and the batteries or inverter.	Extracting the full potential from the PV panels in any conditions
Recommended for smaller installation	Works at high efficiency while used at bigger installations
Lower price	Higher price

Table 7. Regulator and MPPT

For the installation is designed to use a MPPT manufactured my Schneider Electric, a German company specialized in electric management that provides different types of electric equipment all around the world. To have a better link between the equipment, the inverter will be provided by the same company giving the opportunity to see the dates on the display for a better control.
The XW MPPT 80 600 model fits with the needs of the installation via its output up to 600 V in DC (operating range 195 – 550 V), load current of 80 A, maximum power at 4800 W

(45 ^{o}C) at an efficiency of 96 % nominal power for 48 V battery bank. Moreover, the load controller has incorporated protection for ground faults plus three selectable stages of algorithm for charging conferring manual control in order to maximize the performance according to the needs. The technology installed, Shade Tolerant Fast Sweep ^{TM} MPPT, cause better harvesting under partial shadow conditions. [33] The purpose of MPPT is to maximize the accumulation of energy and to offer a long life for the battery bank.

To store the energy, the system uses the batteries fabricated by Tab+ Batteries (Figure 33). The reason for using OPzS batteries include: low life discharge, high capacity, low maintenance (water level easy to be checked) and ergonomic. The manufacturer provides a wide range of batteries that provide from 60 Ah up to 2675 Ah in different conditions, recommended to supply energy for self or back up installations.[34]

Figure 33.Tab+ Battery - OPzS series [34]

The transfer from DC to AC is made by the Schneider inverter, Conext XW+ 5548 NA. This inverter has the ability to work on single phase as well as on three phases from 7 kW to 102 kW in temperatures that can reach 70 ^{o}C. The system is able to prioritize solar energy use, peak shaving, load shifting and assists generators with heavy duty loads. [35]In addition, the inverter is easy to install being mounted on the wall, share the same display with the MPPT making monitoring easier.

For back-up generator, the installation will use the existing generator shown in Figure 16. Although, to power the pump GJ012-25, it is required 25 % of the capacity of the generator resulting in pointless fuel burn and pollution. Another option could be the purchase of a smaller generator. An example of smaller generator is the one manufactured by Genesal Energy S.L., a company specialized in generators that can be used in different environments and purposes (Gas Generator, Diesel Generator, Hybrid Generators, Marine Generator, Light Tower, Generators for special power). Considering the needs of the system, the generator able to be used is XS Power Gen22KC with sound isolation (Figure 34) that covers the power needs. [36]

Figure 34.Genesal Generator XS Power Gen22KC [36]

1.7. Design of the PV array

Analysing the previews subchapter we can determin the type of structure needed to support the PV modules. The structures have to support 21 kW PV modules representing 68 modules separated in 17 modules/ set or 16 kW PV modules via 52 modules separated in 13 modules/ row. Each system will use the dimension of the module provided in Table 8 (1956x992x50 mm) and will contain 2 series per string (Figure 35).

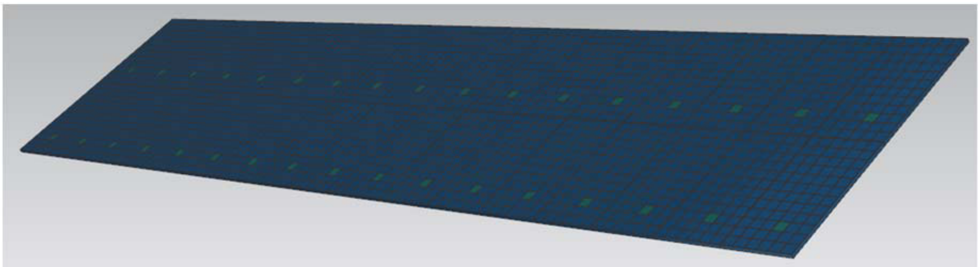

Figure 35. 2 series/ row – 21kW PV installation

The next requirement is to find the separation distance between the rows in order to have a minimum of 4 hours of sun over the PV panels in the shortest day of the year, 21 December (international regulation). For this it is required to know the length of the modules per set. The modules are placed on the structure at 20 mm to each other leading the calculation to the following:

$$2 \text{ (modules) x } 1956 + 20 = 3932 \text{ mm } (\approx 4 \text{ m}) \qquad \text{Eq. (5)}$$

Considering the proper angle to be $\beta = 20^{o}$ and the length of the set 4m, we can substitute the values shown in the Figures 36 to find the height.

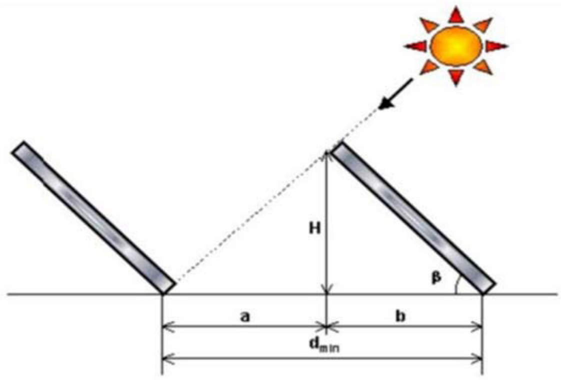

Figure 36. Separation distance [20]

$$H = \sin\beta \times lenght = \sin 20^\circ \times 4m = 0.342 \times 4 = 1.368\ m \qquad \text{Eq. (6)}\ [20]$$

$$b = \cos\beta \times lenght = \cos 20^\circ \times 4m = 0.939 \times 4 = 3.756\ m \qquad \text{Eq. (7)}\ [20]$$

$$a = \frac{H}{tg\,(61^\circ - place\ latitude)} = \frac{1.368}{tg\,(61^\circ - 39.9^\circ)} = \frac{1.368}{tg\ 21.1^\circ} = 4.786\ m \qquad \text{Eq. (8)}\ [20]$$

$$d_{min} = a + b = 4.786 + 3.756 = 8.542\ m \qquad \text{Eq. (9)}\ [20]$$

As a result, a minimum distance of 8.542 m can assure 4 hours of sun for both installations. In Table 8 the type of structure used is presented in order to make the PV array like in Figure 37.

Manufacturer	Turbo Energy	
Type	Aluminium structure bend at 20°	
Number of modules	4	2
For 21 kW system	8	1
For 16 kW system	6	1

Table 8. Type of structure

Figure 37. Model of PV array [37]

1.8. The impact of the project on rural development

As specified above, PV energy presents lots of benefits in rural areas. From economic growth due to low energy price, business stimulation, new job opportunities, low migration rate to big cities to energy sustainability. Depending on the amplitude of the PV installation, these factors can be in different proportion.

Another factor that influences the impact is the purpose of the installation. RE systems can be used for social reasons ordered by the government as well as for private contractors. Therefore, the size of the system can differ in many ways (Table 9).

Type of contractor	Government - society	Private
Dimension	Larger	Smaller
Energy demands	Higher	Lower
Complexity	Higher	Simpler
Cost	High – easier to sustain	High – harder to sustain
Other	Because the installation is for society, more persons have benefits from this	The contractor is the main beneficiary of the installation. Depending on the contractor needs, the private installation can increase in dimension, power and complexity.

Table 9. Difference between the contractors

It must be taken into account that both types are located in rural environments and the most important is to fit in the landscape as well as to preserve the environment while they assure the energy needs.

Over the years, interests in PV energy have grown. In particular in agriculture, all over the Earth there are different types of systems that provide irrigation water in different conditions from different sources. The most common type for isolated areas is the PV installation that uses the VDF in the circuit because of the following reasons:

- Less equipment in the circuit result in lower initial cost as well as easier maintenance;
- Irrigation is mostly required in sunny days when the Sun provides enough energy for the system. In cloudy or rainy days, even if the system does not have enough power for the pump, the irrigation may not be required;
- The VDF can start running the pump at lower frequency in exchange of lower flow. For this situation it is recommended to use a reservoir.

In another train of thoughts, to design a PV installation includes analysis, assembly and maintenance. These steps involve all kinds of resources: human resources (engineers, constructors, etc.), natural resources, financial resources, energy and time. Each resource is involved in different proportion contributing but also polluting as such. The following subchapters mean to highlight these implications.

1.8.1. Environmental impact

Environment impact of the project involves the natural resources used to provide all the conditions to make a project to be realized as well as its strains and emissions in nature. It implies:

a) Space, landscape and soil manipulation;
b) Energy exploitation;
c) Air pollution and green house emission;
d) Water demand and pollution;
e) Noise and visual impact;
f) Waste production and management.

a) Space, landscape and soil manipulation.

Considering that the project is placed in an agricultural area of 75.660 m^2 located on the hills of Jerica, the facility is designed to not affect the stability of the soil and to use a minimum surface needed that provides the required energy. The soil suffers minimum changes when constructing. Furthermore, the top height of the PV being 2 m, the influence over birdlife is minim due to integration into the landscape.

Soil resources used in all the process are meant to be used in manufacturing the equipment (PV modules, structure, electric components, wires, etc.) as well as to build the structure and not the least, collateral resources used by the people involved in the project. Maintenance of the batteries can produce acid spill leading to small contamination of the area. In consequence, the installation is designed to reduce the entire pollution risks.

b) Energy exploitation.

Energy exploitation refers to all the resources used to provide electrical and potential energy needed for all the steps of the project, from first steps when designing the project (power for computers), from the time of building the installation (gas for generators and for machines/cars – movement). After building it, all the energy requirements are provided by the installation.

c) Air pollution and green house emission.

The PV installation does not produce pollution during energy production. The only pollution is made indirectly by the process of manufacturing the PV modules and the building process. However, some pollution is made when the generator is powered. All the stages make a carbon footprint on the environment.

Thus the system is designed to use the generator just in special cases such as maintenance on the PV array or cloudy days. By comparing the dates provided by Weather National Agency of Spain (Table 2) and the maintenance requirements of the equipment, the generator has an

average of 5 days of running per month. Although, depending on the dryness of the soil and the rainy days during each month of the year, the owner has the final decision over the hours of irrigation.
To see the differences between the actual installation, PV system with actual generator, PV system with substitute generator and the grid, it is necessary to taken into account the following data:

- Generator operate in average 1074 hour a year with a consumption of 8.59 l/h;
- Equivalent $kgCO_2$ emission per one litre of diesel fuel: 2.79 kg [38];
- Grid electrification emission factor: 0.372 $kgCO_2/kWh$ [39];
- For PV system: - 175 hours of operating generator;
  - Energy requirement for all year: 11770 kWh;
  - Actual generator consumption (less than 50 of capacity): 5.73 l/h;
  - Substitute generator consumption (approx. 75% of capacity): 4 l/h;

Source of power	Actual system	PV with actual Generator	PV with substitute Generator	Grid
$kgCO_2$ per year	25739.59	2797.67	1953	4378.44

Table 10. Equivalent $kgCO_2$ per energy source

d) Water demand and pollution.

