M.Sc. in Energy Engineering School of Industrial and Information Engineering

Toward the design of carbon-neutral energy communities: the renewable energy budget of an Italian town.

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Abstract

The main objective of this thesis is to examine, and report all available renewable energy sources that may be used in a particular community while preserving current agricultural practices (i.e., avoiding installation in agricultural regions). Then, calculate the energy production and carbon emissions saved via this transition using the available data of these resources. Finally, asses the project's feasibility on micro, and macro levels (the possibility of doing such project with only locals or still there is a need for the interception, and guidance of the governments, and officials).

The methods used in this thesis calculations are separated into three categories. The first is calculating the energy output of accessible energies using simple calculation methods such as basic equations, references, or known computational equations for each technology, as illustrated in chapters three and five in the total energy output, economic analysis, and carbon emission avoided. Also, use in chapter four in the energy output, and carbon emission avoided.

The second method is shown in the economic analysis of chapter four, as it is made with the help of the anaerobic digestors economic assessment tool (SADEAT) which is developed with MATLAB software.

The third method is by calculating the energetic and economic feasibilities of a specific project (for this thesis it is a one-dwelling residential house) with the help of an open-source energy analysis program (RETscreen), which helps to evaluate the micro vision of the consumer side (demand side) after implementing some technologies to increase the energy efficiency of the building.

A simple overall energy balance is made to see the energetic feasibility of the project after using all the available (technically usable) energy sources in the community, and finally, concluding the thesis with a demonstration of the feasibility of the whole project.

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1. Introduction

The idea of a carbon-neutral energy community (EC) is to organize the energy generation needed for a specific community which can be a village, a small town, or even a residential block in a big city, for which most of the energy needed by this community is generated within the community itself, and to make sure that this energy is generated by renewable energy sources (RESs) (solar, wind, biomass, etc.). Involving the citizens of the local EC by making them participate, and organize the energy system which would lead in helping the local communities by opening new businesses and opportunities, and will also help in solving a critical problem in the energy sector, which is the energy transition needed to decarbonize the world's energy production. [1]

The EU has always supported the development of RESs energy production with incentives, funds, and legalizations. For example, the Cohesion Fund which supports the energy projects that help in decreasing the greenhouse gases, either by increasing the efficiencies of existing power plants or by increasing the usage of RES. Also, there is the Recovery and Resilience Facility (RRF), the main purpose of this project is to rise stronger after the COVID-19 pandemic, and to help the EU in achieving climate neutrality by 2050. The success of the RFF project depends on improving six main aspects to achieve the green transition. These aspects are shifting to digital transformation, improving the economic cohesion, optimize the productivity, improving the social and territorial cohesion, decreasing the harmful emissions and strengthen institutional resilience, policies for the next generation. [2]

1.1.1. Cleaner electricity production in Europe

Due to the implementation of the methods and projects indicated in the previous section, the EU electric energy production has shown a greener change especially after the COVID-19 pandemic, there was clear progress in the transition to green electric energy production in the EU and key neighbors (UK, Turkey and Western Balkans). The demands for coal, fossil fuels and, nuclear electrical energy decreased clearly after the pandemic in comparison to the pre-pandemic demands, even though the total electricity demand in the first half of 2021 is almost back to the total electricity demands of the pre-pandemic.

As shown in figure 1, the total electric energy production of fossil fuels decreased, which led directly in decreasing the emissions by almost 12%. Likewise, the same happened with coal production which led directly in decreasing the emissions by 16% in the first half of 2021 compared to the first half of 2019. [3]

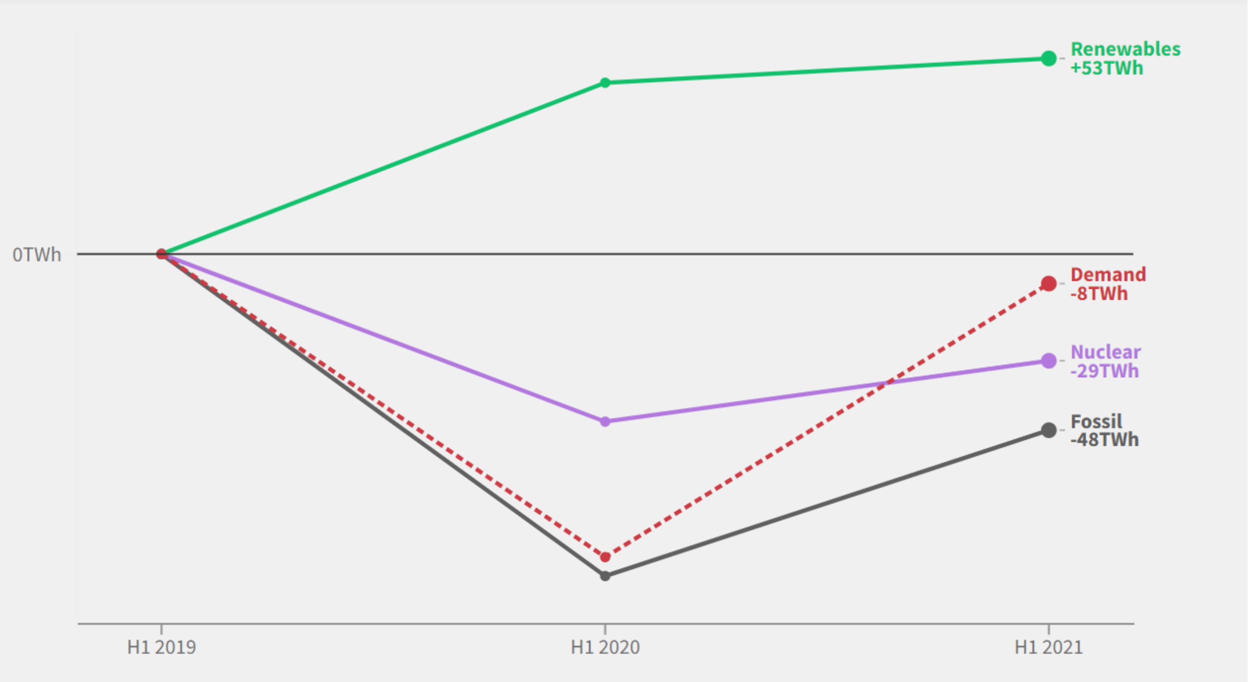


Figure 1 - Change in EU-27 electricity generation by source compared to H1 2019 [3]

This certainly shows that the projects implemented by the European Commission with the help of the EU citizens and residents can make a direct impact on having a sustainable and cleaner environment. But the main question here is “is it enough?”

1.1.2. Global energy mix

Even though the EU and many other governments worldwide are pushing in the direction of the green and sustainable energy transition, the production of energy globally is still mainly produced from fossil fuels (including coal) which causes directly about 75% of the global greenhouse gas emissions, As shown in Figure 1, the global primary energy consumption has shown an increase of production of RESs but there is still a long run to achieve the goal of having a sustainable environment or worldwide climate neutrality. Reaching this goal is not only for the matter of climate change that happened in the last couple of centuries or for the future of our environment. The burning of fossil fuels and biomass also comes at a high cost to human health, at least five million deaths are attributed to air pollution each year. [4]

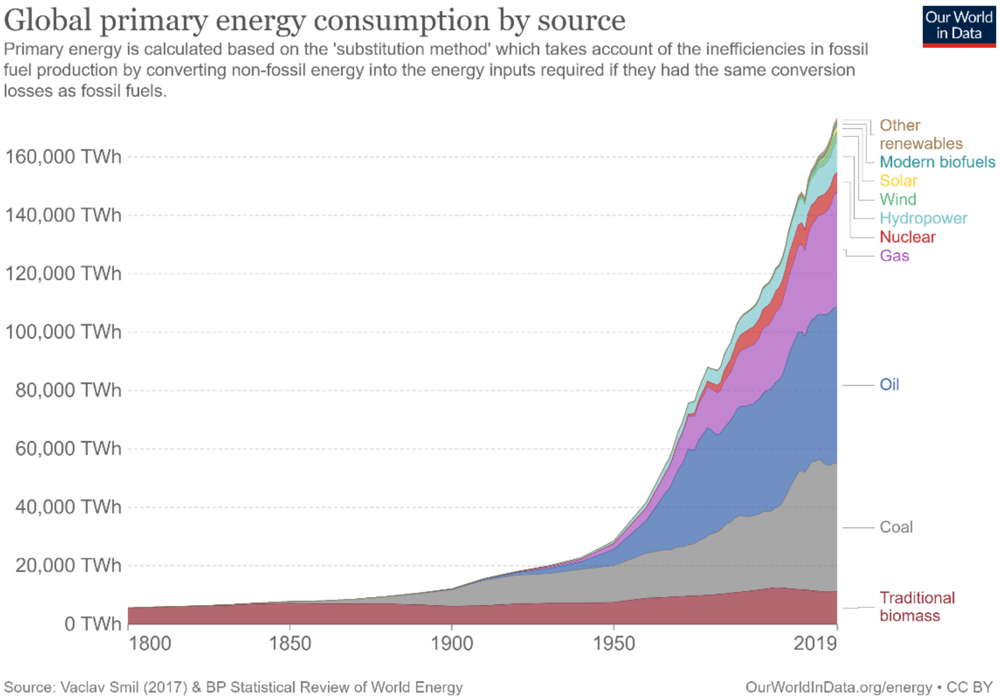


Figure 2: Global primary energy consumption by source [4]

The world therefore needs to shift away from fossil fuels to an energy mix dominated by low-carbon sources of energy, specifically shifting to mostly clean low-impacted renewable technologies.

1.1.3. Energy communities main aspects and organization

1.3.1 Organization

The main purpose of the energy communities is to produce energy as clean as possible within a small community (which can be a small city, a town, or even a compound of buildings) and transfer this energy within the community, while taking into consideration that the organizer of this process are the citizens within the community. Shifting the community form an energy consumer, to an energy provider. An analysis of the European Commission's Energy Initiative for Science and Knowledge Services or the Joint Research Center (JRC) shows that some or all of the following activities can be carried out:

Generation: An Energy community project collectively uses or owns power generation systems (mainly solar, hydro and wind). Members supply the generated energy to the grid, and sell it to their suppliers rather than consuming it themselves.

Supply: Sale (and resale) of electricity and gas to customers (electricity, wood pellets, biogas, etc.). Large municipalities can have a large number of end customers in their neighborhood, perform aggregate activities that combine customer load and flexibility, or generate electricity for sale, purchase, or auction in the electricity market.

Consumption and sharing: The energy generated by the energy community is used and shared within the community. This includes both consumption (individual and collective self-consumption) and the local distribution of energy between members generated by power plants within the community.

Distribution: ownership, and/or management of community-managed distribution networks, such as the local electricity grid or small district heating and gas (bio) networks; often cooperatives can both produce and distribute energy, but grid infrastructure is central to their business.

Energy services: Improving the current energy systems (Demand, transition and power generation sides) by improving the energy efficiency or energy savings (e.g., building refurbishment, energy auditing, consumption monitoring, heating, and air quality assessment); flexibility, energy storage, smart grid integration. Also, improving the energy monitoring, and energy management for network operation.

Electro-mobility: Operate and manage carsharing, carpooling and/or toll stations, and providing electronic cards to members and cooperatives.

Other activities: Advisory services for developing community ownership initiatives, establishing local co-operatives, conducting information and awareness campaigns, and promoting poverty policy. [5]

1.3.2. Main Aspects

After knowing the organization, and the framework of a small or large energy community, the following aspects must be met to achieve the energy efficiency of a community.

Local energy source: When using local sources, all externalities related to architectural and landscape changes, or competition with other local activities such as tourism and agriculture should be considered.

Local safety of energy supply: The EU's dependence on foreign energy in 2018 was 58%. Therefore, it is essential to consider the impact on the internalization of primary energy procurement.

Shorter transport distances, and reduced energy transmission losses: As the distance, and therefore the energy loss of transmission, decreases, the management of distribution networks becomes more complex.

Community development and unity: When decisions (and even investments) are made together, the acceptance of new infrastructure is higher. This raises awareness among the community of the positive effects of business initiatives on social relationships and economic activity.

1.1.4. Existing energy communities in Europe

Although the trend of the independency of energy communities is new, the idea itself is not very new for the continent. The following projects already exists and some of them are even completely working efficiently:

1.4.1. Energy communities in Europe (excluding Italy)

Samsø, Denmark: Through strategies such as consumption, monitoring and promotion. Also, by installing heat pumps, and penetrating RES (solar and wind) in the city. This project started in 1997, the island community aims for a fossil-free energy system by 2030. [6]

Ulfborg, Denmark: The project started in 1978 as part of the Tvindkraft project. An example of how the will for sustainability can be put into practice with a complete dependance on the locals. Local teachers are sponsoring the construction of windmills providing clean energy to schools. The result was the largest wind turbine (2 MW) in the world at that time, supplying energy to the entire neighborhood as a response to the oil crisis. [7]

Island of Eigg, Scotland: The island is connected to the UK’s national grid, but still covers almost 100% of the island's energy needs, including wind and hydropower. The project is supported by the charity Community Energy Scotland, with the goal of the total dependency of local green sustainable energy sources for the 50 inhabitants of the island, which is a proof that municipal energy systems can be set up by a group of local business owners looking for diversifying their income while benefiting their community. [7]

Edinburgh Community Solar Co-operative (ECSC), Scotland: With 683 members, this community in the middle of the capital city of Scotland is successfully generating electricity from solar power at 30 different host buildings across Edinburgh, which generates roughly per year 1.5 GWh of clean electric energy. The profits of the projects are distributed to all the members of this community. [8]

1.4.2. Energy communities in Italy

Municipality of Benetutti, Sassari: With more than 1100 users participating in this community, Benetutti plans to an energy service provider instead of an energy buyer. Now it is in the third stage, the intelligent networks complex project for energy management by the renewable energy platform of Sardegna ricerche, and the university of Cagliari is almost making this true. Instead of importing energy from the grid, it will be able to inject about 585 MWh per year into it. Also, with the help of the production of biogas obtained from the recovery of non-forest biomass, it is possible to stabilize production as well as the power to co-generators for heating and cooling public buildings. The energy system the local electricity distribution network is completely owned by the municipality and the citizens. Thus, there are no regulatory constraints that block the creation of smart grids. For this project the region has allocated 1.75 M€. [9]

Piedmont region: the most successful first experiments of ECs in Italy, with 150,000 inhabitants, the EC was created after the signing of a memorandum of understanding between a group of local municipalities which had the purpose of creating the first Oil Free Zone in Italy. The current goal is to achieve energy self-sufficiency with renewable sources, local production of energy, self-consumption and self-exchange of clean energy. The Piedmont Region has made € 50,000 available to the municipalities in favor of the development of energy communities. Each applicant will be allocated a sum between five and ten thousand euros until the endowment is exhausted. [10] [11]

As shown, there are lots of potential and support for the ECs in Italy, but there not a lot of implementations yet. In this thesis, a techno-economic analysis is made to show the feasibility of applying these ideas to a small town in Italy with the consideration of energy production potential from all the renewable energy technologies available, capital, and installation costs of these technologies (if not already existing), without taking any consideration of the economic benefits offered by the government to see the feasibility of the project with the current energy pricings.

2. Project scope

The aim of this project is to analyze the technical and economic feasibility of shifting a community from being dependent on energy (especially electrical and heating energy) from external (conventional) sources, to being an independent and sustainable energy community.

A full technical analysis is made in order to see the available energy potential from renewable energy sources (RES) in the community, and also the complete energy (electrical and thermal) demand of the users in order to find the energy balance to see whether there will be a shortage of energy that should be still imported from outside the community, or the community would be completely energy-dependent. Also, an economic analysis is made in order to see if it is financially feasible to make such a shift. Furthermore, the amount of CO2 emission that will be avoided by implementing these technologies in the community is calculated in order to see the positive environmental impact that could be achieved.

The analysis is made by methods that could be applied in any other community, but for the sake of calculations, a small town in Italy is used as an example.

2.1. Energy community selected

Piadena, a small municipality in the Province of Cremona, was selected for the analysis, located in the region of Lombardy in the Northwest of Italy with a total area of 19 Km2, total population of 3455 (Male 1,675; Female 1,780), population density (per Km2) of 174.2, totaling of 1485 families, and living in 1561 units. Which is a perfect choice for the analysis for its size and capacity. [12]

Figure 3: Location of Piadena

2.2. Technologies and methods

In this chapter, a general introduction of the technologies and methods used to achieve the energy independence and sustainability of an energy community are stated. Green and renewable energies were the only technologies chosen as these technologies are the vital inputs for the sustainability, and the growth of the community. Also, managing the demand side by analyzing the impact of increasing the energy efficiency of buildings.

2.2.1. Solar Technologies

The fact that each hour 430 quintillion Joules of energy hits the earth from the sun [13] makes scientists interested in developing new technologies to exploit the sun’s solar radiation energy efficiently, whether directly by using this power to heat water (as in solar water heaters) or superheating water, convert it to steam, and then exploiting it to electricity (as in concentrating solar power), or indirectly by transforming the solar radiation into electricity by photovoltaic technologies.

