Proposal to improve energy efficiency in municipal facilities.

Miquel Merino Carrascio, *UAB*

Resum: En aquest projecte he volgut trobar maneres innovadores d'operar els municipis de manera més eficient tenint en compte la situació global. La guerra en curs a Ucraïna i l'augment dels preus de l'energia han augmentat la necessitat d'explorar mitjans alternatius d'operacions municipals i neutralitat energètica. El projecte pretén desenvolupar un pla integral que integri tecnologies i estratègies provades per augmentar l'eficiència i reduir la dependència de fonts d'energia no renovables. Se centra en pràctiques sostenibles, com ara l'eficiència energètica, la gestió de l'aigua i el funcionament general municipal. La segona meitat del projecte consisteix a simular l'impacte de les mesures proposades en un municipi de banc de proves de l'AMB (Àrea Metropolitana de Barcelona) per mostrar les possibilitats de millora de ciutats i pobles.

Abstract: On this project I've wanted to find innovative ways to operate municipalities more efficiently considering the global situation. The ongoing war in Ukraine and rising energy prices have increased the need to explore alternative means of municipal operations and energy neutrality. The project aims to develop a comprehensive plan that integrates proven technologies and strategies to increase efficiency and reduce dependence on non-renewable energy sources. It focuses on sustainable practices, including energy efficiency, water management, and overall municipal operation. The second half of the project involves simulating the impact of proposed measures in a test bed municipality in the AMB (Area Metropolitana de Barcelona) to showcase possibilities for improving cities and towns.

1 INTRODUCTION

THE current global situation has brought to light the importance of finding new and innovative ways to operate municipalities more efficiently. With the ongoing war in Ukraine and the subsequent rise in energy prices, coupled with the search for energy neutrality, it has become essential to explore alternative means of municipal operations. This project aims to address these issues by developing a comprehensive plan that integrates proven technologies and strategies to increase efficiency and reduce dependence on non-renewable energy sources. By focusing on sustainable practices and incorporating innovative technologies, this project will aim towards summarizing a portfolio of proposals in the field of energy neutrality, energy efficiency, water management, and a more efficient municipal operation overall.

In the second half of the project, I aim to try to simulate the impact of the proposed measures in a municipality of the AMB, to try to showcase the possibilities that we can manage to improve our cities and towns.

- *Miquel Merino Carrasco 1565158, 1565158@uab.cat*
- *Tutor: Enric Alibech Romero (Computer Science & Artificial inteligence).*

- Course: 2022/2023

2. Objectives

My objectives for this TFG are to collect and summarize different proposals that can help municipal governments to meet their objectives of carbon neutrality, energy usage efficiency, and water management and make a more sustainable city or municipality; the idea it's to take a reference municipality in the AMB (Area Metropolitana de Barcelona) as the test bed as how these ideas would work.

• Summarize the proposals in the realm of energy efficiency in a municipal

• Summarize the proposals in the realm of water management at a municipal level.

• Summarize the proposals in the realm of energy neutrality at a municipal level.

• Quantify the savings with the proposals in the municipality that is chosen as a test bed.

3. State of the Art

3.1. Photovoltaic solar energy

Photovoltaics, or solar cells, are devices that convert sunlight directly into electricity. They have become a popular and increasingly affordable renewable energy source, with the potential to reduce carbon emissions and provide a reliable source of energy.

Technology and Types of Photovoltaics

There are several types of photovoltaic cells, including monocrystalline, polycrystalline, thin-film, and tandem cells.

Monocrystalline cells are made from a single crystal of silicon and have high efficiency and durability but are also more expensive to manufacture.

Polycrystalline cells are made from multiple crystals of silicon and are less expensive to manufacture but have lower efficiency than monocrystalline cells.

Thin-film cells are made by depositing a thin layer of photovoltaic material, such as cadmium telluride or copper indium gallium selenide, onto a substrate. They are less expensive to manufacture than crystalline cells but have lower efficiency and durability.

Tandem cells are made by stacking two or more different types of photovoltaic materials to increase efficiency.

Recent Advancements in Photovoltaic Technology

One of the main challenges of photovoltaic technology is the high cost of materials and manufacturing. However, recent advancements in materials and manufacturing processes have led to a decrease in the cost of photovoltaic systems.

One such advancement is the use of new materials, such as perovskites, which have high efficiency and can be manufactured using low-cost methods.

Another advancement is the use of 3D printing technology to manufacture photovoltaic cells and modules, which can reduce the cost and time of production.

In addition, there has been significant progress in the development of photovoltaic modules that can withstand harsh environmental conditions, such as high temperatures and humidity.