Special for PV installation water is needed for construction mixing it with cement to fix the structure in to the soil. Also, water is used to clean the PV array. Water used for cleaning is provided by the irrigation system itself.
Pollution of the water can be made by pesticides used for agriculture purposes.

e) Noise and visual impact.

Noise pollution has low levels because the installation does not include moving parts. Still, some noise is provided by the generator in the moments of running. For this reason, the generator has a soundproof design to minimize noise.

The visual impact of the installation is minimal being a small installation with a maximum height of 2 m making it unnoticeable.

f) Waste production and management.

In first instance, the PV installation does not produce waste due to the operation system. The wastes produced around the installation are due to initial installation work of the structure, PV modules, equipment and wires and due to the end of life cycle assessment (LCA). For this case, the EU has mentioned in 2012 in Waste Electrical and Electronic Equipment Directive (WEEE) the recycling policy. Applying the regulation of WEEE, the PV installation it is designed to recycle the components by sending it to a collection centre located at 80 km away from the installation point, in Castellón de la Plana. Furthermore, the waste will be sorted depending on material: semiconductors, glass, ferrous and non-ferrous and so on. [41]

During LCA of PV modules (20 – 30 years), the batteries are recycled 2-3 times due to their life assessment (around 10 years) in special condition because of the electrolyte toxicity.

Moreover, the company designed a plan in which the wastes from technological process are used to extract oil and essence. The leftover may be sold to a biomass company for woodchips, pellets, sawdust, etc.

1.8.2. Social and rural impact

The purpose of modern technology is to improve the life of the habitants but in a rural environment the social impact of the installation has a big influence for the people. To clarify, the social impacts are as following:

a) Energy security;
b) Economic development;
c) Climate impact.

a) Energy security

The most important advantage of having an off-grid system involves the economic aspects of it. Many companies give a warranty of at least 15-20 years of operating system without any changes if the operational and maintenance (O&M) requirements are respected.
Energy price from the grid during the years get affected by inflation resulting to higher cost by time. Therefore, the price of the energy produced by PV installation can be considered to be constant and by comparing the prices, the PV installation pays back the investment.

b) Economic development

Energy price affects the price of the products in many companies leading to competitive deficiency and difficulty in management. Energy security can contribute to adjust the prices and creating competitiveness. Moreover, it can be used in marketing as it gives extra value and distinguish through competition. Giving the purpose of the land, the company helps to supply more food for people from rural and urban areas. In actual situation, the PV installation gives the opportunity to diminish the cost and to increase productivity creating a good opportunity to increase the income and develop the company. The owner is planning to extend the product range by harvesting rosemary in the coming months. More people can be hired in order to take advantage of the new conditions.

In an indirect way, the process to develop and sustain the PV installation involves specialists in different domains such as: engineers, electricians, constructors but also unqualified workers. Besides, it can be used as an example in school projects, making the new generations to be more interested in this field due to the futuristic design and the worldwide information in renewable energy. Furthermore, during the expositions, speeches and local meetings, the benefits of RE can be shared. In addition, by multiplying the PV installation in the area, the young people can be motivated to study RE.

c) Climate impact mitigation

The data in Table 10 shows the different quantity of equivalent CO_2 released into the local atmosphere in one year. From that we can determine the total of tCO_2 released in 20 years as shown in Figure 38 and Table 11.

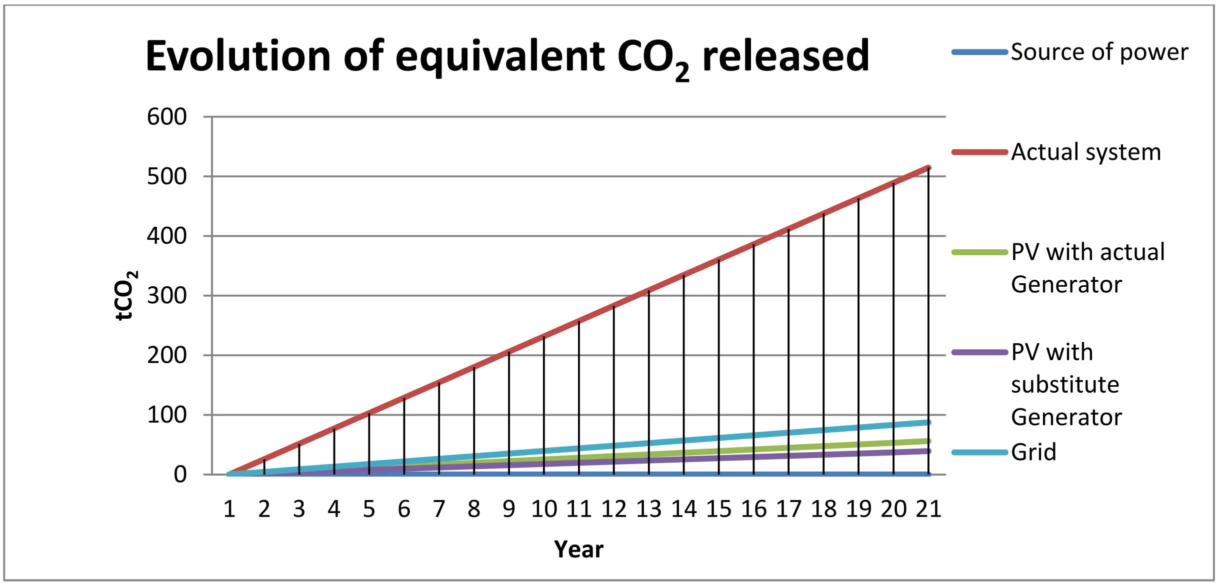

Figure 38. Evolution of equivalent CO_2 released in 20 years

Source of power / Year	Actual system	PV with actual generator	PV with substitute generator	Grid
1	25,740	2,798	1,953	4,378
2	51,479	5,595	3,906	8,757
3	77,219	8,393	5,859	13,135
4	102,958	11,191	7,812	17,514
5	128,698	13,988	9,765	21,892
6	154,438	16,786	11,718	26,271
7	180,177	19,584	13,671	30,649
8	205,917	22,381	15,624	35,028
9	231,656	25,179	17,577	39,406
10	257,396	27,977	19,530	43,784
11	283,135	30,774	21,483	48,163
12	308,875	33,572	23,436	52,541
13	334,615	36,370	25,389	56,920
14	360,354	39,167	27,342	61,298
15	386,094	41,965	29,295	65,677
16	411,833	44,763	31,248	70,055
17	437,573	47,560	33,201	74,433

18	463,313	50,358	35,154	78,812
19	489,052	53,156	37,107	83,190
20	514,792	55,953	39,060	87,569

Table 11. Equivalent tCO_2 in 20 years

This analysis reveals the climate benefits of changing the actual system. Each situation presents a high reduction of greenhouse emissions:

- PV with actual generator: 89.13 %;
- PV with substitute generator: 92.41 %.

1.9. Conclusions

Given the purpose of the project, the final installation was chosen from four possible installations, based on many factors showed in every chapter. Starting from the first chapter, we can see the technical differences of the installations with advantages and disadvantages that fit for our case. These differences are highlighted in the second chapter for a better analysis, resulting in the plans presented in chapter 4. Starting from the technical data, an economic analysis was made in chapter 3 in order to see the costs and the payback time of the installations.

Therefore, the most convenient installation is the photovoltaic installation of 21 kW power that uses variable frequency driver to power the water pump. As a backup system a Genesal generator is recommended to be used.

The decision was made given the following main reasons:

- irrigation is not a priority during cloudy and rainy days;
- it is easy to maintain the system;
- low initial investment & low O&M cost;
- pollution is at the minimum. When the generator is not used, the installation will not emit any greenhouse emission;
- the owner saves a big amount of money that can be reinvested or used in different activities for the local environment.

The installation gives more benefits over the year for the local area:

- promoter of RE in rural area;
- it can stimulate people to use RE;
- it is a good example for others how to benefits from RE.

Based on the analyses and the estimations, the owner of the land has improved his management plan. As a result, he has decided to extend the product range of the company and to get involved in more activities in relation to rural development due to the social impact of the company.

1.10. References

Web references:

[1] Shubhangi Khapre (2016.03.08). Maharashtra budget 2016-17: Deadline for irrigation projects likely. URL:http://indianexpress.com/article/cities/mumbai/maharashtra-budget-2016-17-deadline-for-irrigation-projects-likely/

[2] Groundwater Engineering Limited (2014.03.03). Introduction to solar water pumping. URL:https://www.groundwatereng.com/blog/2014/03/introduction-to-solar-water-pumping

[3] IRENA (2016). Renewable Energy and Jobs, Annual Review 2016. URL:http://seforall.org/sites/default/files/IRENA_RE_Jobs_Annual_Review_2016.pdf

[4] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. URL:http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0028

[5] REN21 (2016). RENEWABLES GLOBAL STATUS REPORT 2015. URL:http://www.ren21.net/wpcontent/uploads/2015/07/REN12GSR2015_Onlinebook_low1.pdf

[6] Eurostat (2013 February). Rural development statistics by urban-rural typology. URL:http://ec.europa.eu/eurostat/statistics-explained/index.php/Rural_development_statistics_by_urban-rural_typology)

[7] URL:http://www.geohive.com/earth/pop_urban.aspx

[9] Wikipedia (2017.03.28). Jérica. URL:https://en.wikipedia.org/wiki/J%C3%A9rica

[10] Google Maps. URL:https://www.google.ro/maps/place/J%C3%A9rica,+12450,+ Castell%C3%B3n,+Spain/@39.8565044,0.7929493,10.08z/data=!4m5!3m4!1s0xd607dfdd 52a96ed:0x402af6ed72240f0!8m2! 3d39.8873558!4d-0.5730713