2.2.1.1. Photovoltaics (PV)

The most famous method to exploit energy from solar radiation is by installing a PV system. The concept is simple, having many photovoltaic cells which are made up of semiconductor materials that absorb photons from the sun, and produce an electric current. When photons impact a semiconductor material such as silicon, the electrons in its atoms are released, leaving a free space. The free electrons roam around searching for a new "hole" to fill. The electrons must all move in the same direction in order to generate an electric current. Two forms of silicon are used to do this. The sun-exposed silicon layer is doped with phosphorus atoms, which have one more electron than silicon, while the other side is doped with boron atoms, which have one less electron. The layer with excess electrons is designated as the negative terminal (n), while the side with a lack of electrons is designated as the positive terminal (p) and the point where the two layers meet, an electric field is formed. The electrons go to the n-side by an electric field when they are excited by photons, while the holes drift to the p-side. The electrons and holes are directed to the electrical contacts on both sides before passing as electrical energy to the external circuit. This generates a direct current. Nowadays, PV systems are installed in almost all the countries of the world but it still faces some challenges, as the PV panels (solar cells) have low efficiencies as the max PV panel efficiency is 22.6% (model Maxeon 3 made by SunPower [14]), but it had improved a lot in comparison to when it was first invented, for example in the 1950s, solar cells had an average efficiency of 8-9%. Another problem that makes PV systems feasibly not attractive is the price, and the life time of the battery systems. For off-grid PV systems, in regions with unstable energy supply, the battery system is crucial. Depending on the type of battery, installation location, backup power requirements, and type of inverter utilized. Average household batteries can cost anywhere from $4000 for a small 4kWh battery to $15,000 or more for a large 13kWh battery [15]. That would make the payback period really high as in most of the PV projects, the batteries pack changes twice or sometimes even three times in the lifetime of the PV panels array as the average lifetime of a PV panel is from 25-30 years [16], while from 5-15 years for the batteries [17]. In this project, PV systems will be installed without storage systems to make the project cheaper, considering that the power will also be provided by other renewable sources and, ultimately, can also be supplied by the existing national grid.

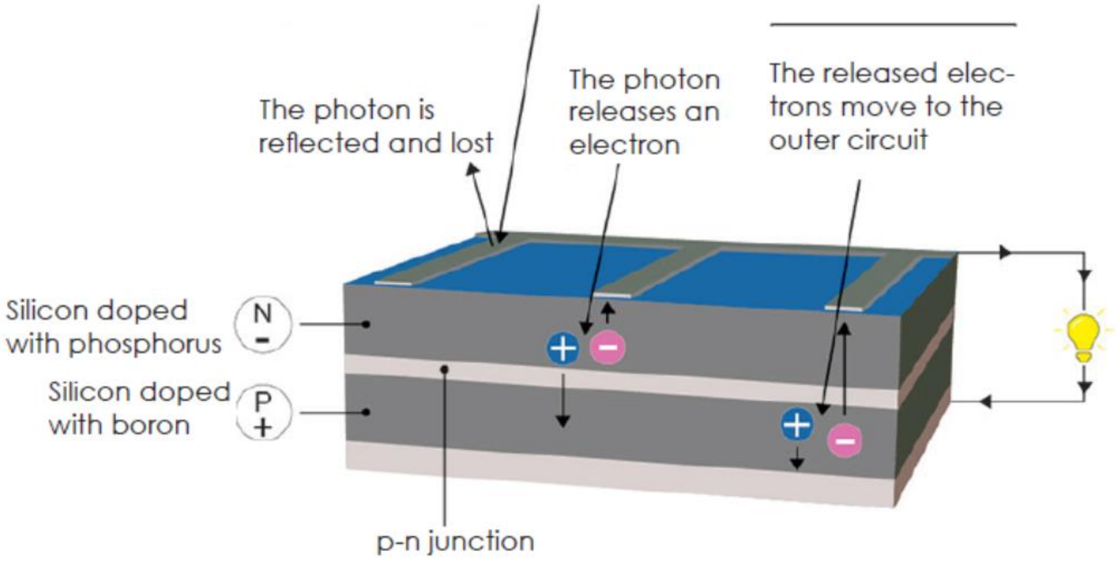


Figure 4: Basic structure of p–n junction solar cell.

2.2.1.2. Solar Water Collectors

One of the oldest methods to exploit solar energy is by installing a solar collector to heat up a water passing through its pipes, and directly using it. Solar collectors have been documented in the United States since around the beginning of the 1900s, with a black-painted tank erected on a rooftop. Clarence Kemp of Baltimore enclosed a tank in a wooden box in 1896, resulting in the first batch of a water heater as we know it today. In Maadi, Egypt, Frank Shuman constructed the world's first solar thermal power plant, which used parabolic troughs to power a 45-to-52-kilowatt engine that pumped 23,000 liters of water per minute from the Nile River to nearby cotton fields. In the 1920s, flat-plate collectors for solar water heating were popular in Florida and Southern California. After 1960, and especially after the 1973 oil crisis, there was a surge in interest in North America. [18]

In this project thermal solar collectors will be used in heating water domestically with the possibility to back up this technology with other green technologies to satisfy the water heating demand of the community.

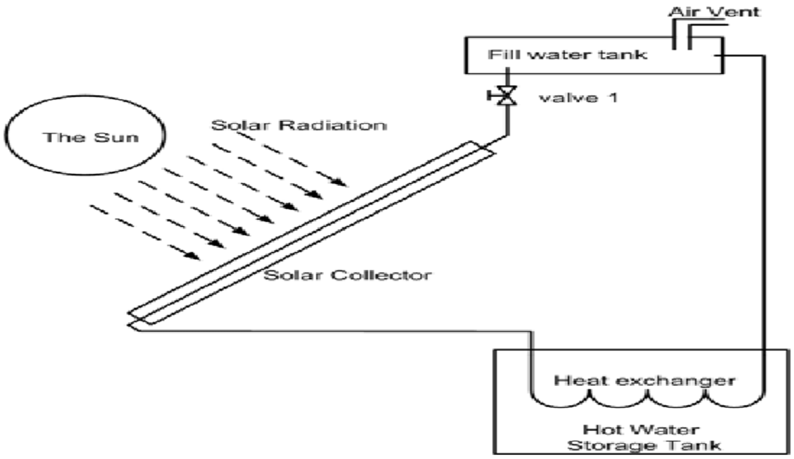


Figure 5: Schematic of the self-circulated solar water heater system

2.2.2. Wind Turbines

Of course, wind energy is one of the most efficient systems for exploiting clean energy, with efficiencies that could reach up to 50% in some offshore projects [19], Wind turbines operate on a very simple principle, where the wind turns the blades of a turbine, causing the rotation of an axis, which is connected to a DC generator, which is then converted to AC via an inverter. The more powerful the wind, the more electricity is generated by its motion. It is also one of the oldest technologies of usage of clean energy as the idea was firstly used by the Egyptians to propel boats along the Nile River as early as 5,000 BC. Windmills with woven-reed blades were grinding grain in Persia and the Middle East by 200 BC, and simple wind-powered water pumps were used in China [20].

In this project wind energy is not used as the wind speeds in Piadena range from 2.8 to 2 m/s which is a very low speed to exploit even with today's technologies [21]

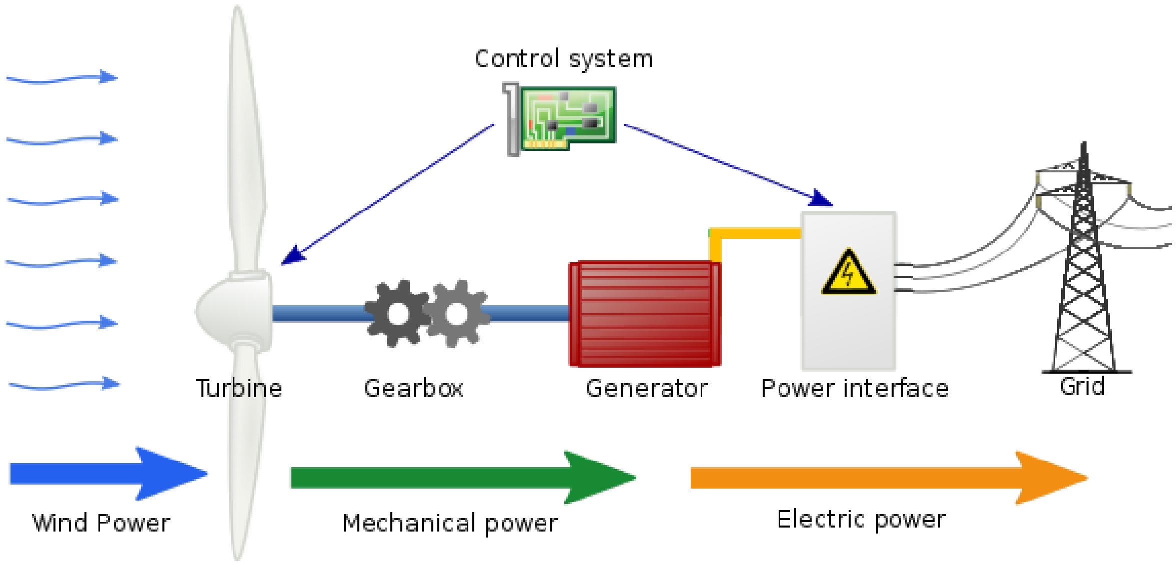


Figure 6: Simple Wind Turbines Schematic

2.2.3. Organic Materials

2.2.3.1. Biomass

It is considered the oldest method of exploiting renewable energy, as it was first used when mankind discovered fire. Biomass is one of the most basic renewable energy sources of combustible carbon on the planet, and we use it to generate heat, and cook food.

Modern biomass energy production is an important source of renewable energy. Some would even debate that it is now a better source of energy than wind energy and solar energy in the search for renewables. Biomass feedstock can be processed and converted to energy in a variety of ways. While burning woody biomass (forest biomass materials, wood pellets, etc.) is still the most common way to use this renewable energy resource, there have been significant advances in the field of biomass energy. Energy crops that are mass-produced, and converted into biofuel and biogas, as well as landfills that use anaerobic digestion to convert biomass into biogas for everyday use, are examples of innovation.

In this project, biomass technologies are used as Piadena is a urban agricultural center and it has lots of potential for the usage of its agricultural residuals.

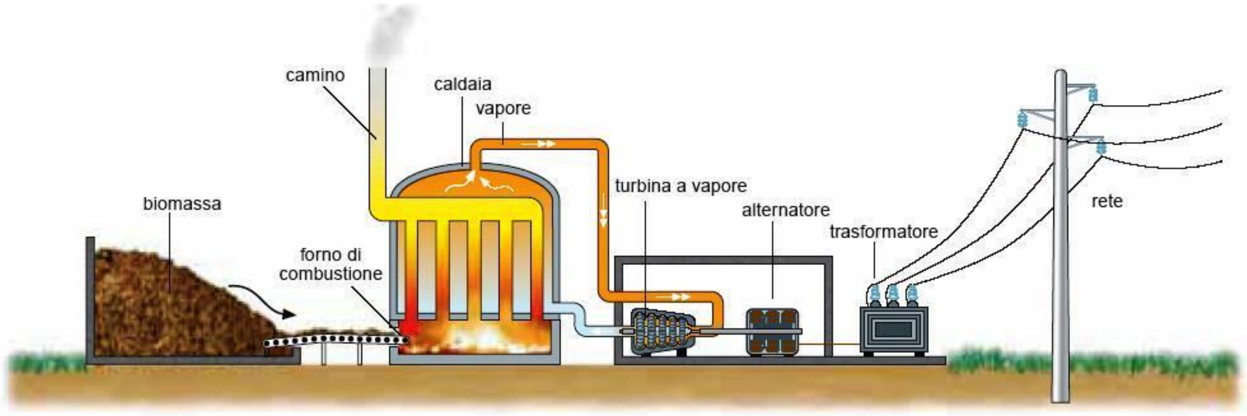


Figure 7: Biomass Process Schematic (Electric generation)

2.2.3.2. Biogas

As biomass, biogas is also considered one of the oldest methods for exploiting renewable energy as the first human use of biogas is thought to have occurred in the Middle East around 3,000 BC, when the Assyrians used it to heat their baths. [22] Biogas or methane digestion entails the fermentation of anaerobic (without air) residues, and a variety of organic materials (cattle dung, pig, human feces, etc.). This fermentation results in the formation of biogas, a methane-rich gas. This energy source is directly used to power appliances such as refrigerators, gas lamps, and burners, or it is used to generate electricity via a generator.

In this project, biogas technologies are also used, as Piadena territory has an intense farming activity which means that there is potential for using the animal residuals produced on the farms.

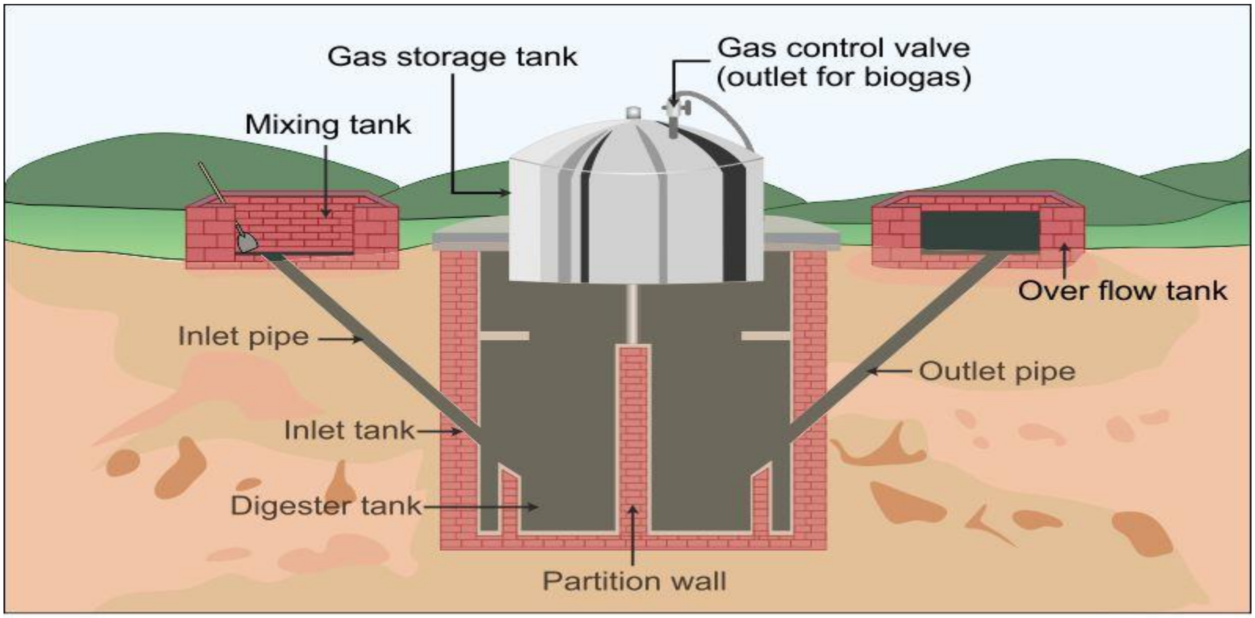


Figure 8: Biogas Process Schematic (Gas generation)

2.2.3.3. Technology used to exploit the biomatter energy

In this project an Anaerobic digestor (AD) or as it is sometimes called biogas treatment is used. Anaerobic digestion is a series of microbial processes that break down biodegradable materials in the absence of oxygen. This process is used for industrial or domestic purposes for waste management or for fuel production. [23] This process is very common in many natural environments, such as swamps or stomachs of ruminants and cows. But what is really important about anaerobic digestion is that the micro-organisms produce biogas, which is a mixture of methane and carbon dioxide. Methane is really what is important for this project, as it is flammable, and can be used as an energy source.

Anaerobic digestion is becoming popular for waste management. In Europe, many units are being built and operated producing. Even in developing countries, it's becoming very interesting, especially as it is considered as a renewable energy resource.

2.2.3.4. Pros and cons of AD

The key benefits of anaerobic digestion are that as mentioned before it is a renewable energy source, and that means reducing the world dependency on fossil fuels, and thus, reduction in the greenhouse gases. No need for much space in some of the small-scale AD applications, as it can be built underground. Of course, it also reduces solid waste volumes, and thus avoids disposal costs. Finally, it is a great trade recovering value from waste to gas and nutrients.

There are also a few drawbacks of AD, especially when compared to composting. The process of AD is more sensitive as it is slower, and less energy intensive. In fact, the energy is contained in the methane, but that means that there is also no heat generation, and that has implications for hygienization. AD is also technically more complex and therefore needs higher levels of skills and investment.

2.2.3.5. Biochemical process of an AD

Anaerobic digestion happens in four steps. However, these processes happened partly simultaneously. The first step is hydrolysis. It is the slowest of the four degradation steps. Bacteria transform complex organic materials into liquefied monomers and polymers. The second step is acidogenesis. That's where sugars and amino acids are converted. The third step is acetogenesis. That is where the substances are then transformed into hydrogen, carbon dioxide and acetic acid. Finally, the last fourth step is methanogenesis, where the methanogenic bacteria convert hydrogen and acid acetic into methane gas and carbon dioxide. Typically, the gas mixture will also contain hydrogen sulfide, that's the stuff that smells of rotten eggs, but also nitrogen, oxygen and hydrogen. In volume percent, methane amounts to roughly about 60% while CO2 is around 40%. Hydrogen sulfide is usually lower than 2%.