Benefits and Challenges of Photovoltaics

Photovoltaics have several benefits, including their renewable and sustainable nature, their low carbon emissions, and their potential to reduce dependence on fossil fuels. They also have the advantage of being modular, which allows for flexible installation and scalability.

However, there are also several challenges associated with photovoltaics. One of the main challenges is the intermittent nature of sunlight, which can affect the reliability of photovoltaic systems. This can be mitigated using energy storage systems, such as batteries, to store excess energy generated during the day and release it at night or during periods of low sunlight.

Another challenge is the high initial capital cost of photovoltaic systems, which can be a barrier to widespread adoption. However, as the cost of materials and manufacturing continues to decrease, photovoltaic systems are becoming more affordable.

Prospects

Photovoltaics are expected to play an increasingly important role in meeting global energy demand in the coming decades. According to the International Energy Agency (IEA), photovoltaic electricity could provide up to 30% of global electricity by 2050, up from less than 3% in 2018.

In addition, the development of new materials and manufacturing processes, as well as improvements in energy storage systems, are expected to further reduce the cost and increase the efficiency of photovoltaic systems.

3.2. Solar thermal energy

Solar thermal energy is a renewable energy source that has gained increasing attention in recent years due to its potential to provide low-carbon energy. It involves the conversion of solar radiation into thermal energy, which is then used to produce electricity or heat.

Technology and Types of Solar Thermal Energy

There are three main types of solar thermal energy systems: concentrating solar power (CSP), solar water heating (SWH), and solar air heating (SAH).

CSP systems use mirrors or lenses to concentrate solar radiation onto a small area, which heats a fluid to produce steam. The steam is then used to generate electricity through a conventional steam turbine.

SWH systems use a collector to absorb solar radiation and heat water, which can then be used for domestic or industrial purposes.

SAH systems are like SWH systems, but they heat air instead of water. The heated air is then used for space heating or industrial processes.

Recent Advancements in Solar Thermal Energy Technology

One of the main challenges of solar thermal energy is the high cost of materials and manufacturing. However, recent advancements in materials and manufacturing processes have led to a decrease in the cost of solar thermal systems.

One such advancement is the use of new materials for solar collectors, such as advanced polymers and nanomaterials, which have higher thermal conductivity and can withstand higher temperatures than traditional materials.

Another advancement is the use of 3D printing technology to manufacture solar collectors, which can reduce the cost and time of production.

In addition, there has been significant progress in the development of thermal energy storage systems, which can store excess heat generated during the day and release it at night or during periods of low solar radiation. This allows solar thermal energy systems to provide a reliable source of energy even when the sun is not shining.

Benefits and Challenges of Solar Thermal Energy

Solar thermal energy has several benefits, including its renewable and sustainable nature, its low carbon emissions, and its potential to reduce dependence on fossil fuels. It also has the advantage of being able to provide both electricity and heat.

However, there are also several challenges associated with solar thermal energy. One of the main challenges is the intermittent nature of solar radiation, which can affect the reliability of solar thermal energy systems. This can be mitigated using thermal energy storage systems, as mentioned earlier.

Another challenge is the high initial capital cost of solar thermal energy systems, which can be a barrier to widespread adoption. However, as the cost of materials and manufacturing continues to decrease, solar thermal energy systems are becoming more affordable.

Prospects

Solar thermal energy is expected to play an increasingly important role in meeting global energy demand in the coming decades. According to the International Energy Agency (IEA), solar thermal energy could provide up to 16% of global electricity by 2050, up from less than 1% in 2018.

In addition, the development of new materials and manufacturing processes, as well as advancements in thermal energy storage systems, are expected to further reduce the cost and increase the efficiency of solar thermal energy systems.

3.3. Water Management

3.3.1. Greywater Recycling

Greywater recycling is the process of collecting and treating household wastewater, such as from showers, baths, and washing machines, for reuse in non-potable applications, such as watering plants, flushing toilets, and washing clothes.

Benefits and Challenges of Greywater Recycling

Greywater recycling has a number of benefits, including: Water conservation: Greywater recycling can significantly reduce the amount of freshwater used for non-potable applications, such as watering plants and flushing toilets.

Cost-effective: Recycling greywater can reduce water bills, particularly in areas where water is scarce and expensive.

Reduced wastewater: Recycling greywater can reduce the amount of wastewater generated by households, reducing the strain on wastewater treatment facilities.

Reduced carbon footprint: By reducing reliance on municipal water supplies and reducing the amount of wastewater generated, greywater recycling can help to reduce the carbon footprint of households and communities.

Water Quality: Greywater contains contaminants, such as bacteria and chemicals, that must be properly treated before reuse. Proper filtration and treatment of the water are necessary to ensure its safety for human use and environmental protection.