[11] Photovoltaic geographical information system (PVGIS). URL:http://re.jrc.ec.europa.eu/pvgis/apps4/MRcalc.php

[12] Photovoltaic geographical information system (PVGIS). URL:http://re.jrc.ec.europa.eu/pvgis/apps4/DRcalc.php

[13] Spain's National Meteorological Agency. URL:http://www.aemet.es/en/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l= 8500A&k=val

[14] Wikipedia (2017.03.28). Jérica. URL: https://en.wikipedia.org/wiki/J%C3%A9rica#Economy

[18] LEONICS CO. Stand-alone Solar Power System. URL:http://www.leonics.com/system/solar_photovoltaic/stand_alone_solar_power_system/stand_alone_solar_power_system_en.php

[20] Wikipiedia (2017). Sunlight. URL:https://en.wikipedia.org/wiki/Sunlight

[21] URL:http://www.biofuturo.net/

[23] URL:http://lifefreeenergy.com/w/what-is-photovoltaic-panels.html

[24] URL:http://delmonsolar.com/Products.php

[25] GPIIISolar. Solar Tracking. URL:http://www.gpiiisolar.com/solar_tracking/tracking_system

[27] Victron Energy. Gel and AGM Batteries. URL:https://www.victronenergy.com/upload/documents/Datasheet-GEL-and-AGM-Batteries-EN.pdf

[28] SBS LLC. Comparison Between Flat and Tubular Positive Plates. URL:http://www.sbsbattery.com/PDFs/SBS_WP_101_BattComp-WithRefs.pdf

[29] Alternative Energy Tutorials. Solar Power Inverter. URL:http://www.alternative-energy-tutorials.com/solar-power/solar-power-inverter.html

[33] Schneider Electric (2013.01.16). XW MPPT 80 600 (Annex 6). URL:http://www.schneider-electric.com/press/es/es/schneider-electric-presenta-su-nuevo-controlador-de-carga-xw-mppt-80-600/?isDisplayed=1&lastUpdate=01/21/2013

[34] Tab + Batteries. URL:http://www.tab.si/index.php/industrial/display_stationary/2

[35] Schneider Electric. Conext XW+ NA (Annex 7). URL:http://solar.schneider-electric.com/wp-content/uploads/2015/10/Conext-XW-NA-Datasheet_ENG.pdf

[37] URL:http://www.x-elio.com/sites/default/files/styles/structure_big/public/hap_2p_11.jpg?itok=gSEdew_e

[38] Emission factors in kg CO2-equivalent per unit. URL:https://www.researchgate.net/file.PostFileLoader.html?id=577fbc1996b7e4acc040a883&assetKey=AS%3A381587750440960%401467989017021

In2Rural Courses:

[19] Module 2, Chapter 1, Part 1-1

[26] Module 2 – Chapter 1, part 1-2

[39] Module 2 – Chapter 4, part 4-3

[40] Module 2 - Chapter 3, part 3-1

[41] Module 2 – Chapter 1, part 1-3

[42] Module 2 - Chapter 2, part 2-1

[43] Module 2 - Chapter 2, part 2-2

Annexes:

[15] Heliotec Case study. Annex 1 - Heliotec Case Study - Bombeo Solar Fotovoltaico

[16] Carod Generator. Annex 2 - Generator Carod CTM-6 L

[30]HN Bombas (2016). Annex 3 - HN Bombas - GJ012-25

[31]Amerisolar Co. Annex 4 - Amerisolar PV Module - AS-6P-310

[32] Baico. Annex 5 - Baico VFD - ISKUT Solar 425

[36] Genesal Electric. Annex 8 - Generator Genesal Energy XS POWER GEN22KC

Other sources:

[17]Helitec. Irrigation system designed to be changed

[8] Renewable Energy to Rural Development - Executive Summary Brief for Policy Makers

[22] Solar Radiation Atlas for Spain based on Surface Irradiance Data from EUMETSAT Climate Monitoring-SAF

Co-funded by the Erasmus+ Programme of the European Union

Calculations

2. Calculations and design

The following calculation and design is specific for the location provided (near to Jérica, Castellón, Spain. Coordonate: 39°54′ N 00°34′ W) within the 3 month of summer: June, July and August. The system has a nominal time of running for 5 hours daily.

The calculations are related to the information provided by the Photovoltaic Geographical Information System (PVGIS) for a photovoltaic installation fixed on a structure inclined at 20^{o} (Chapter 1.5.A.b).

First of all, the calculation will refer to the system that operates without batteries followed by the calculation for a system that operates with batteries.

2.1 Energy demand, system losses and performance rate

The starting point of this project is given by the client. In the interest of raising the productivity of the land for almond, an irrigation system is required. Because the flow of surface water is low, the next option is to submerse a water pump into the ground. The optimal depth for the ordered pump is situated 130 m providing 260 l/min. As the surface area is 75.660 m^2, we can calculate the flow for an hour per m^2.

$$260\ l/\min \times 60 = 15600\ l/h \qquad \text{Eq. (10)}$$

$$75660\ m^2/15600\ l/h\ = 4.85\ l/m^2 \qquad \text{Eq. (11)}$$

To determine the consumption of the pump daily, monthly and season, technical data provided by the manufacturer is required. (Table 12)

Table 12. Water pump[30]

Manufacturer		HN Bombas	
Model		GJ012-25	
kW	HP	11	15
Voltage		400 V	
Nominal Frequency		50 Hz	
Nominal flow		200 l/min	
Flow range		35 - 31 l/min	
Maximum depth		431 m	
Maxim efficiency		60 %	
Nominal speed		2900 rpm	

Knowing the power of the pump and the average hours of running per month, we can calculate monthly consumption and total consumption per year.

Table 13. Monthly consumption

Month	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Hours	3	4	4	5	5	5	4	3	2
Days	31	30	31	30	31	31	30	31	30
Cons. (kW)	1023	1320	1364	1650	1705	1705	1320	1023	660
Total consumption									11770

To design a proper installation, the losses of the system have to be taken into account. In our case, the losses are estimated as in the following:

- Azimuth (horizontal angle) is 0^{o} resulting 0% orientation loss;
- Dirt loss is considered to be 5 %;
- Shadow and cabling loss: 2 % & 4 %;
- VFD / inverter performance: 96 %;
- Regulator/ MPPT performance: 97 %;
- Battery performance: 80 %;
- Cells temperature losses estimated to be 4 % per every 10^{o} C.

These losses are calculated as a performance rate (PR). By using the data provided by PVGIS, PR can be determined as in the next equation:

$$PR = \frac{Production}{Radiation} \quad \text{(Eq. 12)}$$

Table 14. Performance Rate[11]

Month	E_d	E_m	H_d	H_m	PR_d	PR_m
January	2.72	84.2	3.39	105	0.802	0.802
February	3.46	96.8	4.35	122	0.795	0.793
March	4.36	135	5.63	174	0.774	0.776
April	4.51	135	5.95	178	0.758	0.758
May	4.89	152	6.57	204	0.744	0.745
June	5.36	161	7.31	219	0.733	0.735
July	5.43	168	7.5	233	0.724	0.721
August	4.93	153	6.8	211	0.725	0.725
September	4.15	125	5.62	168	0.738	0.744
October	3.58	111	4.74	147	0.755	0.755
November	2.82	84.7	3.6	108	0.783	0.784
December	2.43	75.4	3.04	94.4	0.799	0.799
Annual average	4.06	123	5.38	164	0.755	0.75
Annual total	1480		1960		0.755	

Acronyms:

E_d - Average daily electricity production from the given system (kWh)
E_m - Average monthly electricity production from the given system (kWh)
H_d - Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)
H_m - Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

In order to maximise the installation for the summer months, the values that are going to be used are: June – 0.73 (73 %), July – 0.72 (72 %), August – 0.72 (72 %). These values need to be multiplied with the daily Global irradiation (G) in order to determine the power of the PV panels. As a result, the differences can be seen in the following figures:

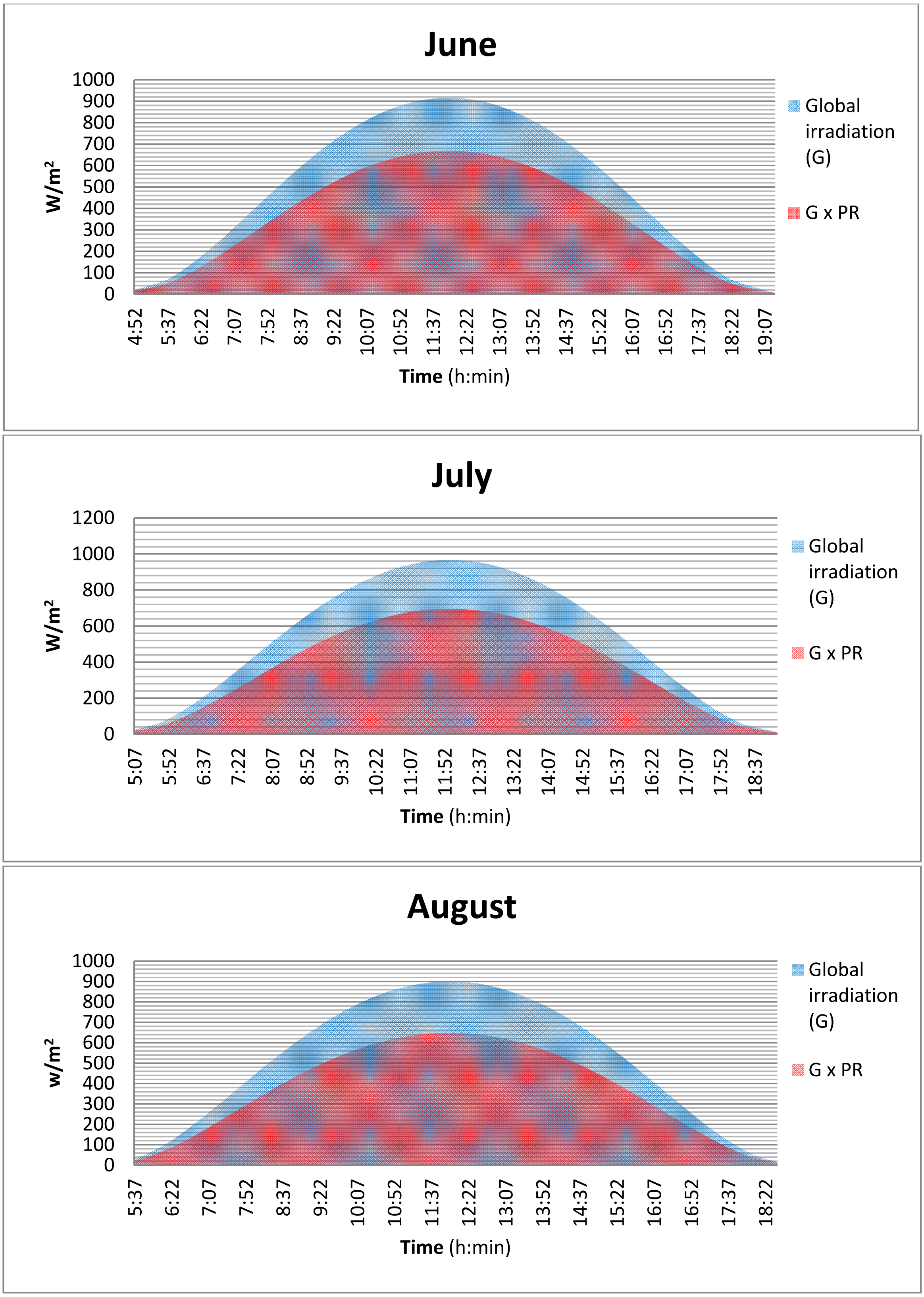

Figure 39. Average daily graphics of Global Irradiation by performance rate per month