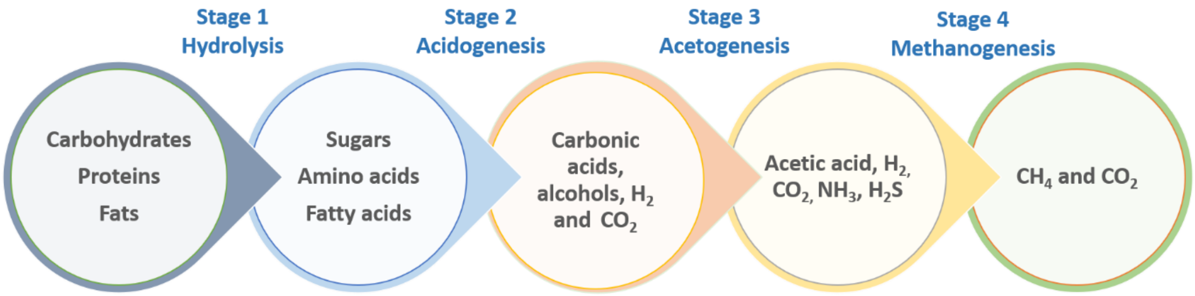
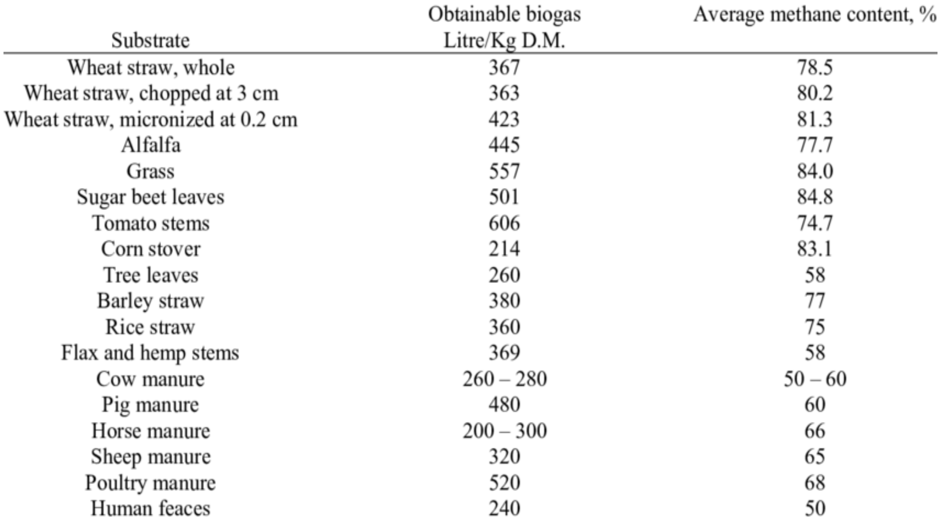


Figure 9: Chemical prosses scheme of an Anaerobic Digestion

2.2.3.6. Parameters and operational conditions of AD

Starting from the feedstock, it is possible to distinguish between solids and water content. Dry matters also known by us as total solids (TS), are not all biodegradables. In this context, biodegradable organic fraction is relevant which are called volatile solids (VS). The levels of TS and VS are different depending on the type of waste dealt with. Depending on the type of waste, different amounts of methane can be expected. In the table below some examples of different kinds of wastes with the gas yield, and methane percentages are shown.



Substrate	Obtainable biogas Litre/Kg D.M.	Average methane content, %
Wheat straw, whole	367	78.5
Wheat straw, chopped at 3 cm	363	80.2
Wheat straw, micronized at 0.2 cm	423	81.3
Alfalfa	445	77.7
Grass	557	84.0
Sugar beet leaves	501	84.8
Tomato stems	606	74.7
Corn stover	214	83.1
Tree leaves	260	58
Barley straw	380	77
Rice straw	360	75
Flax and hemp stems	369	58
Cow manure	260 – 280	50 – 60
Pig manure	480	60
Horse manure	200 – 300	66
Sheep manure	320	65
Poultry manure	520	68
Human feaces	240	50

Table 1: Biogas yields from various substrates

An important parameter in an AD is the organic loading rate (OLR). This parameter quantifies the amount of organic waste fed per unit volume of the digester per day, with a unit of kilograms of volatile solids per cubic meter per day. A good daily load rate for an ideal reactor is two or less with a stirred reactor this value can be higher, with values that could reach up to 8. The potential of the hydrogen (pH) range for anaerobic digestion is neutral with values between 6.5 to 7.5. However, in the acidic phase, the pH must be lower, while in the methanogenesis phase it gets higher. However, if the feed rate is too high, the bacteria producing will cause acidification of the reactor. Pathogenic bacteria are quite sensitive to these conditions and will therefore be inhibited by. If this problem occurs, the load speed must be reduced or adding some materials to increase the pH level such as lime or sodium hydroxide.

Temperature is another factor affecting the AD process as operating at below 15 degrees Celsius really slow down the activity of the organisms. Underground construction or installation can buffer this variation of temperature, but the anaerobic process is most comfortable in two temperature zones: the mesophilic temperature zone between 30 and 40, and the thermophilic temperature zone between 45 and 60. Operation in the mesophilic range is more stable, and can tolerate greater changes in parameters, and consumes less energy. However mesophilic organisms are slower in degrading, and so needs more time. Thermophilic organisms however are faster, but the system is more sensitive to changes.

A further parameter that influences the process is hydraulic retention time (HRT), which is the amount of time that the material stays in the reactor, in other words, it is the volume of the reactor per the volume of input per day. Ideally, this time is between 10 and 40 days, the lower value is rather for higher temperature in the thermophilic range as the process is quicker. Having an optimum operation depends on the parameters of the inputs or the size of the reactors, for example, if for given inputs the reactor volume is small, then the retention time will be low, which will lead to a lower biogas yield as there is less time for the process. If the reactor volume is large, then retention time increases and this higher yield, but at the cost of having a large reactor means more space needed, and higher investment costs.

Another parameter is the carbon to nitrogen (C/N) ratio. A value between 16 and 25 is optimum, and a higher value means a limited supply of nitrogen, which is food for the bacteria, and therefore less gas production. A lower C/N ratio can cause ammonia accumulation which then inhibits the anaerobic process.

Finally, the last parameter is the particle size of the input material, the smaller the particle size the better. Particle sizes below five centimeters are ideal, as simply increasing the surface area of the material allows the microorganisms to degrade the material faster. So, usually the input material is chopped up through a shredder, to make the particles as small as possible. [24]

2.2.4. Energy Management

Increasing the electric (and thermal) dependency on green energies exploitations is an important sector for reaching the sustainably of an energy community, but what is even more important is to decrease the electrical (and thermal) demand (End-use energy) and thus the supply, and at the same time not affecting the comfortableness of the users. To do so, reducing the energy leakages, and improvement of the appliance’s energy performance is a must. In this project, managing the performance of demand in four main aspects are applied on the buildings of the community in order to increase their energy performance. The four aspects are as follows:

- An improvement of the thermal insulation of the opaque envelope of the building
- A replacement of the heating system with a more performing one
- Replacing the electrical devices in the building with more efficient ones.

Applying those aspects may allow energy savings around 30% with consistent economic, and environmental benefits. [25]

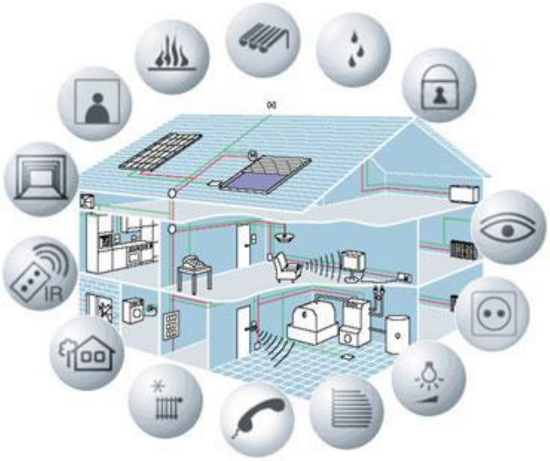


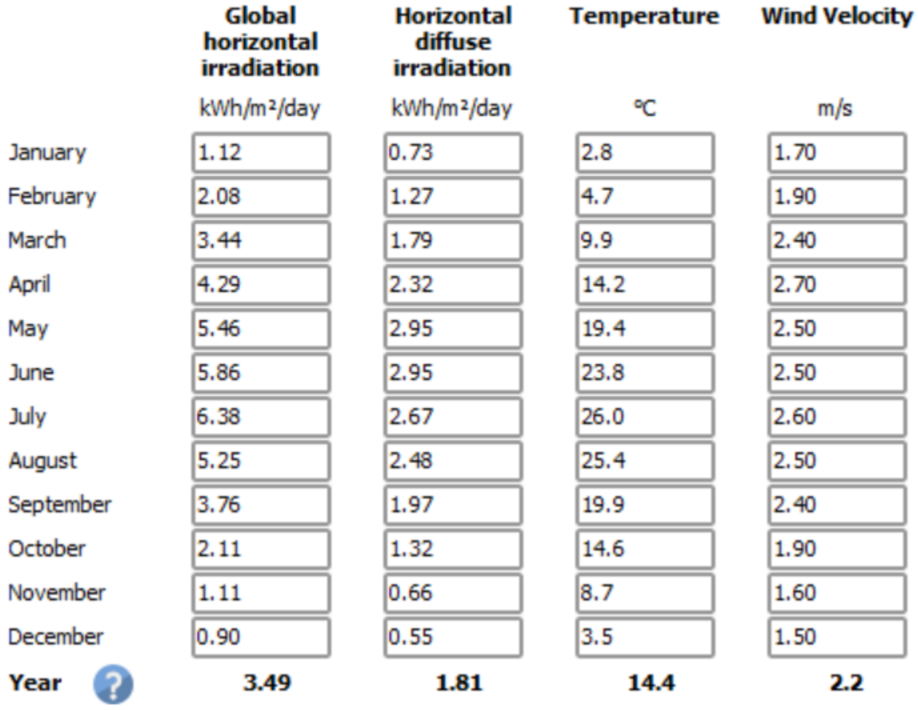
Figure 10: Building Management System layout

3. Photovoltaics systems

As mentioned before Piadena, is located in the Province of Cremona, Italy, with a maximum and minimum ambient temperature based on Weather Spark website [21] is considered 30℃ and -1℃ with exact location of 45.1300° N, 10.3670° E. In this section a calculation of the available electrical energy that can be produced by PV panels installed on the available spaces on the rooftops of the residential buildings in the town is made in order to make an energy balance of all the electrical energy that could be potentially produced within the town.

3.1. Solar radiation information

The solar radiation data for Piadina is extracted from PVGIS database. The two figures below depict the solar radiation data and the horizon line for the selected location. As shown in figure 9 average value of incident solar radiation is equal to $5.3\ \frac{KWh}{m^2.day}$



	Global horizontal irradiation kWh/m²/day	Horizontal diffuse irradiation kWh/m²/day	Temperature ℃	Wind Velocity m/s
January	1.12	0.73	2.8	1.70
February	2.08	1.27	4.7	1.90
March	3.44	1.79	9.9	2.40
April	4.29	2.32	14.2	2.70
May	5.46	2.95	19.4	2.50
June	5.86	2.95	23.8	2.50
July	6.38	2.67	26.0	2.60
August	5.25	2.48	25.4	2.50
September	3.76	1.97	19.9	2.40
October	2.11	1.32	14.6	1.90
November	1.11	0.66	8.7	1.60
December	0.90	0.55	3.5	1.50
Year	**3.49**	**1.81**	**14.4**	**2.2**

Figure 11: Solar radiation data for Piadena

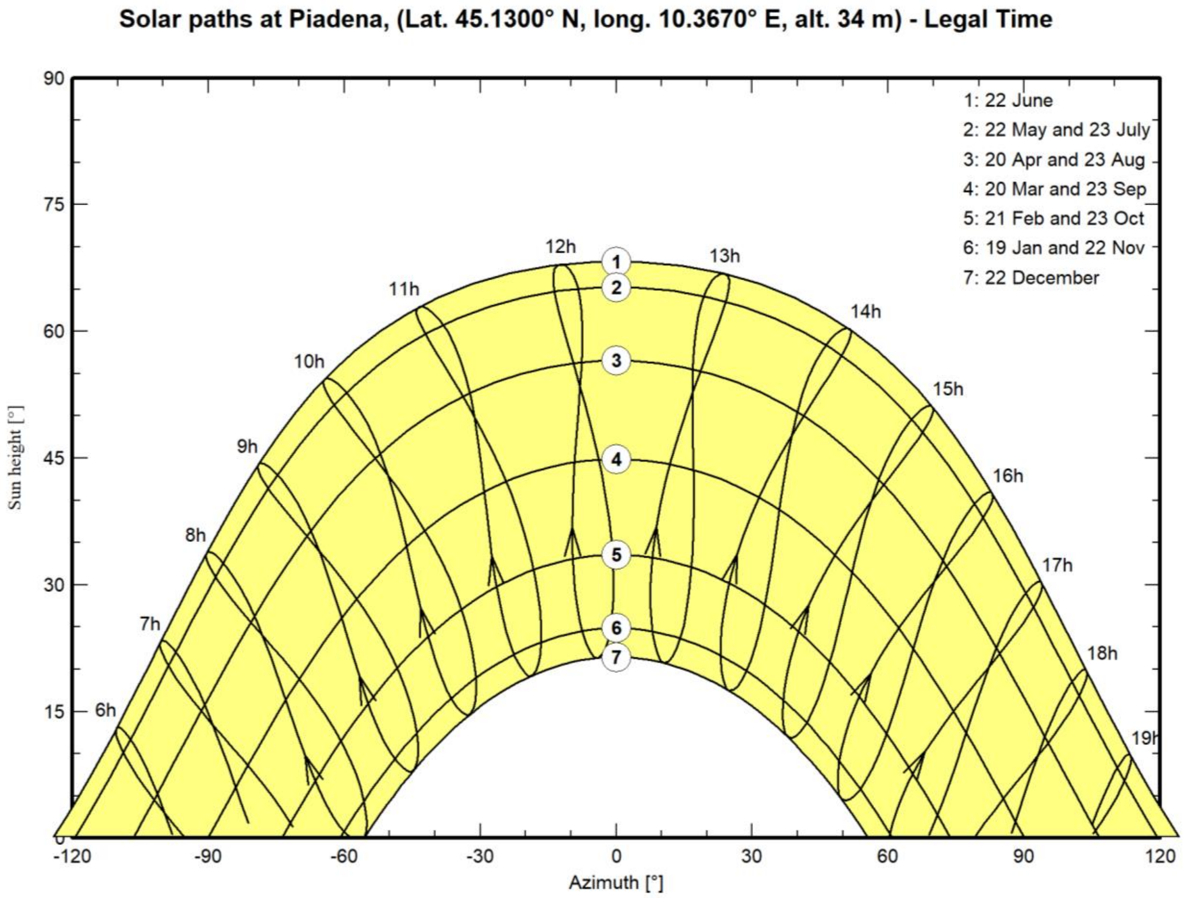


Figure 12: Horizon Line

3.2. Installing area availability

Using the information available from the statistical data sheet of Piadena, it is stated that the municipality surface is 19 Km^2, the number of residential buildings is 1688 units, total rooftops surface area of 188000 m^2 with a usable surface area (for installing PV panels) of 47000 m^2 (25% of the total area of the rooftops). [26]

With a simple calculation, it is estimated (as it was assumed that all the buildings have the same rooftop area for simplification) that each house has an available area for PV panels installation of 27.85 m^2.

3.3. Solar Module Selection

The bifacial double glass mono crystalline module (AE550MD-144BD) [27] manufactured by AE SOLAR alternative energy is chosen for the installations on rooftops of the the residential buildings. The module has 30 years manufacturer guarantee on 85% of the nominal performance, with high module conversion efficiency of 21.31%, lower operating temperature, excellent weak light performance, withstanding harsh environments (like farms) and high-power output of 550 Wp. That makes this module perfect for this project.

In table 2 and figure 13, the module specifications are stated.

ELECTRICAL DATA (STC)		**STP550S-C72/PMH+**
RATED POWER	PMPP [W]	550
RATED VOLTAGE	VMPP [V]	42.57
RATED CURRENT	IMPP [A]	12.92
OPEN-CIRCUIT VOLTAGE	VOC [V]	51.44
SHORT-CIRCUIT CURRENT	ISC [A]	13.67
EFFICIENCY	n [%]	21.31
BASIC MODULE DATA		
LENGTH X WIDTH X HEIGHT	[mm]	2278 x 1133 x 35
WEIGHT (WITH FRAME)	[kg]	33
CELL SIZE	[mm]	182 x 91
CELL MATERIAL		Gallium doped Monocrystalline 182 mm

Table 2: STP550S-C72/Pmh+ module specifications

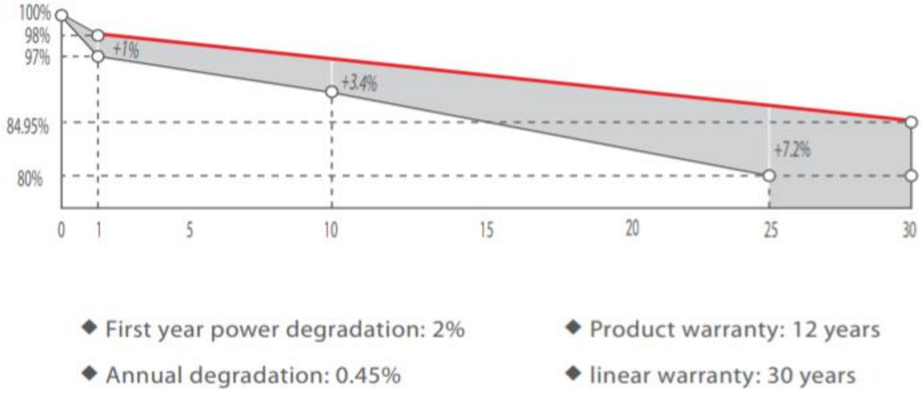


Figure 13:Warranted module performance

3.4. Total electrical energy production

Based on the selected module the area of each module is 2.585 m^2 so considering the geometrical constraints of each building (availability of a useful installing area of 27.85 m^2) it is possible to install ten modules on each rooftop.