Maintenance: Greywater recycling systems require regular maintenance to ensure they function properly. This can be a challenge for households and communities that lack the necessary expertise or resources.

Regulations: Regulations governing greywater recycling vary by location and can be complex. It is important to understand the regulations in your area before installing a greywater recycling system.

Cost: While greywater recycling can be cost-effective in the long run, the initial cost of installing a system can be a barrier for some households and communities.

3.3.2. Rainwater Harvesting

Rainwater harvesting is the collection and storage of rainwater from rooftops, surfaces, and other areas for future use. The practice has been in use for centuries and has gained renewed attention in recent years as a sustainable water management strategy. Rainwater harvesting is a viable alternative to traditional water sources, especially in areas with limited access to freshwater or where water is scarce and help reduce the need for freshwater for certain need and replace it with rainwater.

Modern rainwater harvesting systems are designed to maximize the collection and storage of rainwater. They include filtering systems that remove debris, contaminants, and other pollutants from rainwater. These systems also feature automated controls and sensors that regulate the flow of water, ensuring optimal usage; green roofs are rooftops gardens that are designed to absorb rainwater and reduce the amount of runoff. The plants and soil act as a natural filter, purifying the rainwater as it flows through the system. Green roofs are an effective way to reduce the demand for potable water and mitigate the urban heat island effect. Permeable paving is a type of pavement that allows rainwater to seep through the surface and into the ground. This reduces the amount of runoff and helps recharge groundwater supplies. Permeable paving can be used in parking lots, sidewalks, and other areas to reduce the impact of urbanization on the water cycle.

3.4. Insulated Walls

Wall insulation is the aim to create a thermal barrier that helps to keep the interior of the building warmer in the winter and cooler in the summer, reducing the need for heating and cooling systems to work as hard to maintain a comfortable temperature; the insulation is typically installed in the wall cavity, which is the space between the interior and exterior walls of a building. The insulation can be made from a variety of materials, such as fiberglass, mineral wool, cellulose, foam, or reflective materials, and is designed to slow down the flow of heat through the walls by trapping air in small pockets within the insulation material.

The following are some of the technincs/ways on how to insulate a wall:

Aerogel insulation: Aerogel is a highly insulating material made of a network of porous silica particles. It is an excellent insulator due to its low thermal conductivity and high surface area. Aerogel insulation can be used in walls, roofs, and floors to reduce heat loss and increase energy efficiency. It is also lightweight and easy to install.

Vacuum insulation panels (VIPs): VIPs are thin, highly insulating panels that use a vacuum to reduce heat transfer. They have very low thermal conductivity and are effective at reducing heat loss in walls, roofs, and floors. VIPs are also lightweight and easy to install.

Cellular glass insulation: Cellular glass is a type of insulation made from recycled glass. It has excellent thermal insulation properties and is also resistant to water, fire, and mold. Cellular glass insulation can be used in walls, roofs, and floors to improve energy efficiency and sustainability.

Spray foam insulation: Spray foam insulation is a type of insulation that is sprayed onto walls and other surfaces. It expands and hardens to create an airtight and highly insulating barrier. Spray foam insulation is easy to install and can be used in new construction or retrofit projects.

Eco-friendly insulation: Eco-friendly insulation materials are becoming increasingly popular due to their sustainability and low environmental impact. These materials include cellulose, made from recycled paper; wool, made from sheep's wool; and cotton, made from recycled denim.

4. Methodology.

4.1. Information Sources

The information sources used in this report are secondary and primary; all the data used for the calculus of rainwater is extracted from the Catalan Meteorological Service; it is in a .txt format, and precipitation data comes in a month-by-month format, even though I only use the data from 2018 onwards they provide data from 1950.

To calculate the roof area, I used an Ortofoto from the Catalan Institute of Cartology and Geology taken in 2022, and the data came in a GeoTiff format.

The data used for solar irradiation comes from the EU, all the data from the solar panels come from the report made by the engineering company that got hired by La Palma de Cervelló Town Hall to install solar panels [17], and also I have used the web page www.pveducation.org, to learn and check various facts about photovoltaic panels and how do they work.

The data taken to base my report on is from the report made for the Town hall of Les Preses (Girona) [16]; since the needs are similar enough to use the same boiler and budget, to calculate the savings on pellets, prices were taken from the Catalan Forestal Observatory. The fuel prices are from the Spanish Ministry of Industry and Transports.

The management of the Poliesportiu 1er d’octubre has facilitated the amount of gasoil and electricity consumed yearly since 2018.

4.2. Methods

Since in this report, there are three different sections of improvement, I have used different software and techniques for each proposal.