Table 15. Values in different time of Global Irradiation [12] by performance rate per month

Time	June		July		August	
	Global irradiation (G)	*G × PR*	*Global irradiation (G)*	*G × PR*	*Global irradiation (G)*	*G × PR*
5:22	*49*	*35.77*	*40*	*28.8*	*0*	*0*
5:37	68	49.64	56	40.32	32	23.04
6:22	*174*	*127.02*	*161*	*115.92*	*120*	*86.4*
6:37	217	158.41	206	148.32	162	116.64
7:22	*357*	*260.61*	*355*	*255.6*	*306*	*220.32*
7:37	405	295.65	407	293.04	356	256.32
7:52	454	331.42	459	330.48	407	293.04
8:07	501	365.73	511	367.92	457	329.04
8:22	*548*	*400.04*	*561*	*403.92*	*506*	*364.32*
8:37	592	432.16	610	439.2	554	398.88
8:52	635	463.55	657	473.04	600	432
9:07	676	493.48	701	504.72	643	462.96
9:22	*714*	*521.22*	*743*	*534.96*	*684*	*492.48*
9:37	749	546.77	782	563.04	722	519.84
9:52	782	570.86	817	588.24	756	544.32
10:07	811	592.03	850	612	788	567.36
10:22	*837*	*611.01*	*878*	*632.16*	*815*	*586.8*
10:37	859	627.07	903	650.16	839	604.08
10:52	878	640.94	924	665.28	859	618.48
11:07	893	651.89	941	677.52	876	630.72
11:22	*905*	*660.65*	*953*	*686.16*	*888*	*639.36*
11:37	912	665.76	962	692.64	896	645.12
11:52	916	668.68	966	695.52	900	648
12:07	916	668.68	966	695.52	900	648
12:22	*912*	*665.76*	*962*	*692.64*	*896*	*645.12*
12:37	905	660.65	953	686.16	888	639.36
12:52	893	651.89	941	677.52	876	630.72
13:07	878	640.94	924	665.28	859	618.48
13:22	*859*	*627.07*	*903*	*650.16*	*839*	*604.08*
13:37	837	611.01	878	632.16	815	586.8
13:52	811	592.03	850	612	788	567.36
14:07	782	570.86	817	588.24	756	544.32
14:22	*749*	*546.77*	*782*	*563.04*	*722*	*519.84*
14:37	714	521.22	743	534.96	684	492.48
14:52	676	493.48	701	504.72	643	462.96
15:07	635	463.55	657	473.04	600	432
15:22	*592*	*432.16*	*610*	*439.2*	*554*	*398.88*
15:37	548	400.04	561	403.92	506	364.32
16:22	405	295.65	407	293.04	356	256.32
16:37	357	260.61	355	255.6	306	220.32
17:22	*217*	*158.41*	*206*	*148.32*	*162*	*116.64*
17:37	174	127.02	161	115.92	120	86.4
18:22	*68*	*49.64*	*56*	*40.32*	*32*	*23.04*

2.2 Installation sizing and selection of the equipment

To determine the size of the installation and the optimal equipment it is needed to establish the running hours in order to harvest the highest quantity of solar energy. For this reason, the installation is programmed to work between 9:22 and 14:22 when there is enough irradiation. As a result, power consumption is divided by irradiation values produced from 9:22 to 9:37 giving the power of PV panels needed (Table 16).

Table 16. Irradiation values in running hours

June			July			August		
Time	***G***	***G × PR***	**Time**	***G***	***G × PR***	**Time**	***G***	***G × PR***
9:22	714	521.22	9:22	743	542.39	9:22	684	492.48
9:37	749	546.77	9:37	782	570.86	9:37	722	519.84
9:52	782	570.86	9:52	817	596.41	9:52	756	544.32
10:07	811	592.03	10:07	850	620.5	10:07	788	567.36
10:22	837	611.01	10:22	878	640.94	10:22	815	586.8
10:37	859	627.07	10:37	903	659.19	10:37	839	604.08
10:52	878	640.94	10:52	924	674.52	10:52	859	618.48
11:07	893	651.89	11:07	941	686.93	11:07	876	630.72
11:22	905	660.65	11:22	953	695.69	11:22	888	639.36
11:37	912	665.76	11:37	962	702.26	11:37	896	645.12
11:52	916	668.68	11:52	966	705.18	11:52	900	648
12:07	916	668.68	12:07	966	705.18	12:07	900	648
12:22	912	665.76	12:22	962	702.26	12:22	896	645.12
12:37	905	660.65	12:37	953	695.69	12:37	888	639.36
12:52	893	651.89	12:52	941	686.93	12:52	876	630.72
13:07	878	640.94	13:07	924	674.52	13:07	859	618.48
13:22	859	627.07	13:22	903	659.19	13:22	839	604.08
13:37	837	611.01	13:37	878	640.94	13:37	815	586.8
13:52	811	592.03	13:52	850	620.5	13:52	788	567.36
14:07	782	570.86	14:07	817	596.41	14:07	756	544.32
14:22	749	546.77	14:22	782	570.86	14:22	722	519.84

June: $11000/546.77 = 20.12$ kW   Eq. (13)

July: $11000/570.86 = 19.27$ kW   Eq. (14)

August: $11000/519.84 = 21.16$ kW   Eq. (15)

Since the radiation level for August is lower resulting 21.16 kW, the PV installation power will be designed for 21 kW. For a better perspective, in Figure 39 the amount of consumption related with the power of the PV installation is presented.

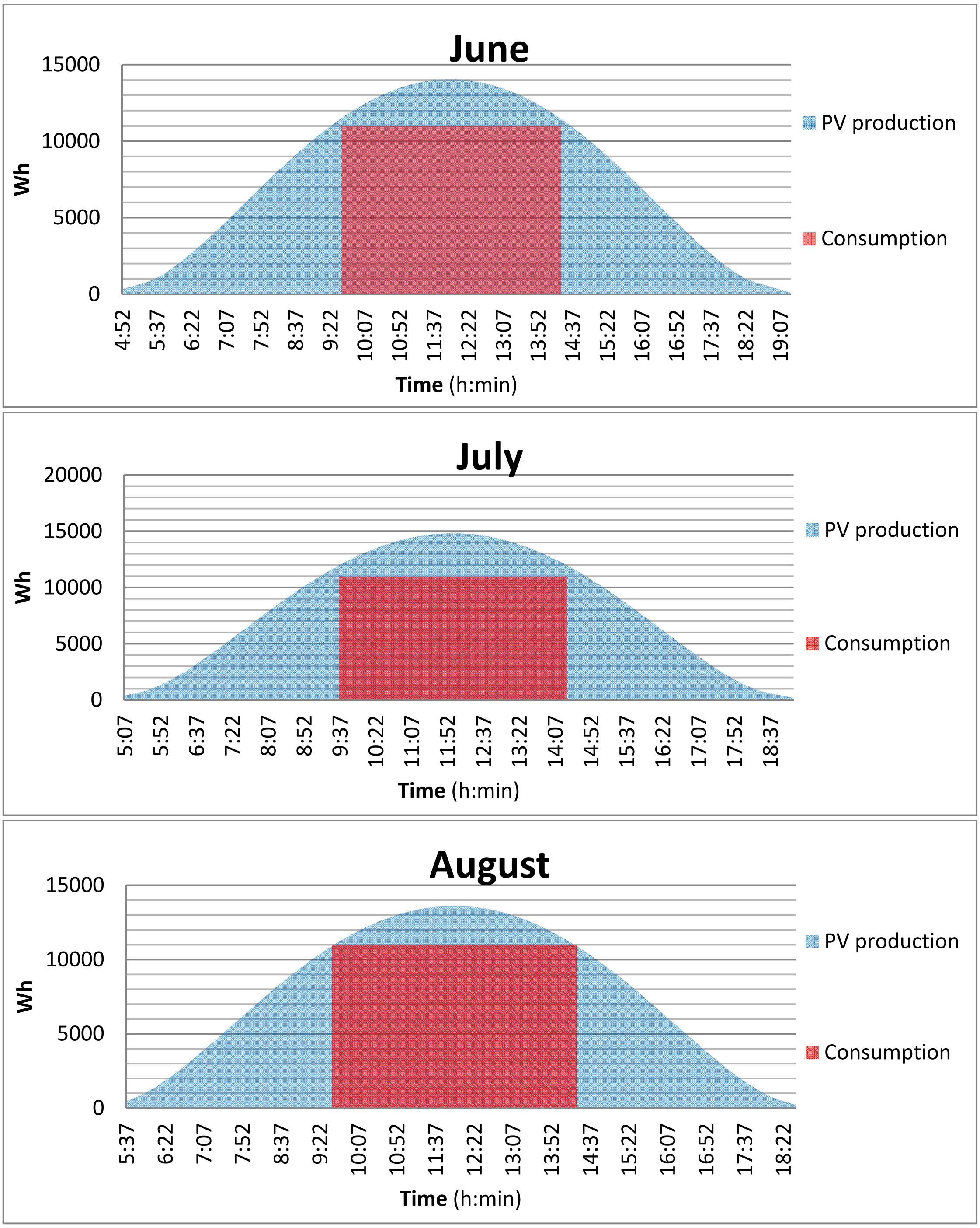

Figure 40. Generated power vs. Consumption

Even though the energy produced by the PV installation can change every day because of the weather, and the deficiency of the generated power can be covered in different ways.
In the first situation, the deficit of the energy can be supplied by reducing the frequency of the installation from 50 Hz to 40 Hz with the VFD, which could lead to extra hours of running during the normal days with the consequence of lower flow of the pump.