To calculate the annual electrical energy produced per each kWp of the PV plant, assuming the efficiency of the PV plant is equal to 0.8:

$$H_{m-year} = \frac{1.71 * 30 + 1.45 * 31 + 1.85 * 31}{30 + 31 + 31} = 2.68\ \frac{hours}{day} \qquad (1)$$

$$E_{spec} = H_{m-year} * \eta_{pv_{plant}} * dd = 2.68 \frac{kWh}{m^2.\,day} * 0.80 * 365\ day = 782.56\ \frac{kWh}{kWp} \qquad (2)$$

Where H_{m-year} is the average incident solar radiation of the worst three months of the year 2.68 $\frac{kWh}{m^2.day}$, and the dd is the days in the year.

Considering ten modules given by the geometry of the rooftops, and the chosen PV module the PV plant rated power, and the yearly electricity production is:

$$P_n = 10 * 0.55\ kWp = 5.5\ kWp \qquad (2)$$

$$E_{year} = E_{spec}.P_n = 782.56\ \frac{kWh}{kWp} * 5.5\ kWp = 4304.08\ kWh = 4.31\ MWh/year \qquad (3)$$

$$E_{year-All-Build} = E_{year}.Num_{of_{buildings}} = 4.3041\ MWh * 1688 = 7.27\ GWh/year \qquad (4)$$

3.5. Inverter selection

In this section some calculations are made in order to see the best inverter applicable for the PV systems installed in the city, according to the chosen configuration of the PV modules (10 in series) to match the minimum MPPT voltage, we should calculate the maximum voltage condition in open circuit and maximum power point, as well as the maximum current condition in short circuit configuration.

The worst current conditions happen when the temperature of the modules is at its highest value, with the help of the online information regarding the highest and the lowest historical temperatures in Piadena (30 ℃ and -1 ℃).

To do so the following equations are used:

$$\text{Tcell,max} = \text{Tamb,max} + \frac{\text{Tcell,NOCT-Tamb,NCOT}}{G_{NCOT}} = 30 + \frac{42\text{-}20}{800} * 1000 = 57.5\ ℃$$

$$\text{Voc@Tmin} = -1°\text{C} = \text{Voc}*(1+\frac{\beta}{100}*(\text{Tmin-Tstc})) = 53.06\text{V}$$

$$\text{Vseries,oc@Tmin} = -1°\text{C} = \text{Voc@Tmin}=-1°\text{C} * 10 = 530.6\text{V}$$

$$\text{Vmpp@Tmin} = -1°\text{C} = \text{Vmpp}*(1+\frac{\beta}{100}*(\text{Tmin-Tstc})) = 44.44\text{V}$$

$$\text{Vseries,mpp@Tmin}=-1°\text{C} = \text{Vmpp@Tmin}\ (\ -1°\text{C}\ ) = 44.44 * 10 = 444.4\text{V}$$

$$\text{Vmpp@Tmax}=57.5\ °\text{C} = \text{Vmpp}*(1+\frac{\beta}{100}*(\text{Tmax-Tstc})) = 37.08\text{V}$$

$$\text{Vseries,mpp@Tmax}=68.75°\text{C} = \text{Vmpp@Tcell,max}=57.5\ °\text{C} * 10 = 330.8\text{V}$$

$$\text{Isc@Tcell,max}=57.5\ °\text{C} = \text{Isc.stc}*(1+\frac{a}{100}*(\text{Tcell,max -Tstc})) = 14.85\text{A}$$

For the choice of the inverter, Sungrow type SG3.0RS-S [28] is selected. The Maximum PV Array Power is 4500Wp, and the Maximum PV Array Open Circuit Voltage is 600 V_{DC}. The lifetime expectancy of the inverter is ten years, so it is expected to change the systems inverter three times during the lifetime of the PV panels lifetime.

To define the number of series, and parallel modules, the following procedure is considered:

$$\text{Min number of modules in series } \geq \frac{Vmin,mpp,inverter}{Vmpp\ (57.5\ °C)} \geq \frac{40}{37.08} \geq 1.08 \cong 2\ modules$$

$$\text{Max Number of modules in series} \leq \min\left\{\frac{Vmax,mpp,inverter}{Vmpp(-1℃)}\right\} \leq \min\left\{\frac{560}{44.44}\right\} \leq 12.6 \cong 12\ modules$$

$$\text{Max number parallel rows} \leq \frac{Isc,inverter}{Isc\ (57.5℃)} \leq \frac{20}{14.85} \leq 1.35 \cong 1\ module$$

3.5.1. Economic analysis

In this section an economic analysis of the total installation of the PV systems in the residential houses rooftops is made. The investigation is carried on the basis of the LCOE comparison. The PV panels cost presented in the report is from ENF [29] solar database. Other costs are provided in the CAPEX breakdown table with the reference.

ITEM	COST PER UNIT	COST
PV PANELS [30]	0.252 [€/Wp]	2,339,291 €
INVERTER [31] *	450 [€/Piece]	590,730 €
WIRING AND BALANCE OF SYSTEM	5%	146,501.04 €
INSTALLATION	4%	117,200.83 €
ENGINEERING AND INDIRECT	8%	234,401.66 €
TOTAL		**3,428,124 €**

Table 3: CAPEX breakdown

*The inverter will be replaced three times during the lifetime of the project, and it will be considered in the calculations of the NPV

The economic parameters related to the Italian electricity market are obtained from Statista website. These include inflation rate, discount rate, and electricity price of the national grid. Table 3 summarize the economical parameters of Italy.

PARAMETERS	VALUE	UNIT
INFLATION RATE	1.79	%
DISCOUNT RATE	8	%
LIFETIME OF THE PROJECT	30	years
YEARLY ELECTRICITY PRODUCTION	14.37	GWh/y
ELECTRICITY MARKET PRICE IN ITALY [32]	0.2153	€/kWh

Table 4: Economic parameters used for the financial analysis

The operation and maintenance is considered to be 2% of the CAPEX **(57267.05 €/y)**, with linear degradation of 0.5017% (2% first year, and 0.45% for the rest of the years)

Using the information stated above the economic values were calculated using an excel spreadsheet over the period of 30 years of operation. The gross present Value is **€17,327,290.84**, the net present value is **€13,701,693.91,** and the levelized cost of electricity (LCOE) is **€0.03589**. IRR is obtained by the same concept as the net present value NPV by setting the NPV to zero. In this project the IRR is equal to **30.41%**. The positive IRR show that the project is economically profitable.

The payback period (PBP) of this project is seven years which is relatively good as in this project no incentives were included in the calculations, and the worst average solar irradiance was used to calculate the total annual energy production of the solar system with a low overall efficiency of the system. So, it is more probable that the project is even more profitable with the real values.

3.5.2. Total CO_2 emissions avoided

By installing these solar panels, the total average CO_2 emissions can be simply calculated. As mentioned in the online statistics, the carbon intensity of the power sector in Italy in 2021 was 224 g/kWh of power [33], so the average CO_2 emissions avoided by this transition is 3219 tons per year.

4. Biogas and Biomass

4.1. Biogas and Biomass availability in Piadena

As mentioned before, Piadena is an agricultural town, so the availability of bio matters is relatively good. The information available on the amount of the bio matter in the city is that there are about 1174 bovines producing 50 kg of sewage/day/animal totaling 58700 kg of sewage/day, 3750 of pigs producing 10 kg/day/animal totaling 37500 kg of sewage/day, and 1500 tons of dry matter per year.

It is estimated that 29 m^3 of biogas is produced from every ton of bovine sewage, and 20 m^3 of biogas is produced from every ton of pigs sewage, totaling 621339.5 m^3/year of biogas from bovine, and 273750 $m^3/year$ of biogas from pigs. The 1500 tons of dry matter produce 64500 $m^3/year$of biogas.

4.1.1. Design of the AD

For the designing process, it is needed first to calculate the feedstock size as mentioned previously, and to do that the TS and the VS are needed. The Bovine (or cow) manure contains 16.28% total solids (TS) and 84.3% Volatile Solids (VS). [34] While the Swine (Pig) manure contains 2.6% total solids (TS) and 77% Volatile Solids (VS). [35]

For the dry matters, the parameters values are slightly difficult as not all the batches of the dry matters have the same waste components, so for simplicity an average value of different waste batches was studied in Sweden (will be slightly the same as the values of the dry matter in Italy). The average values are 57.92% total solids (TS) 60.43%, and Volatile Solids (VS). [36]

Now with all the information available, the feedstock size can be calculated using the method of adding for each liter (assuming a kilogram of biowaste to be equal to one litter) two liters of water.

Thus 175100 liters of bovine manure, 112500 liters of swine manure, and 4109,59 liters of dry matter water mixture are fed to the digester per day. This means that the size of the feedstock should be enough to handle 292709.6 liters of manure fed to it each day. The feedstock as explained before should have a shredder where the manure particles are chopped up into smaller particles to increase the surface area for a faster digesting process.

The next step is to know the quality of the feedstock; to do so, we need to calculate the volatile matter of each substance entering the feedstock. Starting with the Bovine waste, with TS of 16.28%, VS of 84.3%, and a total of 58700 Kg of wet waste per day it would give 8056.01 Kg VS per day per 176100 liters of Bovine manure (total mixture volume with adding the water), which means that the amount of cubic meter would be equal to 45.75 Kg VS/ m^3. Now with the Swine waste, with TS of 2.6%, VS of 77%, and a total of 112500 Kg of wet waste per day it would give 2252.25 Kg VS per day per 112500 liters of Swine manure, which means that the amount of cubic meter would be equal to 20.02 Kg VS/ m^3. Finally, with the dry matter waste using the same sequence, the wight of volatile solids per m^3 is equal to 233.34 Kg VS/m^3.

For the amount, the type of AD used is the continuously stirred tank reactor (CSTR), assuming 20 days retention time, the volume needed for the fluids inside of the AD would be 8781288.12 liters which is equal to 5854.19 m^3, which is only 75% of the size of the reactor, the other 25% would be the area for the gas produced from the process, meaning that the total area of the AD should be around 7805.59 m^3, which is a huge area to be installed for one AD, thus 2 AD of size 4000 m^3 are installed, which is yet a huge area but possible to be constructed as there is an existing AD in Xanthi (Avato), Northern Greece, with a total zone area of 5400 m3 and working volume of 4200 m3. [37]

The OLR is then calculated by multiplying both the total flow rate with the total concentration of the mixture inside the reactor and then dividing this value by the total volume of the reactor, thus the OLR value is 10.9 which is high due to the high TS percentage of the dry waste, and the relatively small retention time but this problem can be solved by either increasing the retention time which will cause in increasing the size of the AD, and thus more capital cost or by decreasing the flow rate.

By knowing the estimations mentioned before about the biogas productivity of each element entering the AD, the 621339.5 m3/year of bovine manure biogas with 60% of methane content, and 273750 m3/year of biogas from pigs with 65% of methane content, and 64500 m3/year of biogas from dry matter with an average of 60% methane content [38], totaling 411503.7 m^3 of methane per year is available to be produced from the AD designed to be installed.

4.1.2. Economic analysis

In this section a simple economic analysis will be made using a paper made by the government of Agriculture, Forestry and Rural Economic Development in the provenance of Alberta, Canada. The CAPEX can be estimated from the gas production of the plant; the total production of gas in the two ADs is 411503.7 m^3 which is equivalent to 4341.3672 MWh per year.

Based on this research, the estimated CAPEX of a biogas electricity generating plant is $3,700 to $7,000/kWh (Canadian dollars) which is equivalate to 2748.05 to 5199.02 €/kWh depending on the size of the plant (the bigger the cheaper) [39]. So in this project it is estimated that the CAPEX price is equivalent to 4000 €/kWh as in an economic study made for different sizes of AD by Tuscana University, Italy the CAPEX was calculated for a 500KW plant size for a 4000€/kW [40] (which is a value in the range mentioned above), thus, with a production of 4341.37 MWh per year of both of the plants, assuming that there are 30 days of complete shutdown maintenance per year, and 24 hours working of the plant in the working days, thus the equivalent is 509.55 kWh multiplying this with the CAPEX price, that would give an estimate of 2038200 € for both of the ADs. The following table shows the other cost related to the operation of the ADs.

NECESSITY	COST	% OF CAPEX
REPAIR AND MAINTENANCE	45859.5	2.25
LABOR	26496.6	1.3
INSURANCE	10191	0.5
BOOK-KEEPING COUNSELLING	10191	0.5

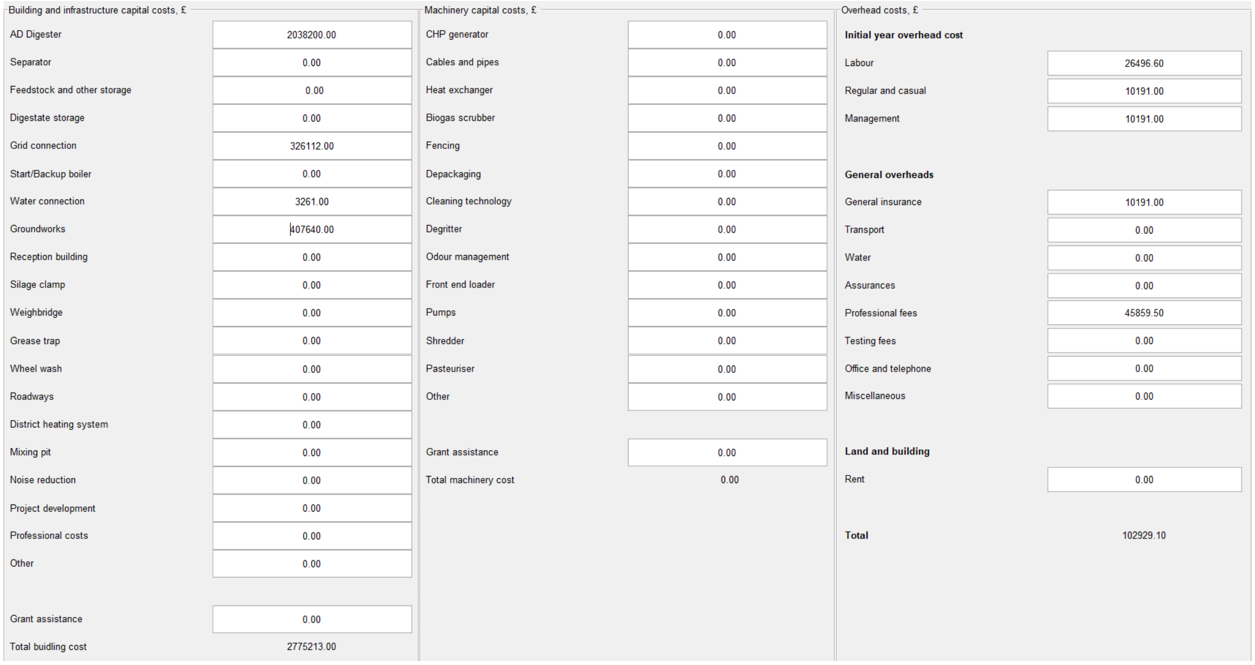
Table 5:Annual AD related costs

The percentages mentioned above were taken from the study made by Tuscana University, Italy [40].

Using an AD economic assessment tool (SADEAT) which is developed with MATLAB software, to see the profitability of this project. Other values were assumed in order to calculate the overall profitability of the project. The following images show the data entered into the tool with justifications.

In the figure below (Figure 14), the capital costs of building the AD, and also the other building needed for running the AD are inserted, as well as the overhead costs (assuming that the costs of the generator are equal to zero as it is already existing). The AD digestor, feedstock and storage costs are all inserted in the AD Digestor field. The grid connection is assumed to be 16% of the AD cost, the water connection 6.5%, and the groundwork 20%. The other costs are neglected as they are irrelevant to this project.

For the overhead costs, the labor and insurance is inserted as mentioned in Table 5. As for the rest of the annual AD-related costs, repair and maintenance is inserted under professional fees and book keeping counseling is inserted under management.



Building and infrastructure capital costs, £

AD Digester	2038200.00
Separator	0.00
Feedstock and other storage	0.00
Digestate storage	0.00
Grid connection	326112.00
Start/Backup boiler	0.00
Water connection	3261.00
Groundworks	407640.00
Reception building	0.00
Silage clamp	0.00
Weighbridge	0.00
Grease trap	0.00
Wheel wash	0.00
Roadways	0.00
District heating system	0.00
Mixing pit	0.00
Noise reduction	0.00
Project development	0.00
Professional costs	0.00
Other	0.00
Grant assistance	0.00
Total buidling cost	2775213.00

Machinery capital costs, £

CHP generator	0.00
Cables and pipes	0.00
Heat exchanger	0.00
Biogas scrubber	0.00
Fencing	0.00
Depackaging	0.00
Cleaning technology	0.00
Degritter	0.00
Odour management	0.00
Front end loader	0.00
Pumps	0.00
Shredder	0.00
Pasteuriser	0.00
Other	0.00
Grant assistance	0.00
Total machinery cost	0.00

Overhead costs, £

Initial year overhead cost	
Labour	26496.60
Regular and casual	10191.00
Management	10191.00
General overheads	
General insurance	10191.00
Transport	0.00
Water	0.00
Assurances	0.00
Professional fees	45859.50
Testing fees	0.00
Office and telephone	0.00
Miscellaneous	0.00
Land and building	
Rent	0.00
Total	102929.10

Figure 14: Economical Assessment Inputs 1

In the next Figure (Figure 15), the simulation parameters were inserted, for the lifetime of the project, which was assumed to be 20 years, the number of cases of the AD project simulated (left as recommended by the programmer), and the seed number that controls stochastic behavior of project parameters (left as recommended by the programmer).