To calculate the amount of rainwater that is possible to harvest in the “Poliesportiu 1 d’Octubre”, I used data from 5 different weather stations since there is no official data on the amount of rainfall in La Palma de Cervelló, 5 of them are located in Barcelona Observatori Fabra, Aeroport de Barcelona, Esparraguera, Terrassa, and Vilafranca del Penedés, and then I correlated the data so the weather station that is closer has a higher relevance than the ones further away.

To calculate the amount that would be possible to harvest, we also need the area of capture; using Qgis and an Ortofoto from ICGC, I calculated the area of the proposed roof for the installation of the rainwater harvesting system; it should be noted that I only used for the calculation the roofs with inclination, since there is a roof that is flat, and it’s already been used for solar panels.

To calculate the performance of solar panels, we need to know the solar irradiation (itself also depends on the latitude), the performance of solar panels with respect to the amount of irradiation received, the amount of cloudiness, the temperature, and the angle in respect of the sun. The data about the prices that the Sport complex pays for its electricity is not available.

The boiler that is being used works with gasoil, and these last five years have consumed.

Data in liters	2018	2019	2020	2021	2022
Diesel	6.545,1	7.471,68	3.343,29	3.804,27	8091,00

Table. 1 Diesel consumption. Own making

To calculate the potential savings in this change of boiler, I calculated the energetic amount needed for the same calorific needs done with diesel and converted it into kg of biomass, so we can calculate the amount of savings.

The fuel price and the price of pellets are calculated following their regression line. To calculate the respective line, I've taken the median price of each product during five years, in the case of diesel, I've taken the period of 2015 – 2019 because the prices between 2020 – 2023 were adulterated by the COVID-19 pandemic and the war in Ukraine, and the period for the pellets its 2018 – 2022 and not 2019 – 2023 because 2023 price got influenced by the increased demand because the war in Ukraine.

The price of diesel it is determined by this ecuation being the initial value of x = 5: $\boldsymbol{y = 0,039x + 1,009}$
The price of pellets it is determined by this ecuation being the initial value of x = 5: $\boldsymbol{y = 5,96x + 166.22}$

5. Area of Study.

For this study, I'll use the sporting center in la Palma de Cervelló, which has a swimming pool, a gym, a sauna, six changing rooms, two multi-use rooms, and a court that can be used for multiple needs; on this building, there are three proposals for improving energy efficiency, installing solar panels, installing a rainwater harvesting system, and a change of boiler to a biomass boiler.

6. Results.

BIOMASS BOILER

To calculate the savings that we can make on switching to a biomass boiler, we need to know how many pellets we need to produce the same amount of heat. Since the administration of the Sports complex facilitated the amount of Diesel consumed on the installation, we just need to take the newest value, in this case, it's 2022, so we can have a more realistic sight of the prices; we will use 2019 prices so the COVID-19 pandemic and the war in Ukraine [6] [11] [13] [15].

- Gasoil Heat Value: 42.000 KJ/l
- Pellets Heat Value: 18.000KJ/kg
- Average Price Gasoil in Spain: 1,21€/l
- Average Price Pellet in Spain: 194,3€/T

First, we need to know how many KJ the boiler outputted with gasoil, and then search how many Kg of pellets we would need to output the same amount of KJ.

$$42000KJ/1l * 8091l = 339822000KJ$$
$$339822000KJ\ /(\ 18000KJ/1Kg) = 18879Kg$$
$$8091l * 1.21€/l = 9790.11€$$
$$18{,}879T * 194.3€/T = 3668.19€$$

As we can see, the yearly cost of fuel there a difference of 6121,92€ between the two options. To calculate the return on investment will consider 150€ as maintenance from the second year onward and the first year 400€ as is usual that the first year of operation of any installation is higher than usual in cost.

As we can see, in the 11th year, the installation would already be repaid; also, by changing the boiler to biomass/pellet, the emission would be reduced substantially because biomass is considered a neutral emission fuel since its possible to regrow biomass.

An important remark should be noted, La Palma de Cervelló it's a town surrounded by forests like many other small towns and villages in Catalonia and Spain; Spain has been not caring about their forests and letting them get dirty, overgrown, and dangerously packed with dead and fallen pieces of trees; and if we take into consideration the situation of drought and the amount of heat that can happen on these locations, its almost mandatory to have forest fires because the heat, the Draught and the dirtiness of the forests. One of the main solutions for these problems is to clean up the forests; it can be a possibility to use all the biomass that can be extracted from the clean-ups of the forests to transform it into pellets or other forms of usable biomass.