Another way to supply the energy needed is by introducing batteries in the system. This gives the possibility to the pump to run in different times of the day as well as having the option to design a PV array for a smaller quantity of energy.

The number of PV modules is determined by dividing the power needed with the nominal power (P_{max}) of the chosen model of PV module (Table 17) resulting in equation 16.

Table 17. AS-6P-310, Amerisolar [31]

Manufacturer	Amerisolar
Model	AS-6P-310
Nominal Power (P_{max})	310 W
Open Circuit Voltage (V_{oc})	45.5 V
Short Circuit Current (I_{sc})	8.85 A
Voltage at Nominal Power (V_{mp})	36.9 V
Current at Nominal Power (I_{mp})	8.41 A
Module Efficiency (%)	15.98
Cell Type	Polycrystalline (156x156 mm)
Number of cells	72 (6x12)
Module Dimension	1956x992x50 mm
Weight	27 kg
Front cover	4.0 mm low-iron tempered glass
Frame	Anodized aluminium alloy
Junction box	IP67, 6 diodes
Cables	4 mm^2, 1000 mm
Connector	MC4 or MC4 compatible

$$21000/310 = 67.7419 \qquad \text{Eq. (16)}$$

Because of equation 16, the PV array will contain 68 modules which can ensure a maximum nominal power of 21080 W (21.08 kW).
Furthermore, a VFD is chosen considering the type of the PV module (Table 8) and the characteristics of the water pump (Table 5).

Table 18. ISKUT SOLAR 425 [32]

Manufacturer	Baico
Model	ISKUT SOLAR 425
Vin (VDC)	320 - 850 V
Vin P1 nom* (VDC)	> 560V
Max V out (VAC)	3 x 400 V
Max I out (A)	25
Weight	8.5 kg

To produce the Max V out = 3x400 V, the VFD need a Min V in of 565 V. To provide enough voltage for the VFD, the PV modules will be divided into 2 strings with 34 modules (2 rows of 17 modules per string).

$$17 \times 36.9V = 627.3 \text{ V (VDC)} \qquad \text{Eq. (17)}$$

As a backup source of energy, the installation has the possibility to connect a generator. This option is available when the energy from the PV is not enough to run the pump (Figure 40).

The connection is made through an automatic switcher that makes the transfer from the PV energy to the generator.

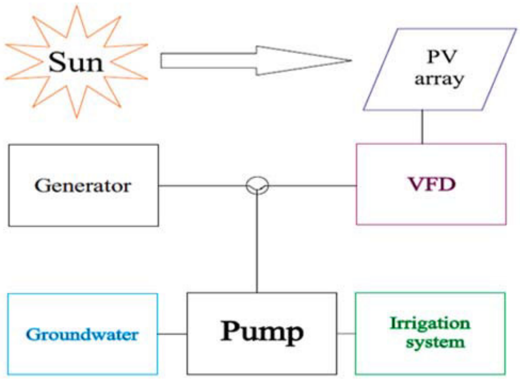

Figure 40 Connection of generator to a PV installation using VFD

For economic reasons, the actual generator will be connected to a PV installation even though it is used at low capacity. Nevertheless, the generator shown in Figure 16 may be substituted by the generator shown in Figure 34. The differences between them are shown in Table 19.

Table 19. CTM-60 L [16] vs. XS Power Gen22KC[36]

Manufacturer		Carod	Genesal Energy
Model		CTM-60 L	XS POWER GEN22KC
Frequency		50 Hz	50 Hz
Voltage		400 V	230 / 400 V
PRM power kVa/kW		60 / 48	20 / 16
STP power kVA/kW		62.5 / 50	22/17.6
Rated at power factor (cos ϕ)		0.8	0.8
Speed		1500 rpm	1500 rpm
Consumption	100 %	11.46 l/h	5.3 l/h
	75 %	8.59 l/h	4 l/h
	50 %	5.73 l/h	N/A

Another way to distribute the power from the panels to the pump is by using the circuit Regulator/MPPT-Batteries-Inverter. This presents the advantage of a smaller PV array but contains more equipment on the energy distribution.

Using the same condition as in the previous model, regarding environment condition, system losses and PV module, the installation will be decided by comparing the minimum of energy required for normal use without batteries and the cost of the equipment in use of batteries. From these terms, it was chosen to install a PV array of 16.1 kW (52 modules AS-P6-310).

Considering the same average of radiation per month, the difference of the power required will be provided by the batteries. As shown in Figure 41, the batteries will be charged during the day when the consumption of energy is nil.

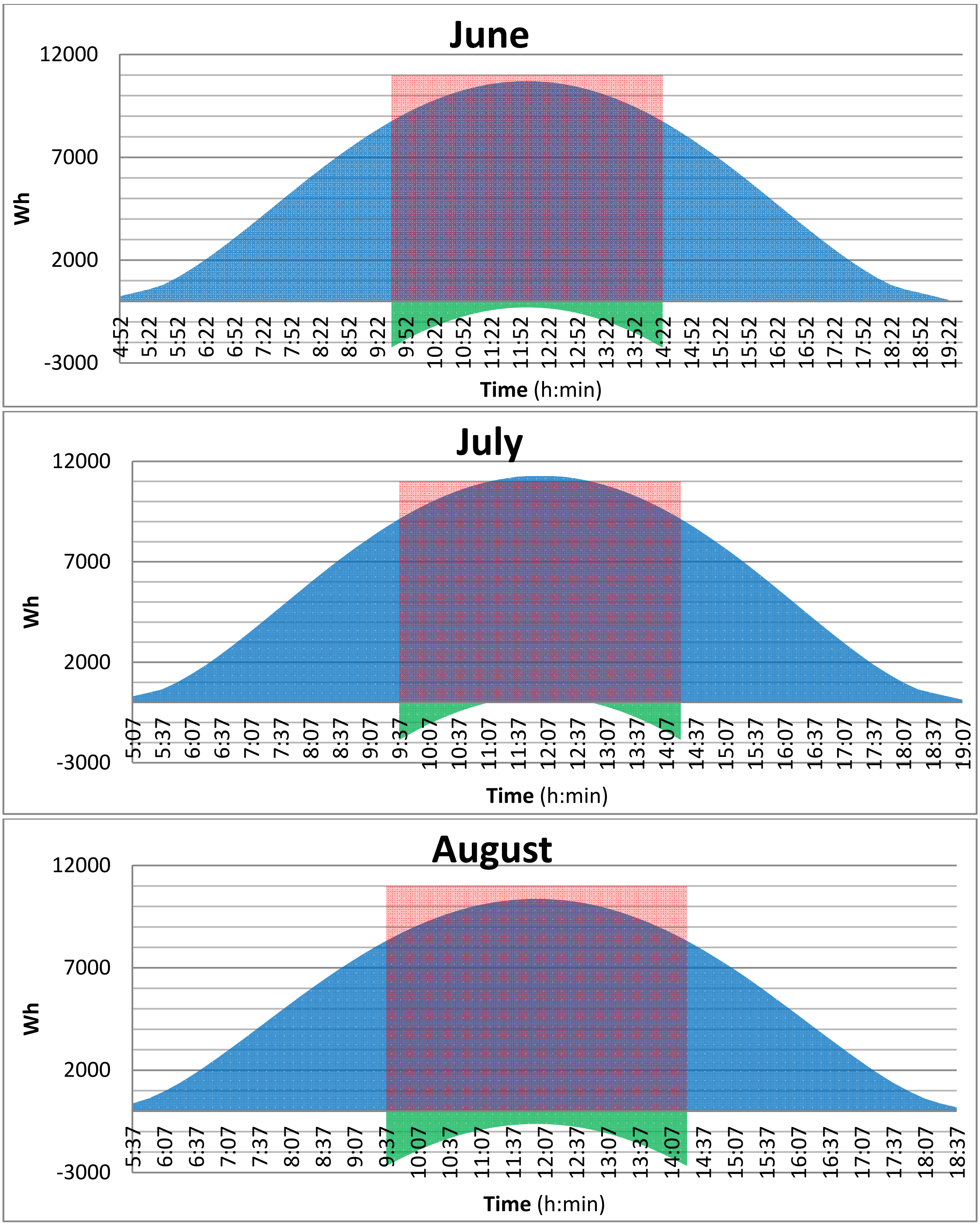

Figure 41. Production, Consumption, Energy from batteries

Legend: blue - PV production (16 kW installation);
red - Consumption;
purple - Consumption sustained by PV panels;
green - Consumption sustained by batteries.

It can be observed that in July the average daily irradiation is enough to make the PV panels generate 11 kW of power during the hours between 11:22 – 12:37.

The modules are designed to be placed in the same position similarly to the previous design, with 26 modules per string. Each string is designed to be connected to a MPPT in order to collect the energy for the batteries or to give it for use during the consumption time. The MPPT that fits the needs is XW MPPT 80 600 (Table 20).

Table 20. XW MPPT 80 600, Schneider Electric [33]

Manufacturer	Schneider Electric
Model	XW MPPT 80 600
Nominal battery voltage	24 and 48 V (Default is 48 V)
PV array operating voltage	195 to 550 V
Max. PV array open circuit range	600 V including temperature correction
Battery voltage operating range	16 to 67 VDC
Array short-circuit current	35A (28 A @STC)
Max. charge current	80 A
Max. and min. wire size in conduit	#6 AWG to #14 AWG (13.5 to 2.5 mm^2)
Max. output power	2560W (nominal 24 V), 4800W (nominal 48 V)
Max. power conversion efficiency	94% (nominal 24 V), 96% (nominal 48V)

By connecting 13 modules in series, the obtained values are situated in the parameters of the MPPT (Table 20).