Simulation parameters

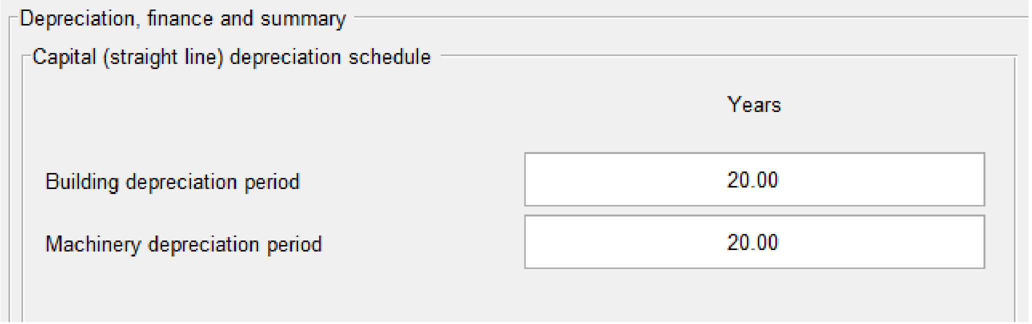
Project lifetime (years) 20.00

Number of cases to simulate 10.00

Seed (for reproducibility of results) 123.00

Figure 15: Economical Assessment Inputs 2

Following that, in Figure 16, The depreciation period has been set.



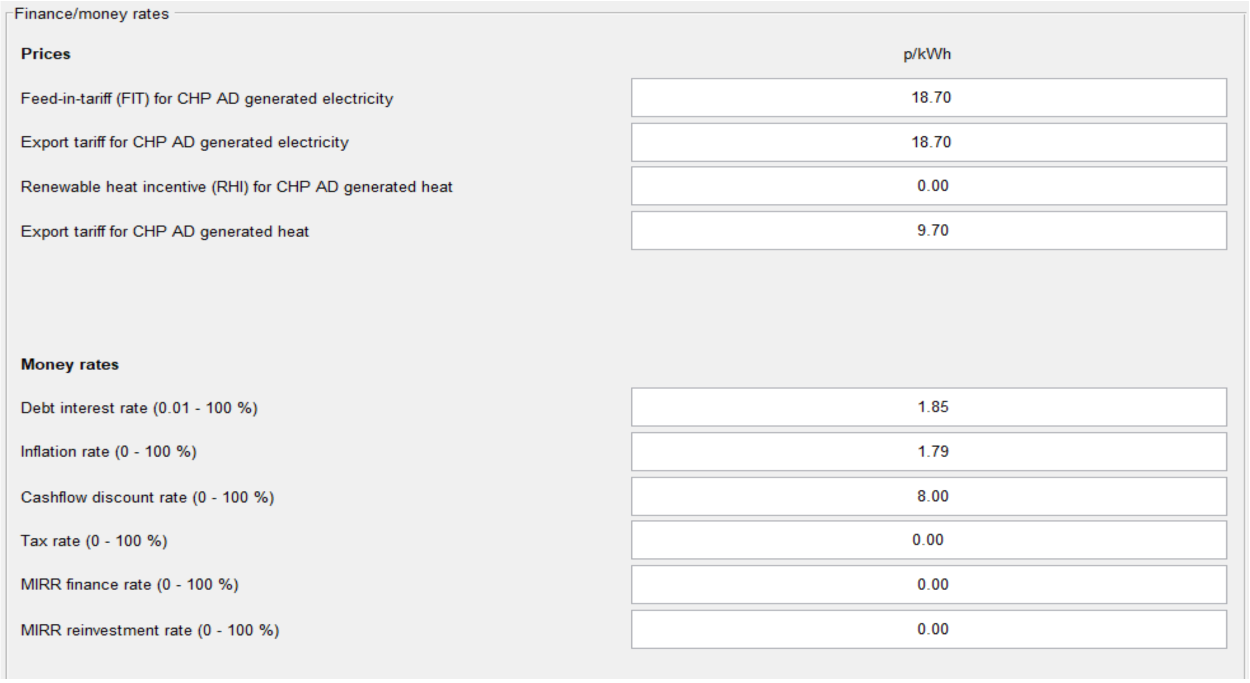
Depreciation, finance and summary

Capital (straight line) depreciation schedule

	Years
Building depreciation period	20.00
Machinery depreciation period	20.00

Figure 16: Economical Assessment Inputs 3

As for the economic rates, electricity, and thermal price rate are inserted, along with the financial rates in Figure 17.

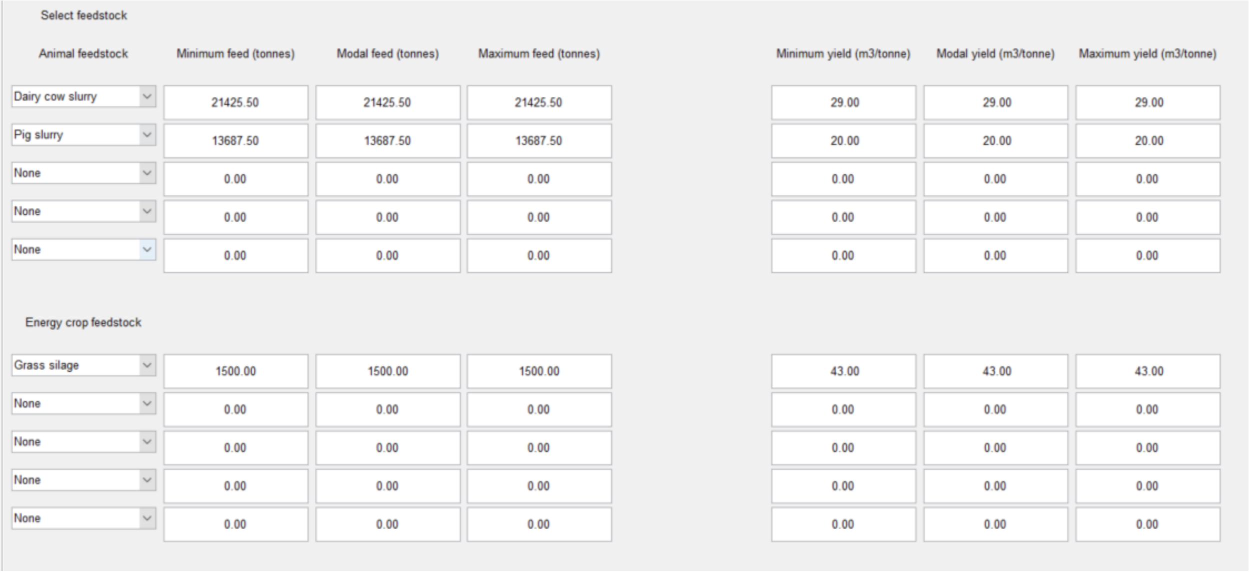


Finance/money rates

Prices	p/kWh
Feed-in-tariff (FIT) for CHP AD generated electricity	18.70
Export tariff for CHP AD generated electricity	18.70
Renewable heat incentive (RHI) for CHP AD generated heat	0.00
Export tariff for CHP AD generated heat	9.70
Money rates	
Debt interest rate (0.01 - 100 %)	1.85
Inflation rate (0 - 100 %)	1.79
Cashflow discount rate (0 - 100 %)	8.00
Tax rate (0 - 100 %)	0.00
MIRR finance rate (0 - 100 %)	0.00
MIRR reinvestment rate (0 - 100 %)	0.00

Figure 16: Economical Assessment Inputs 4

Feedstock mentioned previously in this chapter is inserted in the feedstock tap, each biomatter type with its relevant energy yield in Figure 18.



Select feedstock

Animal feedstock	Minimum feed (tonnes)	Modal feed (tonnes)	Maximum feed (tonnes)	Minimum yield (m3/tonne)	Modal yield (m3/tonne)	Maximum yield (m3/tonne)
Dairy cow slurry	21425.50	21425.50	21425.50	29.00	29.00	29.00
Pig slurry	13687.50	13687.50	13687.50	20.00	20.00	20.00
None	0.00	0.00	0.00	0.00	0.00	0.00
None	0.00	0.00	0.00	0.00	0.00	0.00
None	0.00	0.00	0.00	0.00	0.00	0.00
Energy crop feedstock						
Grass silage	1500.00	1500.00	1500.00	43.00	43.00	43.00
None	0.00	0.00	0.00	0.00	0.00	0.00
None	0.00	0.00	0.00	0.00	0.00	0.00
None	0.00	0.00	0.00	0.00	0.00	0.00
None	0.00	0.00	0.00	0.00	0.00	0.00

Figure 17: Economical Assessment Inputs 5

The results in the figure 19 show that there will be profitability, even without any incentives by the assumption of not paying any taxes to the state, as the main purpose of these calculations is to see the overall value of the project or in other words, whether this project in general economically feasible or not. The results show positive results which means that the project is economically successful. The results show the mean values presented in the blue line, minimum and maximum intervals shown in the two green lines, and finally the 95% confidence intervals for annual revenues in the two red dashed lines.

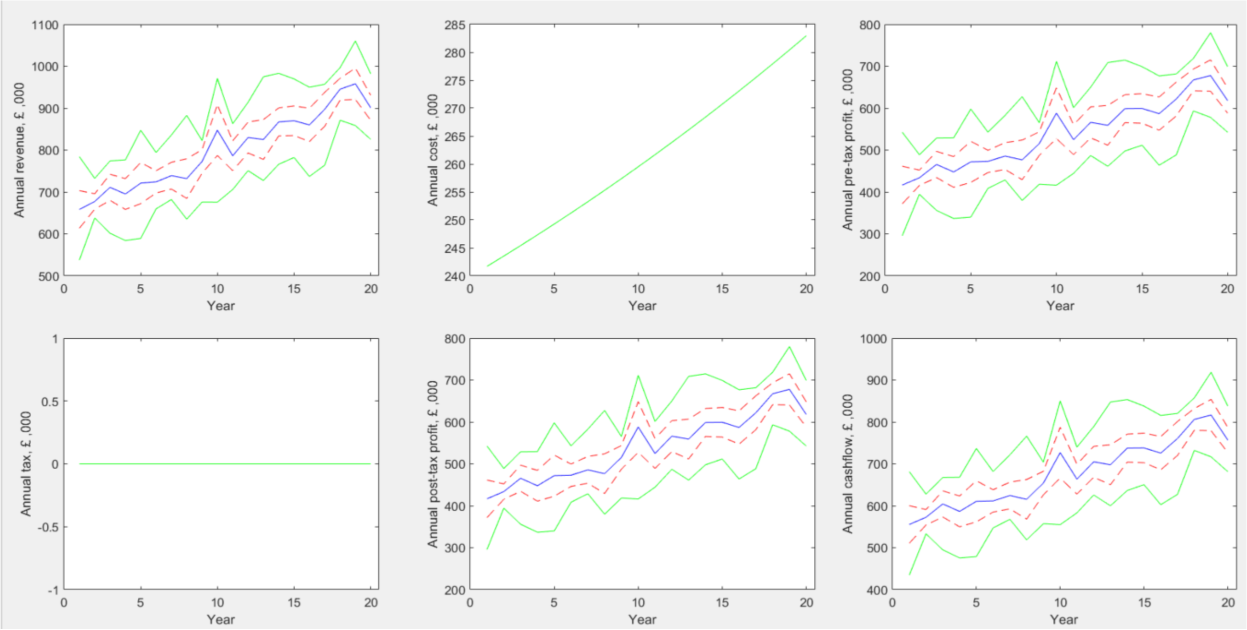


Figure 18: Economical Assessment Result

4.1.3. Total CO_2 emissions avoided

The installations of the ADs would lead to carbon reduction as the average carbon intensity of heat production from natural gas is 1,9 kg CO_2 per m^3 of natural gas [41]. Thus, the expected amount of CO_2 reduction is almost 782 tons of $CO_2\ per\ year$. This is still an underestimation as there are still emission avoided that may have been produced from the manure if left without treatment.

5. Solar water heaters

5.1. Residential hot water demand

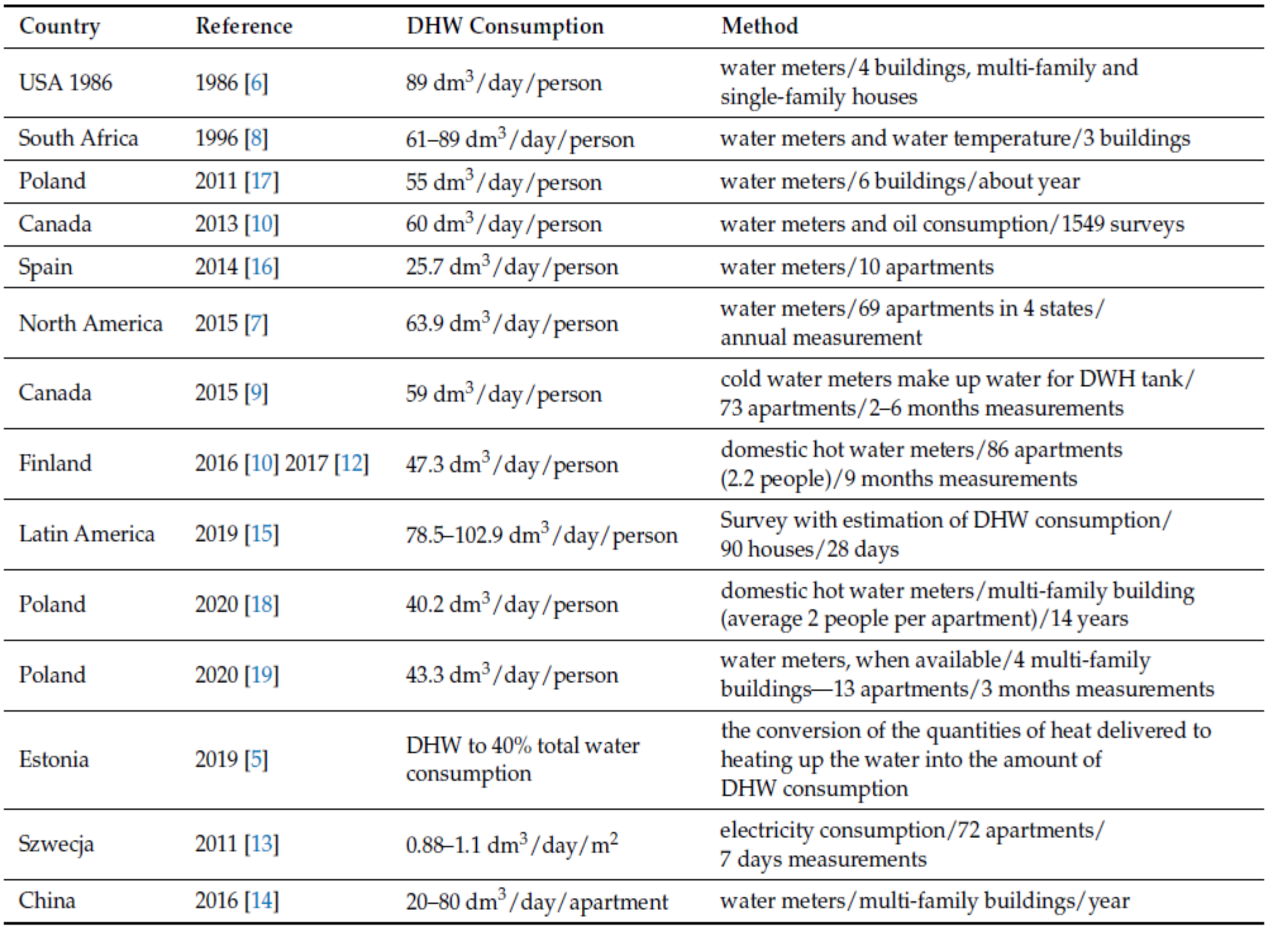
The information about domestic hot water (DHW) consumption varies depending on the location temperatures, altitude, building position, or even sometimes political, and economic status. For example, as stated on the world meters website a county like Turkmenistan has the highest Daily Water Used as its consumption per capita is 16,281 Liters/day, while a country like DR Congo has the lowest consumption of 34 Liters/day [42]. As it is known, water consumption is the main factor affecting DHW consumption, thus, DHW consumption varies between one state and another, if not from one neighborhood to another.

Depending on solarteitalia SRL research, it was stated that the DHW consumption in Italy could be estimated as follows [43]:

TYPE OF USAGE	LITERS (PER DAY PER PERSON)
LOW COMFORT	30 (20 - 40)
AVERAGE COMFORT	50 (40 - 60)
HIGH COMFORT	70 (60 - 80)

Table 6: Average DHW consumption per usage

Also, in study made iat Poznan University of Technology about Real Domestic Hot Water Consumption in Residential Buildings, and its Impact on Buildings Energy Performance, the different DHW consumptions of different locations were stated in table 8. [44]



Country	Reference	DHW Consumption	Method
USA 1986	1986 [6]	89 dm^3/day/person	water meters/4 buildings, multi-family and single-family houses
South Africa	1996 [8]	61–89 dm^3/day/person	water meters and water temperature/3 buildings
Poland	2011 [17]	55 dm^3/day/person	water meters/6 buildings/about year
Canada	2013 [10]	60 dm^3/day/person	water meters and oil consumption/1549 surveys
Spain	2014 [16]	25.7 dm^3/day/person	water meters/10 apartments
North America	2015 [7]	63.9 dm^3/day/person	water meters/69 apartments in 4 states/ annual measurement
Canada	2015 [9]	59 dm^3/day/person	cold water meters make up water for DWH tank/ 73 apartments/2–6 months measurements
Finland	2016 [10] 2017 [12]	47.3 dm^3/day/person	domestic hot water meters/86 apartments (2.2 people)/9 months measurements
Latin America	2019 [15]	78.5–102.9 dm^3/day/person	Survey with estimation of DHW consumption/ 90 houses/28 days
Poland	2020 [18]	40.2 dm^3/day/person	domestic hot water meters/multi-family building (average 2 people per apartment)/14 years
Poland	2020 [19]	43.3 dm^3/day/person	water meters, when available/4 multi-family buildings—13 apartments/3 months measurements
Estonia	2019 [5]	DHW to 40% total water consumption	the conversion of the quantities of heat delivered to heating up the water into the amount of DHW consumption
Szwecja	2011 [13]	0.88–1.1 dm^3/day/m^2	electricity consumption/72 apartments/ 7 days measurements
China	2016 [14]	20–80 dm^3/day/apartment	water meters/multi-family buildings/year

Table 7: DHW consumption in different locations

Showing that the average DHW consumptions in the EU countries stated in the table are almost equal to the 50 Liters per day per person stated by solarteitalia SRL. Thus in this project this value is used in the solar water heater (SWH) sizing measurements.