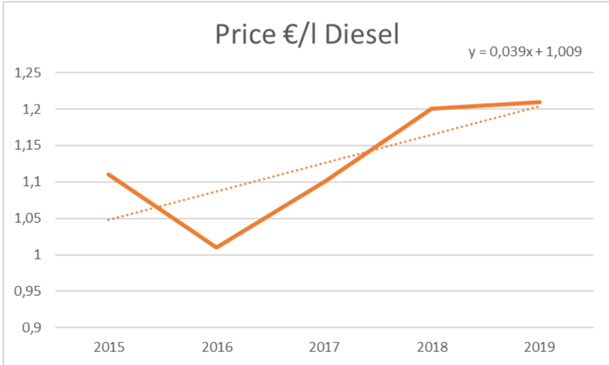


Fig. 1 Evolution price of Diesel. Own making

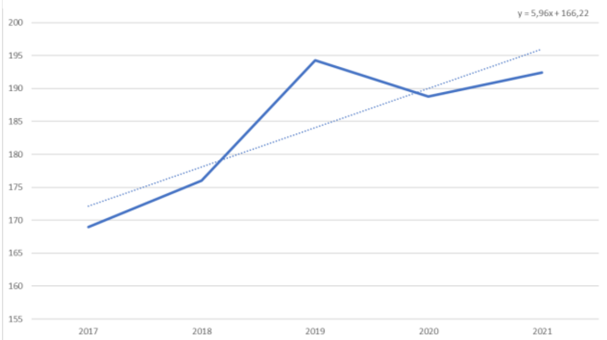


Fig. 2 Evolution price of Pellets. Own making

ANY	MANTENIMENT	QUANTITY PELLETS	PRICE PELLETS	TOTAL COST	QUANTITY DIESEL	PRICE DIESEL	COST DIESEL	PROFITS	ACCUMULATED CASH FLOW
0	0	0	0	0	0	0	0	0	-72056
1	400,00	18,879	196,02	4100,66158	8091	1,204	9741,56	5640,90	-66415,10
2	150,00	18,879	201,98	3963,18042	8091	1,243	10057,11	6093,93	-60321,17
3	154,50	18,879	207,94	4080,19926	8091	1,282	10372,66	6292,46	-54028,70
4	159,14	18,879	213,9	4197,3531	8091	1,321	10688,21	6490,86	-47537,84
5	163,91	18,879	219,86	4314,64599	8091	1,36	11003,76	6689,11	-40848,73
6	168,83	18,879	225,82	4432,0821	8091	1,399	11319,31	6887,23	-33961,50
7	173,89	18,879	231,78	4549,66573	8091	1,438	11634,86	7085,19	-26876,31
8	179,11	18,879	237,74	4667,4013	8091	1,477	11950,41	7283,01	-19593,31
9	184,48	18,879	243,7	4785,29338	8091	1,516	12265,96	7480,66	-12112,64
10	190,02	18,879	249,66	4903,34665	8091	1,555	12581,51	7678,16	-4434,48
11	195,72	18,879	255,62	5021,56596	8091	1,594	12897,05	7875,49	3441,00
12	201,59	18,879	261,58	5139,95628	8091	1,633	13212,60	8072,65	11513,65
13	207,64	18,879	267,54	5258,52274	8091	1,672	13528,15	8269,63	19783,28
14	213,86	18,879	273,5	5377,27063	8091	1,711	13843,70	8466,43	28249,71
15	220,28	18,879	279,46	5496,2054	8091	1,75	14159,25	8663,04	36912,75

Table 2 Return on Investment on the biomass boiler. Own making

SOLAR PANELS

The performance of the solar panels depends on different variables; the first one the amount of solar irradiation, the amount it changes on the latitude that are we planning on intsalling them in this case 41ºN, 2823,03 Kw/m² it's the amount of solar irradiation received annually; the performance of the solar panel its 20,3%, it means that every 1w received it can output 0,203w; another factor that takes part it's the amount of cloud coverage, since clouds block solar irradiation; temperature also takes a part these solar panels work optimally at 25ºC or below, the panels by themselves the heat up while they produce electricity following this ecuation: $Sun\ Irradiation * 0{,}034 - 4$, to take fully into aocunt the effects of th temperature on the panels we have to take into account the ambient temperature and the self produced heat; the angle its also a factor that modifies the performance of the panels, the perfect angle doesn't exist but it's always possible to optimize it, for 41ºN the recommended angle by the web page from the EU says it is 38º, even though the engineering company that made the report [17] proposes to install them at 30º, the closest to the ecuator lower the angle respect the sun should be, and the further away we are from the ecuator higher the number. [8] [9] [10]