13 x 36.9 V (V_{mp}) = 479.7 V (550 V) Eq. (18)
13 x 45.5 V (V_{oc}) = 591.5 V (600 V) Eq. (19)
13 x 310 W (P_{max}) = 4030 W (4800 W) Eq. (20)

Thus, the installation will contain 4 XW MPPT 80 600, one for each 13 modules, connected to the batteries

To find the batteries capacity required for 16kW PV system, first we need to see the uncovered energy needed for consumption (Table 21) and to apply the following formula with the specification that the autonomy of the batteries is chosen for 1 day. The autonomy has been selected to be optimal for the purpose of irrigation.

$$C_{bat} = \frac{1.1 \times E_d \times A}{V_{bat} \times DOD_{max}} \quad \text{Eq. (21)}^{[41]}$$

C_{bat} – capacity of the battery
E_d – energy required
A – autonomy
V_{bat} – Battery voltage; 48 V
DOD_{max} – Depth of discharge – 50 %

Table 21. Uncovered energy by the PV panels

Time	Consumption	Production 16 kW	Production 16 kW	Production 16 kW
9:22	11000	8339.52	8678.24	7879.68
9:37	11000	8748.32	9133.76	8317.44
9:52	11000	9133.76	9542.56	8709.12
10:07	11000	9472.48	9928.00	9077.76
10:22	11000	9776.16	10255.04	9388.80
10:37	11000	10033.12	10547.04	9665.28
10:52	11000	10255.04	10792.32	9895.68
11:07	11000	10430.24	10990.88	10091.52
11:22	11000	10570.40	11131.04	10229.76
11:37	11000	10652.16	11236.16	10321.92
11:52	11000	10698.88	11282.88	10368.00
12:07	11000	10698.88	11282.88	10368.00
12:22	11000	10652.16	11236.16	10321.92
12:37	11000	10570.40	11131.04	10229.76
12:52	11000	10430.24	10990.88	10091.52
13:07	11000	10255.04	10792.32	9895.68
13:22	11000	10033.12	10547.04	9665.28
13:37	11000	9776.16	10255.04	9388.80
13:52	11000	9472.48	9928.00	9077.76
14:07	11000	9133.76	9542.56	8709.12
14:22	11000	8748.32	9133.76	8317.44
Energy difference		23119	13943	30990

As a result, the energy required to overlay are the following:

June 23,12 kW
July 13,94 kW
August 30,99 kW

$$C_{bat} = \frac{1.1 \times E_d \times A}{V_{bat} \times DOD_{max}} = \frac{1.1 \times 30990 \times 1}{48 \times 0.5} = 1420.37\ Ah \qquad \text{Eq. (22)}$$

Since the minimum capacity of the batteries must have at least 1420.37 Ah, from the diversity of the batteries of Tab+ manufactures, it is designed to use the model 12 OPzS mentioned in Table 22. To reach the 48 V, 24 batteries will be connected in series.

Table 22. 12 OPzS 1500, Tab + [34]

Batteries	Characteristics
Manufacturer	Tab+
Model	12 OPzS 1500
Voltage	2 V
Ah C10	1613

The last equipment needed in the system is the inverter. To choose the proper one we have to calculate the minimum power of it. Also it must be taken into account that the pump is with 3 phases, resulting one inverter per each phase.

$$P_{inv} = \frac{P_{cons} \times 1.25}{3} = \frac{11\ kW \times 1.25}{3} = \frac{13.75}{3} = 4.58\ kW/phase \qquad \text{Eq. (23)}$$ [41]

P_{inv} – power inverter;
P_{cons} – consumer power.

In order to improve the performance of the system, the inverter Conext XW+ 5548 NA is chosen from the same manufacturer as the MPPT with the bonus of having the parameters on the same display. Other benefits of the particular inverter includes an automatic switch between the PV array, batteries and the generator (backup system).

Table 23. Conext XW+ 5548 NA, Schneider Electric [35]

Manufacturer	Schneider Electric
Model	Conext XW+ 5548 NA
Output power at 25°C	5500 W
Output power at 40°C	4500 W
Output frequency	50 / 60 Hz
Input DC voltage range	42 / 60 V (48 nominal)
Max. input DC current	150 A
Charger Dc output	
Max. output charge current	110 A
Output voltage range	40-64 (nominal 48 V)
Battery bank range	440-10000 Ah

As mentioned earlier, the backup energy source can be represented by the generators specified before. In this case, the installation allows the generator to charge the batteries through the inverter capacity.
With an average of 5 days of running per month and considering the operating hours during each month, the generators have the following total consumption (Table 24):

Table 24. Total consumption of diesel generators

Month	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
Hours	3	4	4	5	5	5	4	3	2	175
Days to operate	5	5	5	5	5	5	5	5	5	
CTM-60 L	85.95	114.6	114.6	143.25	143.25	143.25	114.6	85.95	57.3	1002.75
XS-GEN22kC	60	80	80	100	100	100	80	60	40	700

Optional, by changing the fix structure of PV panels to a structure with sun tracking system in both types of systems, the efficiency of the PV modules can raise by up to 40%. Adding a sun tracking system can cause different adjustments to each part of the installation in case of maintaining the PV structure. It is required more powerful equipment in order to manage the spare energy. Another solution is to reduce the size of the PV array.

Budget and economic analysis

3. Economical aspects of the project

This chapter aims to provide all the economic data regarding the budget of the installation and payback of the installations presented in the previous chapter with the indication that the pump and the generator are provided by the contractor. The budget will be calculated with the remaining equipment.

Each system presents the cost of the PV module and the system cost named "balance of the system cost" (BOS cost) along with the economic indicator: payback, internal rate of return (IRR), net present value (NPV). Other aspect that influence the budget and the economic efficiency are the operational and maintenance (O&M) cost and the levelized cost of electricity (LCOE).

BOS cost includes the price of: designing the project, fees, equipment, structure, wires, preparation and assembly, combiner box, miscellaneous components and not least labour costs. Depending on the size, structure and site for small systems, the cost of BOS and installation fluctuate between 1 and 1.85 €/W. [42]

In consideration of cash flow, the economic indicators: payback, IRR and NPV reveal how long it will take to recover the finance and show the profitability of the investment comparing it with the cost of the actual system. However, the O&M cost have an influence over the budget. In general, the cost of O&M represents the third highest cost after capital investment and PV modules. A good plan of O&M reduces the risk of malfunction preventing distribution problems, annual degradation and equipment defection, giving the investors financial security. For each year, the O&M cost is calculated as 1.5 % of the initial investment. [43]

LCOE represent the method of comparison between two and/or more systems in order to see the economic reliability as well as the other economic indicators such as payback, IRR and NPV. The LCOE is calculated by using the following formula:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \; (€/kWh) \qquad \text{Eq. (24)}$$ [43]

Where:
I_0 - Investment;
M_t - operations and maintenance expenditures in year t;
F_t - fuel expenditures in year t, which is zero for photovoltaic electricity;
E_t - electricity generation in the year t;
r - discount rate;
n - investment period considered in years.

For further comparison, it is required to know the prices of PV Modules, main equipment (VFD, MPPT, batteries, inverter), structure, wires and auxiliary boxes (string box, protection box, grounding, DC cables, AC cables, etc), personal work (for installing the modules, structure, electric wiring and components, etc) and engineer design. These prices are provided by Heliotec 2006 S.L. a Spanish SME from Castellón province.

3.1. Budget of the installation

The main price difference between the two installations is made by the larger number of components that demand more time for installing and more wires in order to connect but also by the time required to make all the steps of the installations.

As described in previous chapter, the main components have the following prices:

Table 25. Prices of main components

Product	Price per unit
PV module "Amerisolar AS-6P-310"	214
VFD "ISKUT SOLAR 425"	2210.68
MPPT "Schneider XW MPPT 80 600"	921.4
Battery "Tab + 12 OPzS 1500"	458.4
Inverter "Schneider Conext XW+ 5548 NA"	2375.24

For the initial investment of the first system, the size of the installation has to be considered as described in previous chapter to be made from 68 modules of 310 W/modules with a total of 21080 W, equipment prices from Table 25 and the following prices of the other BOS cost components leading to Table 26:

- 106.5 hours of work at 0.119 €/Wp divided in 13.3 days of work;
- design of installation at 2200 €;
- wires and auxiliary boxes at 0.264 €/Wp;
- structure at 50 €/module.

Table 26. Initial investment of 21 kW system

Product	Price per unit (€)	Total (€)
PV module	214 (68 modules)	14552
VFD	2210.68	2210.68
Structure	50	3400
Wires and auxiliary boxes	0.264	5565.12
Personal work	0.119	2508.52
Engineer design	2200	2200
Total	≈ 1.444 €/Wp	30436.32

For the second installation, the BOS cost has changed due to the addition of materials and hours needed to design the proper installation, as follows:

- 117.5 hours of work at 0.158 €/Wp divided in 14.7 days of work;
- design of installation at 2800 €; (≈ 0.174 €/Wp)
- wires and auxiliary boxes at 0.384 €/Wp;
- structure at 50 €/module.
- miniaturization display at 764.22 € (0.041 €/Wp)

Considering the installation made of 52 modules of 310 W leads to a total of 16120 W. Although using the data shown in the list above and equipments prices from Table 25, result the data presented in Table 27.

Table 27. Initial investment of 16 kW system

Product	Price per unit (€)	Total (€)
PV module	214 (52 modules)	11128
MPPT	921.4 (4 units)	3685.6
Batteries	458.4 (24 units)	11001.6
Inverter	2375.24 (3 units)	7125.7
Structure	50	2600
Monitoring display	764.22	764.22
Wires and auxiliary boxes	0.384 €/Wp	6190.08
Personal work	0.158	2546.96
Engineer design	2800	2800
Total	≈ 2.968 €/Wp	47842.16

In order to calculate the economic profitability, it is necessary to make an economic comparison between the actual system (AS), PV system with actual generator (PVAG) and the PV with the substitute generator (PVSG) for the next 20 years. In each case the economic indicators for the two available power of installation (21 kW and 16 kW) will be determined without any aid cost and price evolution due to uncertain evolution of prices that are influenced by many external factors as demand, competition between companies, oil reserve, worldwide politics, etc.

To have the economic comparison between the PV installations and the actual system, firstly the operational cost of the actual installation will be determined considering the actual price of the diesel fuel 1.120 €/litre, a consumption of 8.59 l/h and 1074 hour of running per year results:

$$1074 \times 8.59 \times 1.120 = 10332.74\ €/year \qquad \text{Eq. (25)}$$

O&M cost for all system is estimated to be 1.5 % /year of the initial investment. From this consideration, the O&M cost for the systems is estimated as shown in Table 28.