5.2. Solar water heaters sizing

The average number of people per household in Italy in 2021 as stated on Statista website is 2.29 [45], thus the average DHW consumption in Italy is 114.5 $dm^3/day/household$ (which is equivalent to liters/day/household).

In Piadena, the total number of residential buildings is 1688 units, with the following information:

Year built	Num. of Dwellings	Num. of houses
pre-1930	1	147
	2	78
	3-8	49
	>8	7
1930-45	1	71
	2	38
	3-8	23
	>8	3
1946-60	1	52
	2	28
	3-8	17
	>8	2
< 1960	1	270
	2	144
	3-8	90
	>8	12
1961-76	1	116
	2	62
	3-8	39
	>8	5
1977-92	1	42
	2	23
	3-8	14
	>8	2
1961-92	1	159
	2	84
	3-8	53
	>8	7
1993 - 2006	1	25
	2	14
	3-8	8
	>8	1
post 2006	1	1
	2	0
	3-8	0
	>8	0
SUM		**1688**

Table 8: Residential Buildings classifications in Piadena

As shown, 77,11% of the residential buildings are one and two dwellings houses; thus, in this project only one and two dwelling houses are used for the analysis of the SWH as they have the bigger portion of the number of houses in Piadena, and also as the rooftops of all the buildings are busy with PV panels already installed as stated in Chapter 3.

For the commercial SWHs available, the 150 liters SWH (with available projected hot water from solar at 40 °C of 276 liters) with 24 tubes (which is equivalent to 7.67 kWh per day) is used for the one dwelling house with a little over estimation to ensure the independence of this system throughout the year even though there is a backup connection to the conventional use of natural gas heaters (which uses gas produced from the AD installed in the city). As for the two dwellings houses the 200 liters (with available projected hot water from solar at 40 °C of 414 liters) with 36 solar tubes (which is equivalent to 11.52 kWh per day). [46]

The areas of the system for the one or two dwelling houses are perfect to be installed on the garage, as in the technical information of uber solar the area of the one dwelling system is 2,3m X 1,9m equivalent to 4.37 m2, and for the two dwelling systems, the area is equal to 3,4m X 1,9m which is equivalent to 6,46 m2. [47]

With this sizing it is expected that the system will meet the demand, but for a safety margin, the existing natural gas heaters will not be removed in case of failure in meeting the demand in the winter period (with the calculation and the worst solar irradiance of the year it is supposedly not happening).

5.3. Energy saving from the installed systems

With simple calculations it is estimated that there is total of 831 one dweilling houses in Piadena as shown in table 8, each unity saves almost 7.67 kWh per day thus 2.8 MWh per year per unit, which is equivalent to 2326.8 MWh per year for all the one dwelling houses. As for the two dwelling houses there are 470 houses units, and each system saves 11.52 kWh per day which is equivalent to 4.2 MWh per year, thus there is a saving of 1976.256 MWh per year. In other words, these systems to be installed in the city would save almost 4,3 GWh of thermal energy if used at full capacity which is equivalent to 407583 m^3 of natural gas.

5.4. Economic analysis

In this section an economic analysis of the total installation of the SWH systems for the residential houses is made. The investigation is carried out on the basis of the LCOE comparison. The total SWH cost presented in the report is from UberSolar prices and systems [48] database, other costs are provided in the CAPEX breakdown table with the reference.

ITEM	NUMBER OF UNITS	COST PER UNIT	COST	DESCRIPTION
150L RETROFIT 24 EVT	831	1067 €	886677 €	one system for each one dwelling house
200L RETROFIT 36 EVT	470	1425€	669750 €	one system for each two-dwelling house
TOTAL	1301		**1556427 €**	

Table 9: Total cost of the SWHs

Item	Cost
Installation*	**233465 €**

Table 10: Relative costs

* 15% installation costs of the CAPEX are assumed.

The economic parameters related to the Italian electricity market were obtained from Statista website. These include inflation rate, discount rate, and electricity price of the national grid. Table 10 summarize the economical parameters of Italy.

PARAMETERS	VALUE	UNIT
INFLATION RATE	1.79	%
DISCOUNT RATE	8	%
LIFETIME OF THE PROJECT [49]	20	years
YEARLY EQUIVALENT ELECTRICITY PRODUCTION	4.3	GWh/y
ELECTRICITY MARKET PRICE IN ITALY	0.2153	€/kWh

Table 11: Economic parameters used for the financial analysis

The technical operation and maintenance cost is almost negligible, as a periodic cleaning that is made by the owner of the system is enough. But in this project, it is assumed that every system has an annual maintenance check for 4 hours per year, totaling 5204 working hours per year which is equal to **39030€** per year.

Using the information stated above the economic values were calculated using an excel spreadsheet over the period of 20 years of operation. The gross present Value is **€9,007,007.64**, the net present value is **€7,217,115.64,** and the Levelized cost of electricity (LCOE) is **€0.0323**. IRR is obtained by the same concept as the net present value NPV by setting the NPV to zero. In this project the IRR is equal to **37.46%**. The positive IRR show that the project is economically profitable.

The payback period (PBP) of this project is one year (or even less) which makes sense with the current electricity price of the electricity market in Italy (Europe in general) as the average payback period of a residential SWH is generally in between one to four years [50].

5.5. Total CO_2 emissions avoided

By installing these solar water heaters, the CO_2 emissions avoided by this transition is 775 tons CO_2 per year, as there are 407583 m^3 as the average carbon intensity of heat production from natural gas is 1,9 kg CO_2 per m^3 of natural gas [41].

6. Overall Energy Balance of the community

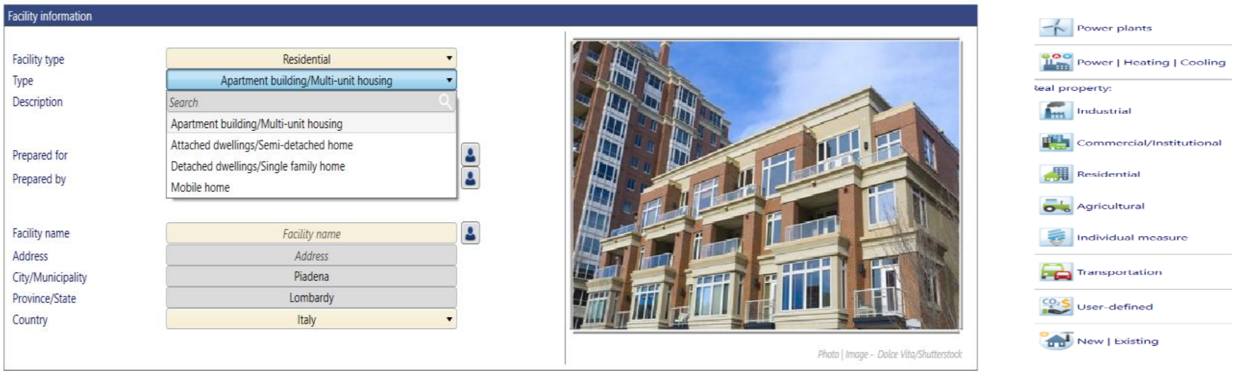
After the calculations made for the technologies to be installed in this community, a simple energy balance is made in this chapter for the residential energy demand. The electrical energy demand for the 1688 residential houses is calculated as number of 1561 dwellings (the number of dwelling that are actually inhabitant by families in Piadena, the rest are empty) multiplied by the energy consumption of the energy consumption calculated by RET screen 13.541 MWh, and that is equal to 21.14 GWh which is much more than the energy produced by the PV systems of the city (only 67.96% will be covered) , while the natural gas demand in the city is 2789529 m^3 (average consumption of natural gas per dwelling is 148.92 m^3/month), while the natural gas saved from shifting from conventional water heaters to SWHs is 407583 m^3 as stated in the previous chapter, from the total natural gas consumption of the one and two dwelling houses (83.34% of the total dwellings) in the city thus the consumption would decrease to 2381946 m^3 (545175 m^3), finally, reducing these consumption with ADs productivity potential of 411504 m^3 per year, giving a total need of 1970442 m^3 of natural gas from external sources (Sources outside the community). The biomatter production would cover 17.27% of the consumption of natural gas (after the reduction of the energy saved from SWHs) of residential buildings, thus although it was proven feasible project economical wise but wouldn't help in the independence of the energy community.

These installations can't make the city totally energy independent as the natural gas, and the electrical consumption is very high in the city, as most of the buildings are relatively old, thus having very low energy efficiency, and the dependency of the city on heating the building with the old conventional gas heaters makes mostly dependent on natural gas. The solution now for this city, is to solve the problem from the roots, which by increasing the efficiency from the demand side, for the next and last chapter of this thesis and energetical and economic analysis is made to see the impact of increasing the efficiency of a 1-dwelling house from a micro point of view of the consumer (thus the demand).

7. Energy analysis with RET screen

7.1. What is RET screen

RET screen is an open-source program that helps its user to have a complete energy analysis on a certain project, whether this project is a renewable energy power facility, a co-generation facility or even a transportation compound in a certain location. It can also analyze the improvement of implementing energy-efficient systems in different buildings, such as residential, commercial, institutional, agricultural, and industrial, where its library has a standard of different facilities types. In the figures below an example of different types of residential buildings that can be analyzed, which are already built in the program, and also the different types of facilities that can be analyzed.



Facility information

Facility type: Residential
Type: Apartment building/Multi-unit housing
Description
Prepared for
Prepared by
Facility name: Facility name
Address: Address
City/Municipality: Piadena
Province/State: Lombardy
Country: Italy

Figure 19: Residential facility choices example and types of facilities that can be analyzed

There are three main sections to be analyzed in every project on RET screen, which are benchmark, feasibility and performance analysis. In each project it is possible to choose only one section of those three to analyze separately, or to analyze all three together.

By choosing the location, the program automatically downloads the climate data of the location chosen from its data base, which is needed for the analysis, also with the economical rates built in the program, which the user can change with the desired values if not applicable for a certain project.

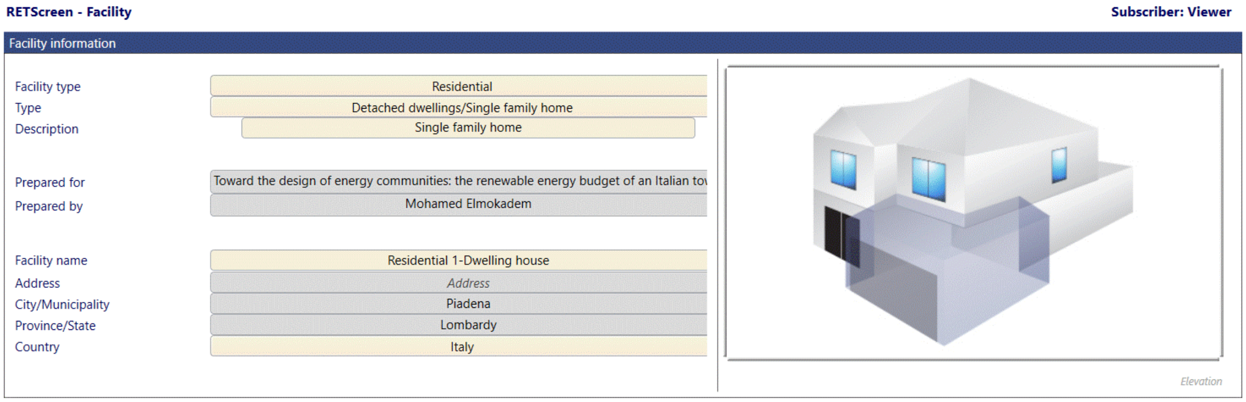
This tool is developed by Natural Resources Canada, the Canadian equivalent of the U.S. Environmental Protection Agency (EPA). Data is from NASA's Prediction of Worldwide Energy Resource (POWER) project.

7.2. Usage of RET screen in this project

In this project the program is used to analyze the energy in a residential one dwelling house with the assumption of the typical energy performance of this house (electrical and gas consumption), and compare the base performance with the modified performance after applying some changes to improve the energy performance of the house after following some recommended methods for increasing its efficiency. This performance analysis will include all the three analysis modes mentioned in the previous section (Benchmark, feasibility, and performance analysis) to have a complete vision of how methods could benefit the user (demand side), and the community as a whole after these improvements.

7.3. Analysis steps

In this section it is only shown how a typical average house in Italy, with an area of 117 m2 [51]. With the energy information available about Piadena energy consumption, it was assumed that the base case of this scenario has an energy intensity of 253.63 kWh/m2, and a target of 25% energy consumption reduction is set for this project. Figures 20 and 21 show the information about the building, and these inputs mentioned above.

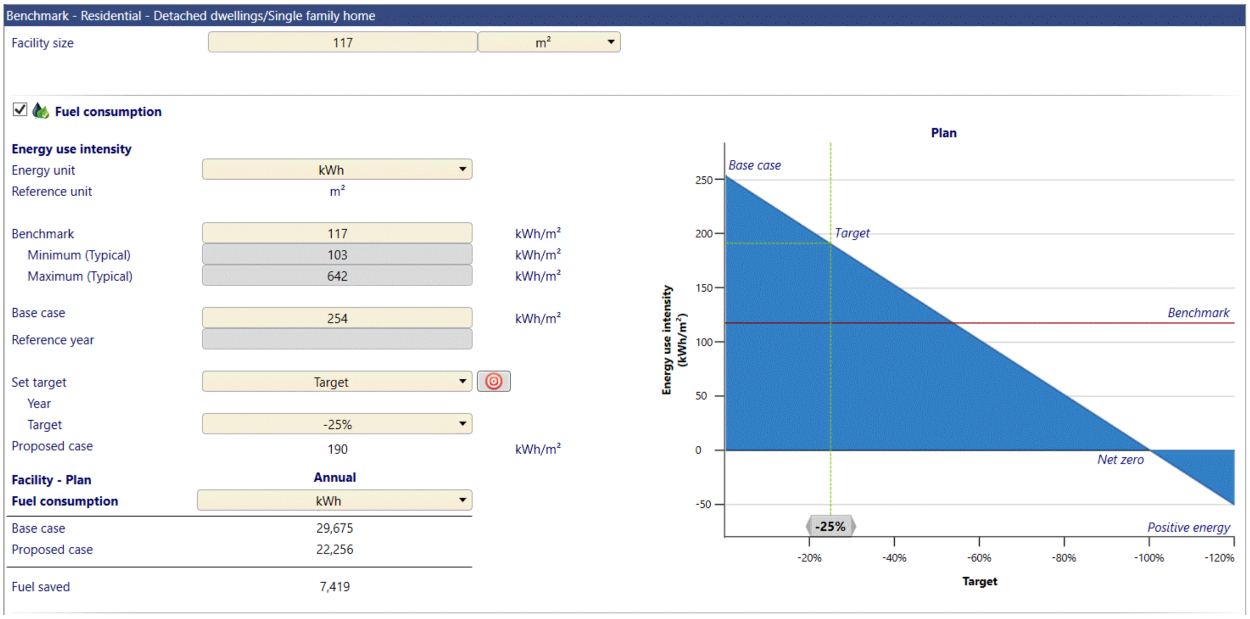


RETScreen - Facility **Subscriber: Viewer**

Facility information

Facility type	Residential
Type	Detached dwellings/Single family home
Description	Single family home
Prepared for	Toward the design of energy communities: the renewable energy budget of an Italian to
Prepared by	Mohamed Elmokadem
Facility name	Residential 1-Dwelling house
Address	Address
City/Municipality	Piadena
Province/State	Lombardy
Country	Italy

Figure 20: RET screen project info

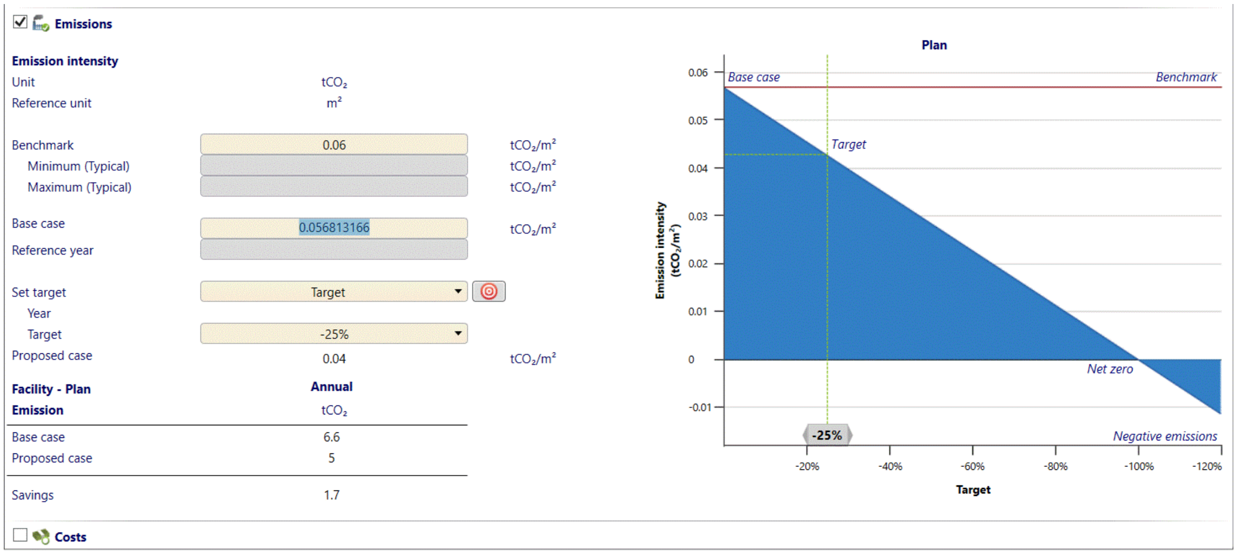


Benchmark - Residential - Detached dwellings/Single family home

Facility size	117	m²
☑ **Fuel consumption**		
Energy use intensity		
Energy unit	kWh	
Reference unit	m²	
Benchmark	117	kWh/m²
Minimum (Typical)	103	kWh/m²
Maximum (Typical)	642	kWh/m²
Base case	254	kWh/m²
Reference year		
Set target	Target	
Year		
Target	-25%	
Proposed case	190	kWh/m²
Facility - Plan	**Annual**	
Fuel consumption	kWh	
Base case	29,675	
Proposed case	22,256	
Fuel saved	7,419	

Figure 21: Energy use intensity inputs

After that, the emissions intensity is inserted in the section below, whereas mentioned before the carbon intensity of the power sector in Italy in 2021 was 224 g/kWh of power [33]. Thus the benchmark, and the base case emission intensity are calculated with the value of this building energy intensity which is equal to 0.0568 tCO2/m2 as shown in figure 22.