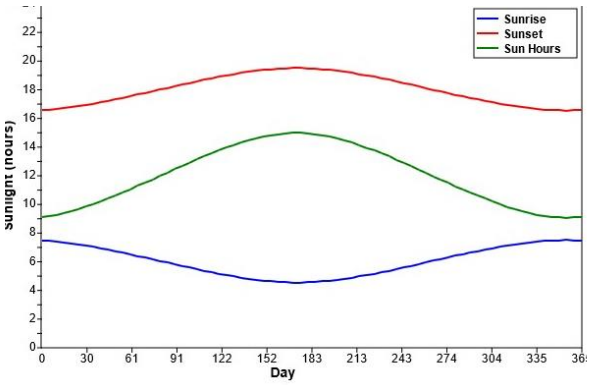


Fig. 3 Evolution of daytime at the Latitude 41º. Made by pveducation

First, not every day at latitude 41o do we have the same level of exposure to the sun; we have more sun irradiation in the months of June, July, and August, and in the months of December, January, and February, we have less sun irradiation. This fact makes the need to optimize the tilt of the panels so we can extract the maximum amount.

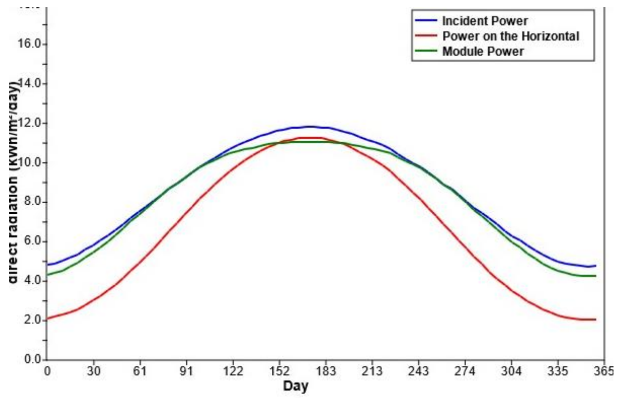


Fig. 4 Performance solar panel at 38º of tilt. Made by pveducation

W e can see on the anterior graph the expected output on a tilt of 38º; we can see the lower performance in summer and a closing line in winter; even in summer, the performance with the 38º tilt is lower than having the panels laying on the floor.

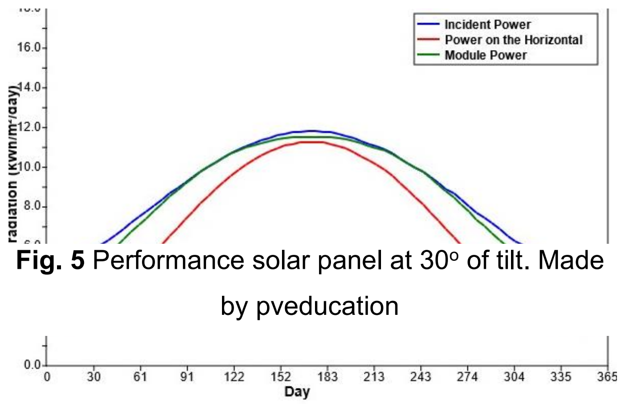


Fig. 5 Performance solar panel at 30º of tilt. Made by pveducation

With the tilt of 30º we can see a higher output in summer and a lower in winter.

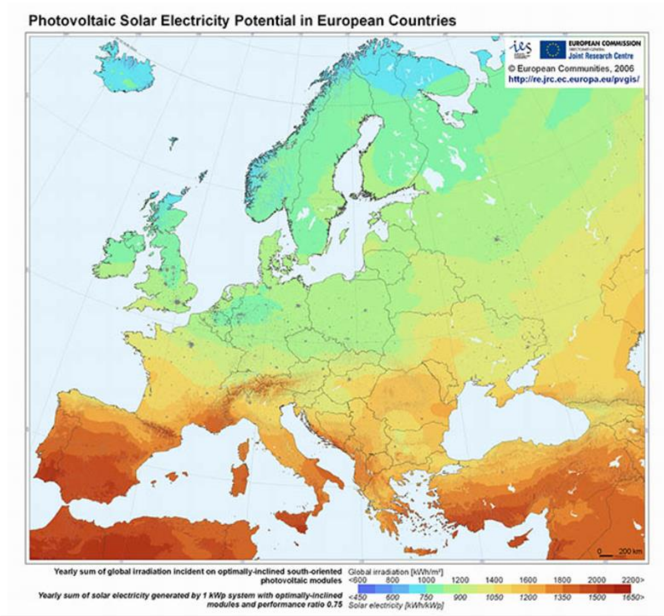


Fig. 6 Solar Irradiation in Europe and North Africa. Made by European Comission

On this representation we can see the expected amount of sun insulation in Europe and North Africa.