Table 28. Estimated O&M cost per year

	21 kW system		16 kW system	
	Initial cost (€)	O&M (€/year)	Initial cost (€)	O&M (€/year)
PV module	14552	218.28	11128	166.92
VFD	2210.68	33.16	-	-
MPPT	-	-	3685.6	55.28
Batteries	-	-	11001.6	165.02
Inverter	-	-	7125.7	106.89
Wires, connection boxes and monitoring display	5565.12	83.48	6954.3	104.32

Structure	3400	51	2600	39
Total	25727.8	385.92	42495.2	637.43

In addition to the annual O&M cost, the backup generator adds an extra annual cost. Considering 175 hours of running of the actual generator at a consumption of 5.73 l/h and the price of fuel at 1.120 €/l, the annual fuel cost is estimated to be 1123.08 €/year. Furthermore, if the owner considers to change the generator with the one propose above (Figure 34) at a cost of 3108 €, the annual cost for fuel will decrease to 784 €/year. With an estimated O&M for the actual generator of 200 €, the annual costs for the next 20 year are:

Table 29. Actual generator cost in 20 years

Year	Energy consumption kWh	Actual generator (€)			
		€ / kWh	Fuel cost	O&M	Total cost
1	11770	0.878	10332.74	200	10532.74
2	11770	0.878	10332.74	200	10532.74
…	…	…	…	…	…
19	11770	0.878	10332.74	200	10532.74
20	11770	0.878	10332.74	200	10532.74
Total	235400	0.878	206654.8	4000	210654.8

Table 30. 21 kW PV panels cost in 20 years

Years	21 kW PV panels (€)				
	O&M cost	Fuel AG	Fuel SG	Total cost AG	Total cost SG
1	385.92	1123.08	784	1509	1169.92
2	385.92	1123.08	784	1509	1169.92
…	…	…	…	…	…
19	385.92	1123.08	784	1509	1169.92
20	385.92	1123.08	784	1509	1169.92
Total	7718.4	22461.6	15680	30180	23398.4

Table 31. 16 kW PV panels cost in 20 years

Years	16 kW PV panels (€)				
	O&M cost	Fuel AG	Fuel SG	Total cost AG	Total cost SG
1	637.43	1123.08	784	1760.51	1421.43
2	637.43	1123.08	784	1760.51	1421.43
…	…	…	…	…	…
19	637.43	1123.08	784	1760.51	1421.43
20	637.43	1123.08	784	1760.51	1421.43
Total	12748.6	22461.6	15680	35210.2	28428.6

Using the data from Table 29, Table 30 and Table 31 in equation 24, result the next LCOEs, depending on the type of installation (Table 32), r = 5 %:

Table 32. LCOE by system

LCOE	AS	21 kW PVAG	21 kW PVSG	16 kW PVAG	16 kW PVSG
€/kWh	0.895	0.338	0.506	0.743	0.684

From Table 32 it can be observed that for the levelized cost of electricity, the highest reliable price is made by the 21 kW PV panels system with values as 0.338 and 0.506 €/kWh

3.2. Payback, IRR and NPV

For calculating the economic indicators, the cash flow of the PV installation is needed. In our case, the cash flow represents the saved money as a difference between the annual cost of the generator and the annual cost of the PV installations (Table 33).

Table 33. Cash flow by system

Year	Actual cost (€)	Total cost of 21 kW PV panels (€)		Total cost of 16 kW PV panels (€)		Cash flow of 21 kW PV panels (€)		Cash flow of 16 kW PV panels (€)	
		AG	SG	AG	SG	AG	SG	AG	SG
0 (II)						-30436.32	-33544.32	-47842.16	-50950.16
1	10532.7	1509	1169.9	1760.5	1421.43	9023.74	9362.82	8772.23	9111.31
2	10532.7	1509	1169.9	1760.5	1421.43	9023.74	9362.82	8772.23	9111.31
…	…	…	…	…	…	…	…	…	…
19	10532.7	1509	1169.9	1760.5	1421.43	9023.74	9362.82	8772.23	9111.31
20	10532.7	1509	1169.9	1760.5	1421.43	9023.74	9362.82	8772.23	9111.31
Total	210655	30180	23398	35210	28428.6	150038	153712.08	127602.44	131276.04

Based on initial investment (II), annual cost and the cash flow from Table 33, we can establish the payback period of each installation (Table 34).

Table 34. Payback of installations

Year	Cash flow 21 kW (€)		Cash flow 16 kW (€)		Payback 21 kW (€)		Payback 16 kW (€)	
	AG	SG	AG	SG	AG	SG	AG	SG
0 (II)	-30436.32	-33544.32	-47842.16	-50950.16				
1	9023.74	9362.82	8772.23	9111.31	-21413	-24181.5	-39069.93	-41838.85
2	9023.74	9362.82	8772.23	9111.31	-12389	-14818.68	-30297.7	-32727.54
3	9023.74	9362.82	8772.23	9111.31	-3365.1	-5455.86	-21525.47	-23616.23
4	9023.74	9362.82	8772.23	9111.31	5658.64	3906.96	-12753.24	-14504.92
5	9023.74	9362.82	8772.23	9111.31	14682.4	13269.78	-3981.01	-5393.61
6	9023.74	9362.82	8772.23	9111.31	23706.1	22632.6	4791.22	3717.7
7	9023.74	9362.82	8772.23	9111.31	32729.9	31995.42	13563.45	12829.01
8	9023.74	9362.82	8772.23	9111.31	41753.6	41358.24	22335.68	21940.32
9	9023.74	9362.82	8772.23	9111.31	50777.3	50721.06	31107.91	31051.63
10	9023.74	9362.82	8772.23	9111.31	59801.1	60083.88	39880.14	40162.94
11	9023.74	9362.82	8772.23	9111.31	68824.8	69446.7	48652.37	49274.25

12	9023.74	9362.82	8772.23	9111.31	77848.6	78809.52	57424.6	58385.56
13	9023.74	9362.82	8772.23	9111.31	86872.3	88172.34	66196.83	67496.87
14	9023.74	9362.82	8772.23	9111.31	95896	97535.16	74969.06	76608.18
15	9023.74	9362.82	8772.23	9111.31	104920	106897.98	83741.29	85719.49
16	9023.74	9362.82	8772.23	9111.31	113944	116260.8	92513.52	94830.8
17	9023.74	9362.82	8772.23	9111.31	122967	125623.62	101285.75	103942.11
18	9023.74	9362.82	8772.23	9111.31	131991	134986.44	110057.98	113053.42
19	9023.74	9362.82	8772.23	9111.31	141015	144349.26	118830.21	122164.73
20	9023.74	9362.82	8772.23	9111.31	150038	153712.08	127602.44	131276.04

In conclusion, Table 34 presents the necessary time of each system in order to be economically profitable (ordered by reliability):

- 21 kW PVAG - 4 years (5658.64 € profit);
- 21 kW PVSG - 4 years (3906.96 € profit);
- 16 kW PVAG - 6 years (4791.22 € profit);
- 16 kW PVSG - 6 years (3717.70 € profit).

Moreover, at the end of the 20 years of evaluation, because of the differences between costs and cash flow, the values showed different reliability of the installations:

- 21 kW PVSG - 153712.08 € profit;
- 21 kW PVAG - 150038.00 € profit;
- 16 kW PVSG - 131276.04 € profit;
- 16 kW PVAG - 127602.44 € profit.

To determine the NPV_0 of the systems, we will take in consideration the discount rate of 5 % as IRR. In conclusion, by replacing the values in Eq. 26 we can calculate the NPV for each year to establish the profitability of the systems (Table 35).

$$NPV_0 = -I_0 + \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} \ (€)$$ Eq. (26) [43]

Where:

NPV_0 - Net present value of the project

C_t - cash flow to be received in period t

n - number of total periods for discounting or the expected years of life of the project

r - discount rate (i.e. required rate of return)

t - number of period during which the discounting occurs

I_0 - initial outlay (or the cash flow at t_0)

Table 35. Payback vs. NPV of installations

Year	Payback 21 kW (€)		Payback 16 kW (€)		NPV 21 kW (€)		NPV 16 kW (€)	
	AG	SG	AG	SG	AG	SG	AG	SG
0 (I_0)	-30436.32	-33544.32	-47842.16	-50950.16				
1	-21413	-24181.5	-39069.93	-41838.85	-21842.28	-24627.35	-39487.66	-42272.72
2	-12389	-14818.68	-30297.7	-32727.54	-13657.48	-16134.99	-31530.98	-34008.5
3	-3365.1	-5455.86	-21525.47	-23616.23	-5862.44	-8047.04	-23953.2	-26137.8

4	5658.64	3906.96	-12753.24	-14504.92	1561.42	-344.22	-16736.27	-18641.91
5	14682.4	13269.78	-3981.01	-5393.61	8631.75	6991.79	-9863	-11502.96
6	23706.1	22632.6	4791.22	3717.7	15365.41	13978.47	-3317.02	-4703.96
7	32729.9	31995.42	13563.45	12829.01	21778.41	20632.45	2917.24	1771.28
8	41753.6	41358.24	22335.68	21940.32	27886.03	26969.58	8854.63	7938.18
9	50777.3	50721.06	31107.91	31051.63	33702.81	33004.93	14509.29	13811.41
10	59801.1	60083.88	39880.14	40162.94	39242.61	38752.89	19894.68	19404.96
11	68824.8	69446.7	48652.37	49274.25	44518.60	44227.14	25023.62	24732.16
12	77848.6	78809.52	57424.6	58385.56	49543.36	49440.71	29908.32	29805.67
13	86872.3	88172.34	66196.83	67496.87	54328.84	54406.01	34560.42	34637.6
14	95896	97535.16	74969.06	76608.18	58886.44	59134.87	38991	39239.43
15	104920	106897.98	83741.29	85719.49	63227.02	63638.55	43210.59	43622.12
16	113944	116260.8	92513.52	94830.8	67360.89	67927.77	47229.25	47796.12
17	122967	125623.62	101285.75	103942.1	71297.92	72012.73	51056.54	51771.35
18	131991	134986.44	110057.98	113053.42	75047.47	75903.18	54701.59	55557.29
19	141015	144349.26	118830.21	122164.73	78618.47	79608.36	58173.05	59162.95
20	150038	153712.08	127602.44	131276.04	82019.43	83137.11	61479.22	62596.90