☑ **Emissions**

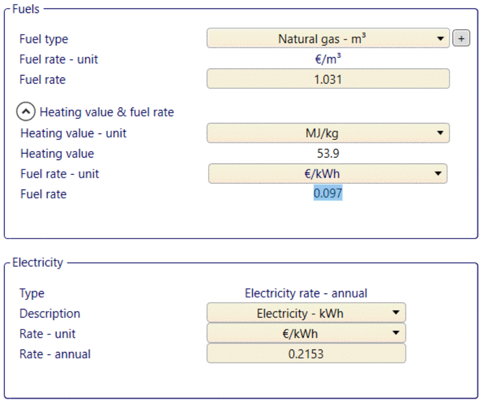
Emission intensity		
Unit	tCO_2	
Reference unit	m^2	
Benchmark	0.06	tCO_2/m^2
Minimum (Typical)		tCO_2/m^2
Maximum (Typical)		tCO_2/m^2
Base case	0.056813166	tCO_2/m^2
Reference year		
Set target	Target	
Year		
Target	-25%	
Proposed case	0.04	tCO_2/m^2

Facility - Plan	**Annual**
Emission	tCO_2
Base case	6.6
Proposed case	5
Savings	1.7

☐ **Costs**

Figure 22: Emission intensity inputs

Then, fuel costs inputs were added in the energy section, with the values of 0.2153 €/kWh, and Natural gas rate of 0.097 €/kWh. [32], [52] as shown in figure 23.



Fuels

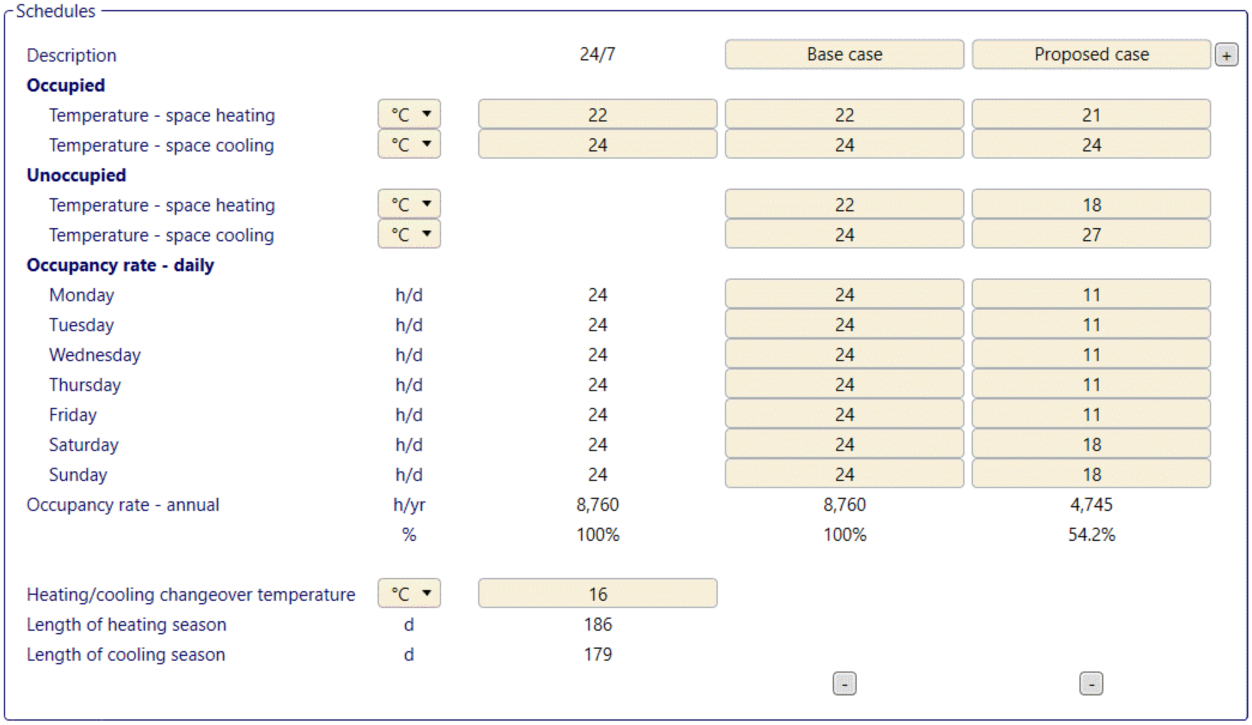
Fuel type	Natural gas - m^3
Fuel rate - unit	€/m^3
Fuel rate	1.031
Heating value & fuel rate	
Heating value - unit	MJ/kg
Heating value	53.9
Fuel rate - unit	€/kWh
Fuel rate	0.097

Electricity

Type	Electricity rate - annual
Description	Electricity - kWh
Rate - unit	€/kWh
Rate - annual	0.2153

Figure 23: Fuel prices

After that the occupation schedules with the space heating and cooling temperatures, were set for both the base case and the proposed case as shown in figure 24.

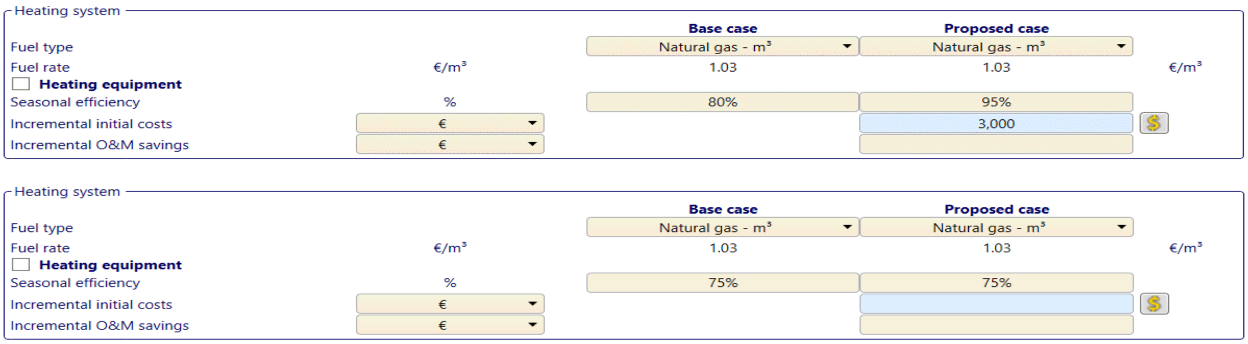


Schedules

Description		24/7	Base case	Proposed case
Occupied				
Temperature - space heating	°C	22	22	21
Temperature - space cooling	°C	24	24	24
Unoccupied				
Temperature - space heating	°C		22	18
Temperature - space cooling	°C		24	27
Occupancy rate - daily				
Monday	h/d	24	24	11
Tuesday	h/d	24	24	11
Wednesday	h/d	24	24	11
Thursday	h/d	24	24	11
Friday	h/d	24	24	11
Saturday	h/d	24	24	18
Sunday	h/d	24	24	18
Occupancy rate - annual	h/yr	8,760	8,760	4,745
	%	100%	100%	54.2%
Heating/cooling changeover temperature	°C	16		
Length of heating season	d	186		
Length of cooling season	d	179		

Figure 24: Occupation schedules with the space heating and cooling temperatures

Then, the space heating, and domestic water heating settings are inserted as shown in figure 25 (increasing the efficiency of the space heaters while keeping the old water heater the same).



Heating system

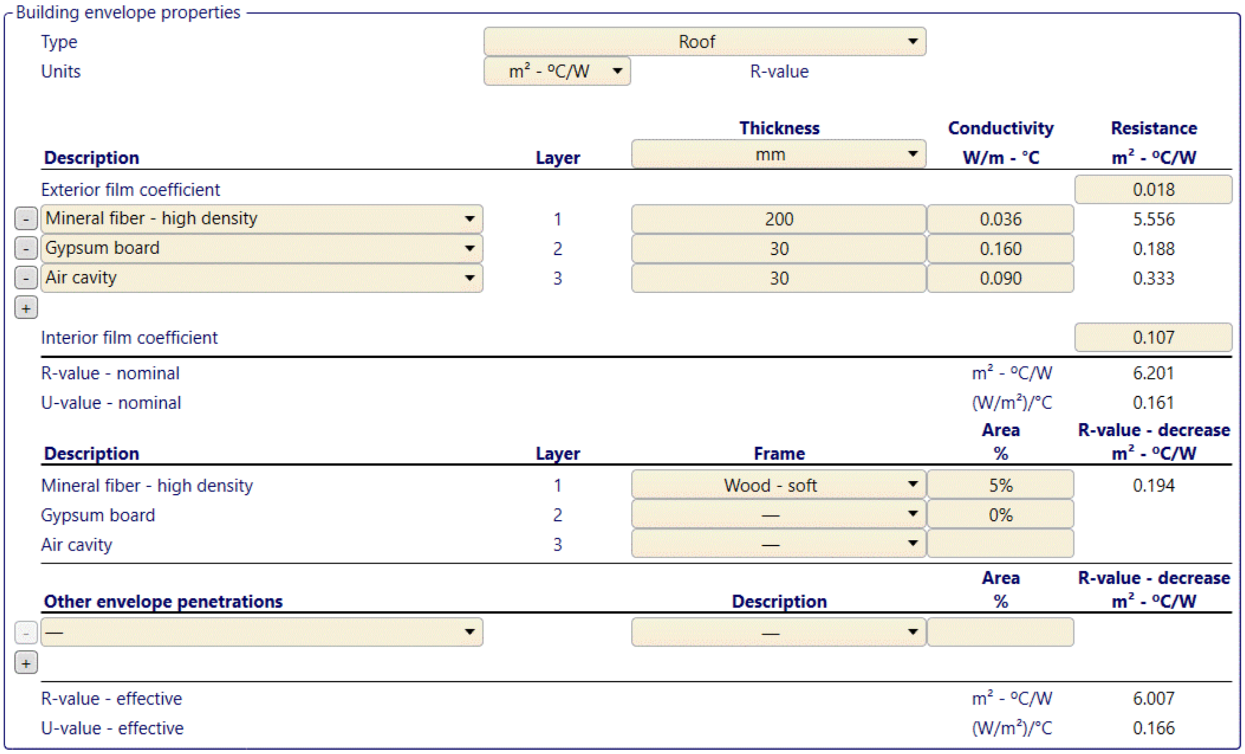
		Base case	Proposed case	
Fuel type		Natural gas - m³	Natural gas - m³	
Fuel rate	€/m³	1.03	1.03	€/m³
☐ **Heating equipment**				
Seasonal efficiency	%	80%	95%	
Incremental initial costs	€		3,000	
Incremental O&M savings	€			

Heating system

		Base case	Proposed case	
Fuel type		Natural gas - m³	Natural gas - m³	
Fuel rate	€/m³	1.03	1.03	€/m³
☐ **Heating equipment**				
Seasonal efficiency	%	75%	75%	
Incremental initial costs	€			
Incremental O&M savings	€			

Figure 25: Heating systems settings

The next step is to add insulation materials on the roof, external and basement walls. Figures 26, 27 and 28 show the types of insulation added to the building.



Building envelope properties

Type: Roof

Units: m^2 - ºC/W R-value

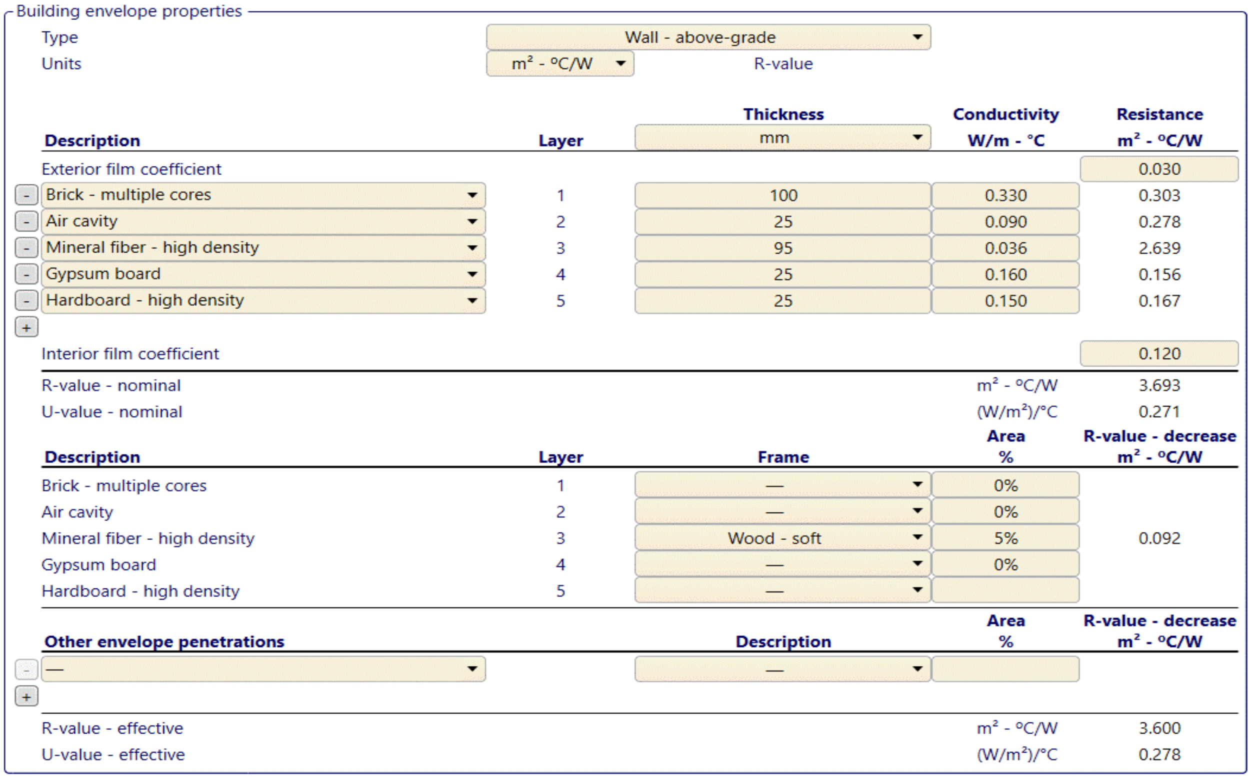
Description	Layer	Thickness mm	Conductivity W/m - °C	Resistance m^2 - ºC/W
Exterior film coefficient				0.018
Mineral fiber - high density	1	200	0.036	5.556
Gypsum board	2	30	0.160	0.188
Air cavity	3	30	0.090	0.333
Interior film coefficient				0.107
R-value - nominal			m^2 - ºC/W	6.201
U-value - nominal			(W/m^2)/°C	0.161

Description	Layer	Frame	Area %	R-value - decrease m^2 - ºC/W
Mineral fiber - high density	1	Wood - soft	5%	0.194
Gypsum board	2	—	0%	
Air cavity	3	—		