Table 3 Solar Irradiation monthly. Own making

		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	
maximum in	kw/m2	143,70	163,59	232,57	269,98	316,21	321,85	324,79	298,89	244,80	223,44	151,66	131,54	2823,03
insolation az	kw/m2	69,09	97,49	120,93	149,66	208,94	205,95	225,78	198,54	141,46	106,37	68,14	61,05	1653,41
insolation - t	insolation 30º	120,65	147,08	150,98	163,35	209,17	197,33	221,19	209,98	168,25	146,69	109,79	109,95	1954,39
	insolation 37º	129,29	153,06	153,77	161,94	203,06	189,85	213,61	206,54	170,02	151,43	116,40	118,29	1967,26

In this table, we can see the amount of solar irradiation in La Palma de Cervelló measured in kWh/m2; the first row it's the perfect orientation to capture all the irradiation, and the second row it's if the panels were laying flat; this scenario would be optimal in the equator, the third row it's the tilt proposed by the engineering company that has made the report for the town hall, 30º offer a higher output in summer but a lower one in the winter and similar in spring and autumn, the tilt proposed by the webpage of the EU, 38º offers an output higher in the winter months and lower in the summer months, the tilt proposal that is intalled in the sport complex can be to much focused on summer production and forget about winter, fotovolatic installations trend to overproduce in summer and almost be irrelevant in winter , but maybe they want to produce the maximum amount possible to cover the augmented consume of electricity made by the utilization of the pool and all the sumer campus that take part on it.

Table 4 Performance solar panel at 30º of tilt. Own Making

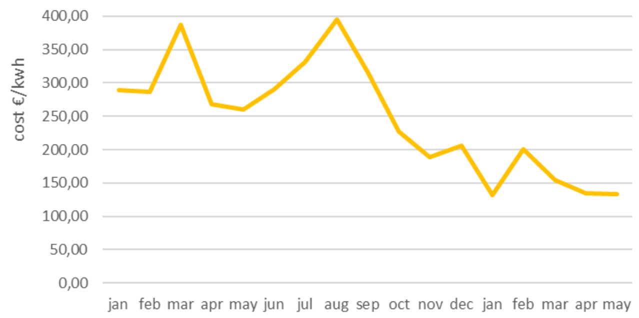
surface FV	107,3322	m2												
production inclination FV 30º		12949,62	15786,78	16204,89	17532,72	22450,22	21179,79	23740,99	22537,13	18058,11	15744,13	11783,97	11801,11	209769,45
20,2%	panel performance	2615,82	3188,93	3273,39	3541,61	4534,95	4278,32	4795,68	4552,50	3647,74	3180,31	2380,36	2383,82	42373,43
	nubosity	18,79	18,79	18,79	18,79	19,24	13,87	7,16	9,84	16,11	20,13	19,69	18,79	200,00
	Temperature	0,00	0,00	0,00	0,00	5,28	7,24	16,09	15,84	2,26	0,00	0,00	0,00	46,71
1,5%	inverter performance	39,24	47,83	49,10	53,12	68,02	64,17	71,94	68,29	54,72	47,70	35,71	35,76	635,60
0,5%	loses wiring	13,08	15,94	16,37	17,71	22,67	21,39	23,98	22,76	18,24	15,90	11,90	11,92	211,87
		2544,71	3106,36	3189,13	3451,99	4419,73	4171,64	4676,52	4435,77	3556,42	3096,57	2313,07	2317,36	41279,25

Table 5 Performance solar panel at 38º of tilt. Own Making

surface FV	107,3322	m2												
production inclination FV 30º		13877,16	16427,82	16504,43	17381,76	21794,81	20377,00	22927,27	22168,45	18248,65	16253,30	12493,78	12696,39	211150,83
20,2%	panel performance	2803,19	3318,42	3333,90	3511,12	4402,55	4116,15	4631,31	4478,03	3686,23	3283,17	2523,74	2564,67	42652,47
	nubosity	18,79	18,79	18,79	18,79	19,24	13,87	7,16	9,84	16,11	20,13	19,69	18,79	200,00
	Temperature	0,00	0,00	0,00	0,00	5,28	7,24	16,09	15,84	2,26	0,00	0,00	0,00	46,71
1,5%	inverter performance	42,05	49,78	50,01	52,67	66,04	61,74	69,47	67,17	55,29	49,25	37,86	38,47	639,79
0,5%	loses wiring	14,02	16,59	16,67	17,56	22,01	20,58	23,16	22,39	18,43	16,42	12,62	12,82	213,26
		2728,33	3233,26	3248,43	3422,10	4289,98	4012,72	4515,43	4362,79	3594,14	3197,37	2453,58	2494,59	41552,71

In these two tables, we can see the total production of the proposed installation, the first row shows the total irradiation times the total area of the installation (107,33m^2), on the second row it's the amount of kw that the installation should be able to output as advertised by the manufacturer, on the fourth row we can see the amount of loses that excess heat makes on the panels, $Sun\ Irradiation * 0{,}034 - 4$ + ambient temperature, if the result of this equation it's higher than 25ºC the panels lose 0,039% of its performance by every degree that goes over, and the fifth and sixth row shows the losses related to the inverter and the wiring; in the case of the inverter, it loses 1,5% of the electricity, and the wiring by itself loses 0,5%.