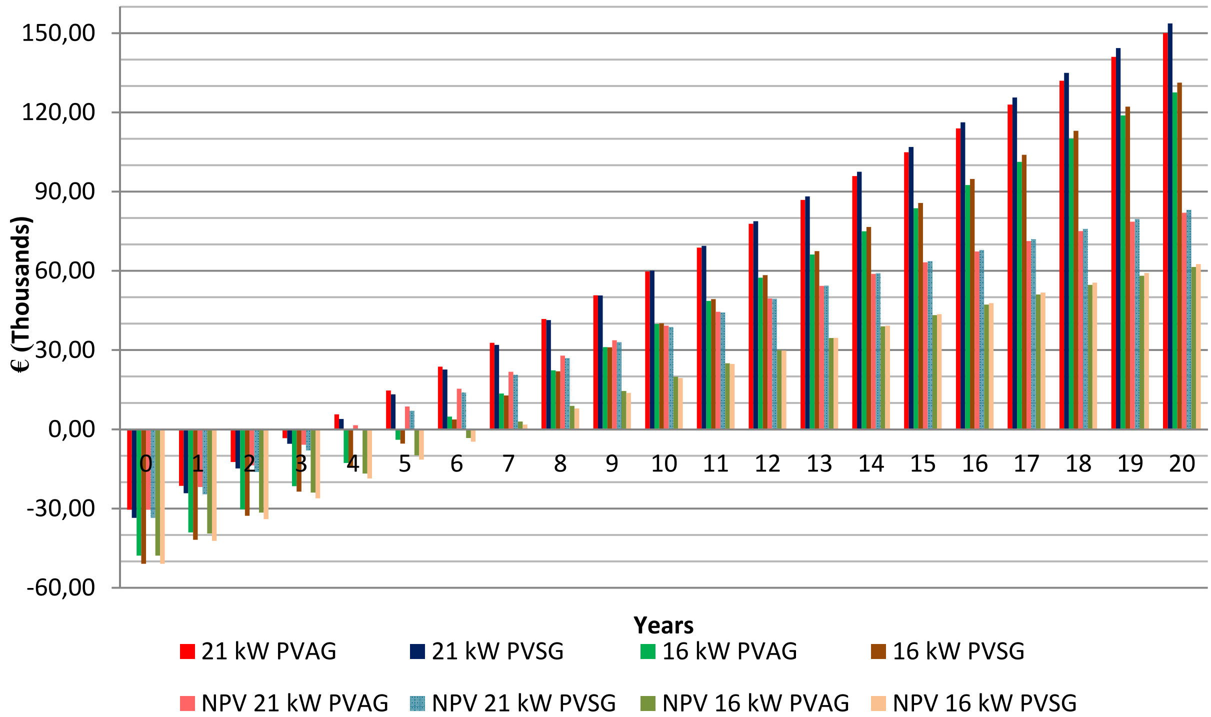

Figure 42. Payback vs. NPV of installations

In equally significant aspect as Table 35, Figure 42 presents the differences between the systems. For the NPVs of the systems, the economic benefits start to appear in:

- 21 kW PVAG - 4 years (1561.42 € profit);
- 21 kW PVSG - 5 years (6991.79 € profit);
- 16 kW PVAG - 7 years (2917.24 € profit);
- 16 kW PVSG - 7 years (1771.28 € profit).

As specified above, the systems present a different order for the NPV values as the payback at the end of the 20 years:

- 21 kW PVSG - 83137.11 € profit;
- 21 kW PVAG - 82019.43 € profit;
- 16 kW PVSG - 62596.90 € profit;
- 16 kW PVAG - 61479.22 € profit.

The internal rate of return (IRR) for each system for the installations is shown in Table 36:

Table 36. Internal rate of return

IRR %	21 kW PV panels		16 kW PV panels	
	AG	SG	AG	SG
	28.24	26.58	17.46	17.03

Despite the technical differences of the systems, each one has proved to be economically efficient due to the high contrast between actual system cost and the predicted cost of the photovoltaic installations.

Project plans

4. Project Plans

The project has as additional components, a series of plans that give a better perspective of the location plan (Figure 43) and the structure of the installations through the electric schemes (Figure 44 and Figure 45). The differences between the electric schemes are given by the components and the working principles of the equipment.
Moreover, the technical data of the equipment are attached to the project as “Annexes”

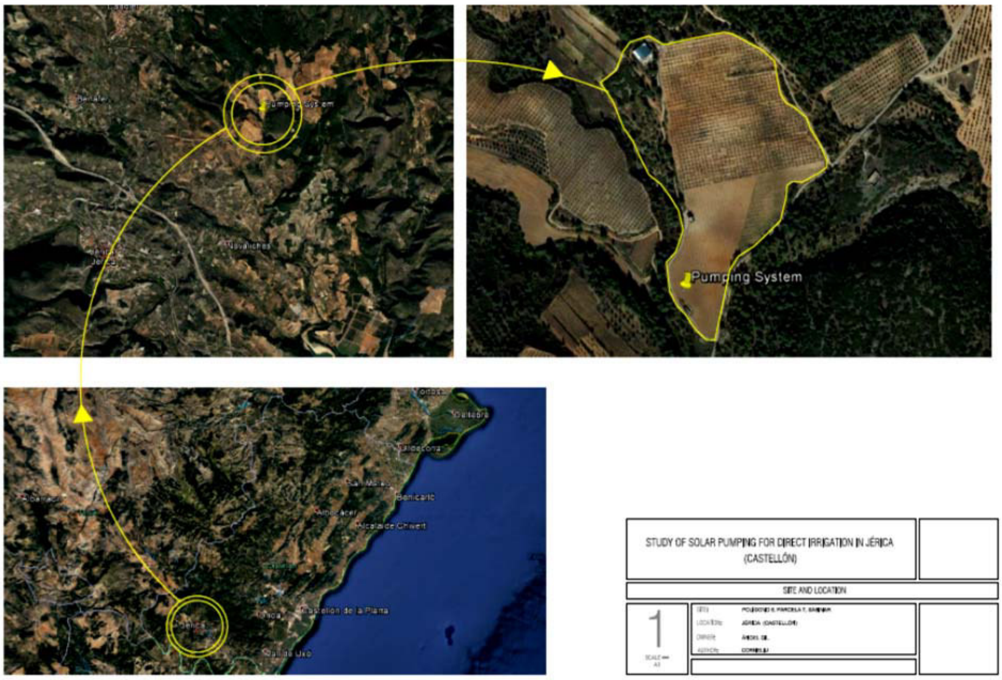

Figure 43. Location Plan

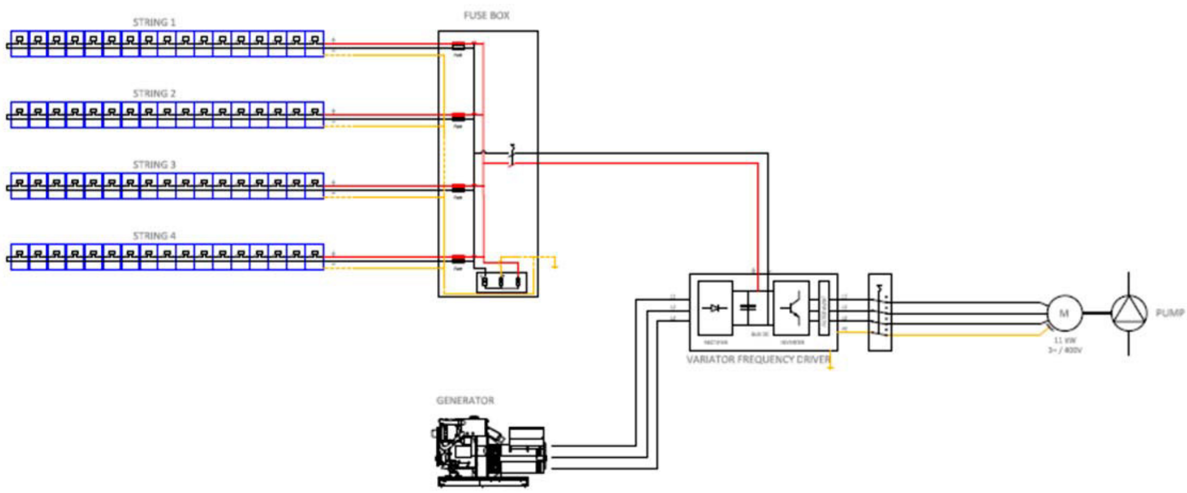

Figure 44. 1’st Installation Electric Scheme

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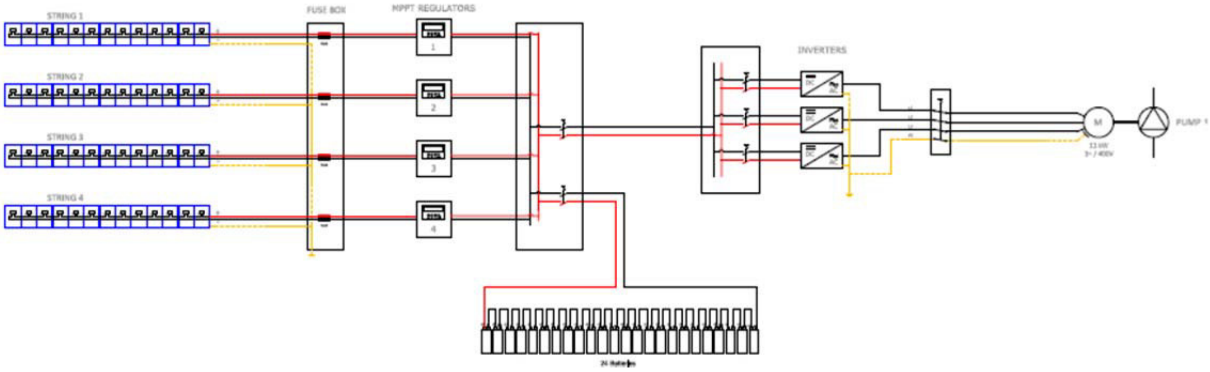

Figure 45. 2’nd Installation Electric Scheme

In Figure 45, the generator can be connected between the inverters and the pump, in order to simplify the circuit.