Fig. 7 Electricty price evolution in Spain Jan2022-May2023



To calculate the savings, I've used the prices of 2023 and consumer prices; I have not been able to find how much the Sport complex pays for its electricity since its when the Iberian exception entered effect and made prices go back to normal, the median price in 2023 has been 150,67€/Mwh = 0,15067 €/Kwh.

Table 6 Average price in Spain 2023. Own Making

Average price in 2023	jan	feb	mar	apr	may	Average
€/Mwh	131,57	200,44	153,92	134,52	132,87	150,67
€/Kwh	0,1316	0,2004	0,1539	0,1345	0,1329	0,1507

$$Expected\ output * electricy\ price = Expected\ savings$$

$$41279{,}25\ Kwh * 0{,}15067\ €/Kwh = 6219{,}54\ €$$

$$41552{,}71\ Kwh * 0{,}15067\ €/Kwh = 6260{,}74\ €$$

If we check the proposed budget by the town hall its 84.320,47 €, so if the prices maintain in a similar level the installation should be repaid in

$$Budget/Expected\ savings\ by\ year = Years\ to\ be\ repaid$$

Installation with a tilt of 30º

$$84320{,}47€ /\ 6219{,}54\ €/year = 13{,}55\ \approx 14\ years$$

Installation with a tilt of 38º

$$84320{,}47€ /\ 6260{,}74€/year = 13.55 \approx 14\ years$$

As we can see there isn't difference on the amount of time we need to repay the investment, it just varies on the optimization of the output.

RAINWATER HARVESTING

First of all, I have not met my objective in the field of rainwater harvesting; the main problem has been how to calculate how much water the system will be able to capture; I couldn't find a way to calculate the performance, but I don't want to throw away my different calculations and research, so I will expose my findings and try to offer different outcomes that could be possible.

To know how much water we can harvest, we need to know how much water has rained in La Palma de Cervelló; using data from 5 weather stations, I correlated them with the distance to the Sports Complex, the average rainfall in La Palma de Cervelló during the last five years its has been 498,63 l/m2.

Table 6 Rainfall in La Palma de Cervelló. Own Making

Data in l/m^2	2018	2019	2020	2021	2022
RAINFALL	818,53	437,91	687,57	279,64	269,52

The total roof area that I planned to use as the capture zone has an area of 1180 m2; if we multiply the total roof area and the average rainfall in La Palma, we have 588.383,4 l; this number it's the potential amount of water that would be possible to capture.

Which uses are possible too for the rainwater that we have captured, the Sport complex has a Pool with a zone with grass turf for its users to lay and relax, water is needed to keep the turf fresh and green, la Palma de Cervelló it's a town with a lot of small plots of land owned by locals, and there are communal canals to distribute water to irrigate the fields; also an option would be to introduce the rainwater to the pool if it was needed, instead of using fresh water.

To irrigate the grass turf its needed 15 l/m2 every three days; the Pool opens from 22/06 to 31/08, a total of 70 days; if we want to irrigate as we said before we would have to do it 23,3 times ≈ 24 time, the total area of turf grass its $273m^2$, $273\ m2 * 15\ l/m2 * 24\ periods = 98280\ l$; in theory this would be well inside of what we could manage to harvest, to be able to fullfil this option apart of the harvesting installation we would need to install a big enough tank to save the water for when its needed.

Fig. 8 Areas of the sport complex, Red tilted Roof, Green Grass, Blue flat Roof

On the second option, the main problem would be to connect to the communal canal, but the distance is 248 m and downhill, so there wouldn't be any need to install any pumping installation or anything, a tank to reserve water for when it is needed, it also would be advisable.

The last option would be to use the rainwater and treat it with the pool installations to be used in the pool instead of replenishing it with fresh water.

All the options could be done at the same time, but I run into the same problem I cannot calculate how much water would be the system be able to harvest. [12] [14].

7. Conclusion

To summarize all the options, offer different ways of saving resources and money and improving the efficiency of the sports facilities, the solar panels are already installed just went online six months ago, so the data they provided me didn't reflect it; the boiler can be a great option to switch to a more economical and sustainable way of heating up the installation and their water. The rain harvesting system can be useful to capture greywater and use it for different options and needs.

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