Other envelope penetrations	Description	Area %	R-value - decrease m^2 - ºC/W
—	—		

R-value - effective	m^2 - ºC/W	6.007
U-value - effective	(W/m^2)/°C	0.166

Figure 26: Roof insulation material



Building envelope properties

Type: Wall - above-grade

Units: m^2 - ºC/W R-value

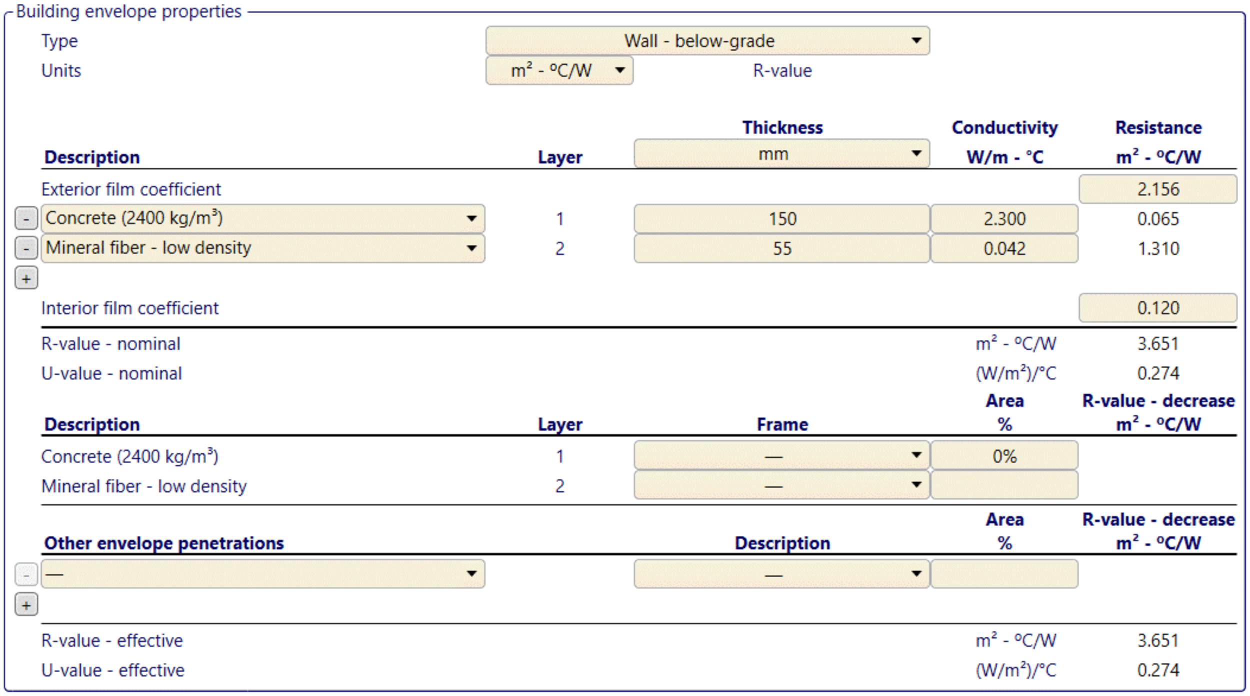
Description	Layer	Thickness mm	Conductivity W/m - °C	Resistance m^2 - ºC/W
Exterior film coefficient				0.030
Brick - multiple cores	1	100	0.330	0.303
Air cavity	2	25	0.090	0.278
Mineral fiber - high density	3	95	0.036	2.639
Gypsum board	4	25	0.160	0.156
Hardboard - high density	5	25	0.150	0.167
Interior film coefficient				0.120
R-value - nominal			m^2 - ºC/W	3.693
U-value - nominal			(W/m^2)/°C	0.271

Description	Layer	Frame	Area %	R-value - decrease m^2 - ºC/W
Brick - multiple cores	1	—	0%	
Air cavity	2	—	0%	
Mineral fiber - high density	3	Wood - soft	5%	0.092
Gypsum board	4	—	0%	
Hardboard - high density	5	—		

Other envelope penetrations	Description	Area %	R-value - decrease m^2 - ºC/W
—	—		

R-value - effective	m^2 - ºC/W	3.600
U-value - effective	(W/m^2)/°C	0.278

Figure 27: Walls insulation materials



Building envelope properties

Type: Wall - below-grade

Units: m^2 - °C/W R-value

Description	Layer	Thickness mm	Conductivity W/m - °C	Resistance m^2 - °C/W
Exterior film coefficient				2.156
Concrete (2400 kg/m^3)	1	150	2.300	0.065
Mineral fiber - low density	2	55	0.042	1.310
Interior film coefficient				0.120
R-value - nominal			m^2 - °C/W	3.651
U-value - nominal			(W/m^2)/°C	0.274

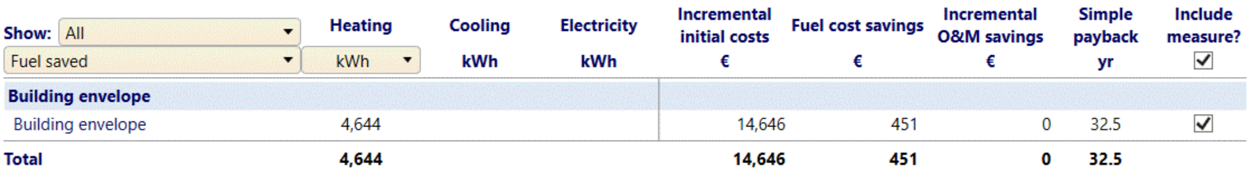
Description	Layer	Frame	Area %	R-value - decrease m^2 - °C/W
Concrete (2400 kg/m^3)	1	—	0%	
Mineral fiber - low density	2	—		

Other envelope penetrations	Description	Area %	R-value - decrease m^2 - °C/W
—	—		

R-value - effective	m^2 - °C/W	3.651
U-value - effective	(W/m^2)/°C	0.274

Figure 28: Basement insulation materials

These materials used in the insulation are all recommended by the RET screen program, where they were needed to decrease the thermal transmittance (U-value) of the roof to around 0.166 (W/m2)C (recommended 0.16 (W/m2)C), upper walls to 0.278 (recommended 0.27 (W/m2)C), and finally the basement to 0.274 (W/m2)C (recommended 0.27 (W/m2)C) [53]. The summary of the savings done by adding these implementations, and the payback period (PBP) is shown in figure 30.

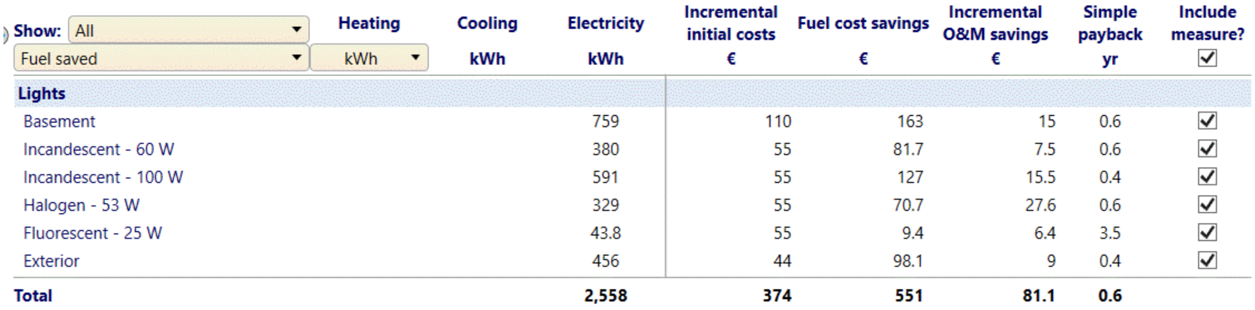


Show: All Fuel saved	Heating kWh	Cooling kWh	Electricity kWh	Incremental initial costs €	Fuel cost savings €	Incremental O&M savings €	Simple payback yr	Include measure? ☑
Building envelope								
Building envelope	4,644			14,646	451	0	32.5	☑
Total	**4,644**			**14,646**	**451**	**0**	**32.5**	

Figure 29: Insulation cost summery

As shown in the results, these insulations would need a really high investment costs, thus long PBP, but they are essential to reach the recommended thermal insulation transmisivity.

For the lighting system in the house, all the bulbs were changed from the less efficient bulb types to LED as shown in figure 31. The payback period of this improvement is about 0.6 years as shown in the figure.

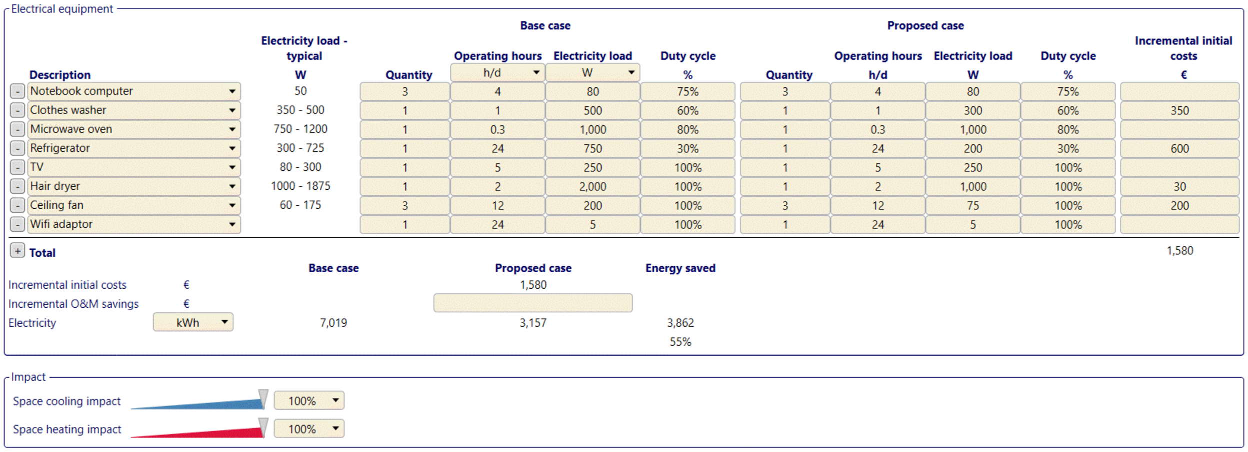


Show: All

Fuel saved	Heating kWh	Cooling kWh	Electricity kWh	Incremental initial costs €	Fuel cost savings €	Incremental O&M savings €	Simple payback yr	Include measure? ☑
Lights								
Basement			759	110	163	15	0.6	☑
Incandescent - 60 W			380	55	81.7	7.5	0.6	☑
Incandescent - 100 W			591	55	127	15.5	0.4	☑
Halogen - 53 W			329	55	70.7	27.6	0.6	☑
Fluorescent - 25 W			43.8	55	9.4	6.4	3.5	☑
Exterior			456	44	98.1	9	0.4	☑
Total			**2,558**	**374**	**551**	**81.1**	**0.6**	

Figure 30: Lighting system savings

As for the Electrical equipment in the house, the basic equipment was added by changing the high consumption equipment to more efficient ones (such as the fridge, clothes washer and the hair drier) with more efficient ones as shown in figure 32.



Electrical equipment

		Base case				Proposed case				
Description	**Electricity load - typical** **W**	**Quantity**	**Operating hours** h/d	**Electricity load** W	**Duty cycle** **%**	**Quantity**	**Operating hours** **h/d**	**Electricity load** **W**	**Duty cycle** **%**	**Incremental initial costs** **€**
Notebook computer	50	3	4	80	75%	3	4	80	75%	
Clothes washer	350 - 500	1	1	500	60%	1	1	300	60%	350
Microwave oven	750 - 1200	1	0.3	1,000	80%	1	0.3	1,000	80%	
Refrigerator	300 - 725	1	24	750	30%	1	24	200	30%	600
TV	80 - 300	1	5	250	100%	1	5	250	100%	
Hair dryer	1000 - 1875	1	2	2,000	100%	1	2	1,000	100%	30
Ceiling fan	60 - 175	3	12	200	100%	3	12	75	100%	200
Wifi adaptor		1	24	5	100%	1	24	5	100%	
Total										1,580

		Base case	**Proposed case**	**Energy saved**
Incremental initial costs	€		1,580	
Incremental O&M savings	€			
Electricity	kWh	7,019	3,157	3,862 55%

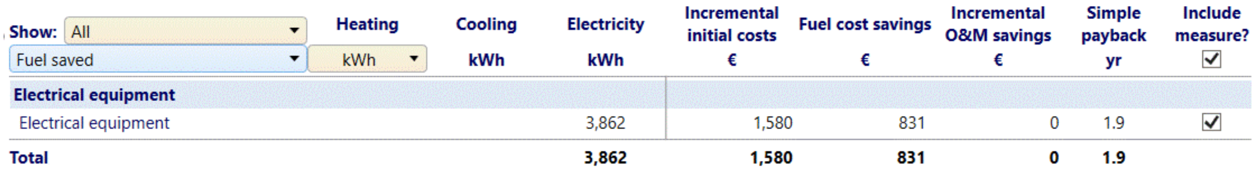
Impact

Space cooling impact 100%

Space heating impact 100%

Figure 31: Electrical equipment performance

The payback period of these improvements is shown in figure 32.

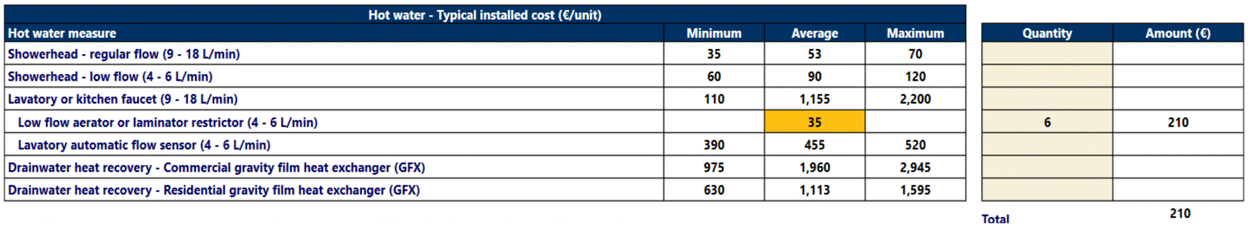


Show: All

Fuel saved	Heating kWh	Cooling kWh	Electricity kWh	Incremental initial costs €	Fuel cost savings €	Incremental O&M savings €	Simple payback yr	Include measure? ☑
Electrical equipment								
Electrical equipment			3,862	1,580	831	0	1.9	☑
Total			**3,862**	**1,580**	**831**	**0**	**1.9**	

Figure 32: Electrical equipment PBP

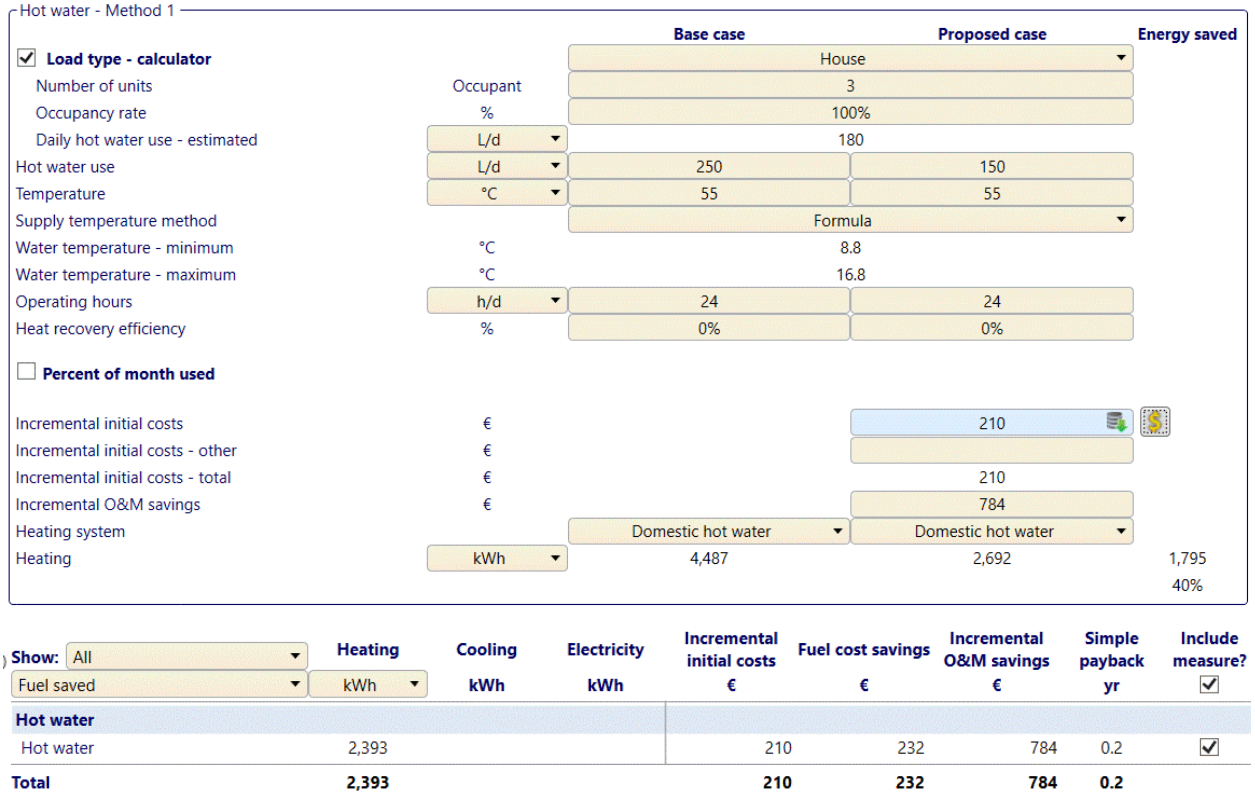
For the domestic hot water consumption, 6 Low flow restrictors were installed to reduce the DHW losses as shown in figure 33.



Hot water measure	Minimum	Average	Maximum	Quantity	Amount (€)
Showerhead - regular flow (9 - 18 L/min)	35	53	70		
Showerhead - low flow (4 - 6 L/min)	60	90	120		
Lavatory or kitchen faucet (9 - 18 L/min)	110	1,155	2,200		
Low flow aerator or laminator restrictor (4 - 6 L/min)		35		6	210
Lavatory automatic flow sensor (4 - 6 L/min)	390	455	520		
Drainwater heat recovery - Commercial gravity film heat exchanger (GFX)	975	1,960	2,945		
Drainwater heat recovery - Residential gravity film heat exchanger (GFX)	630	1,113	1,595		
				Total	210

Figure 33: Insulation for increasing the performance of DHW

This change reduced the energy consumption for the DWH by 40%, and with a fast PBP of 0.2 years as shown in figure 35.



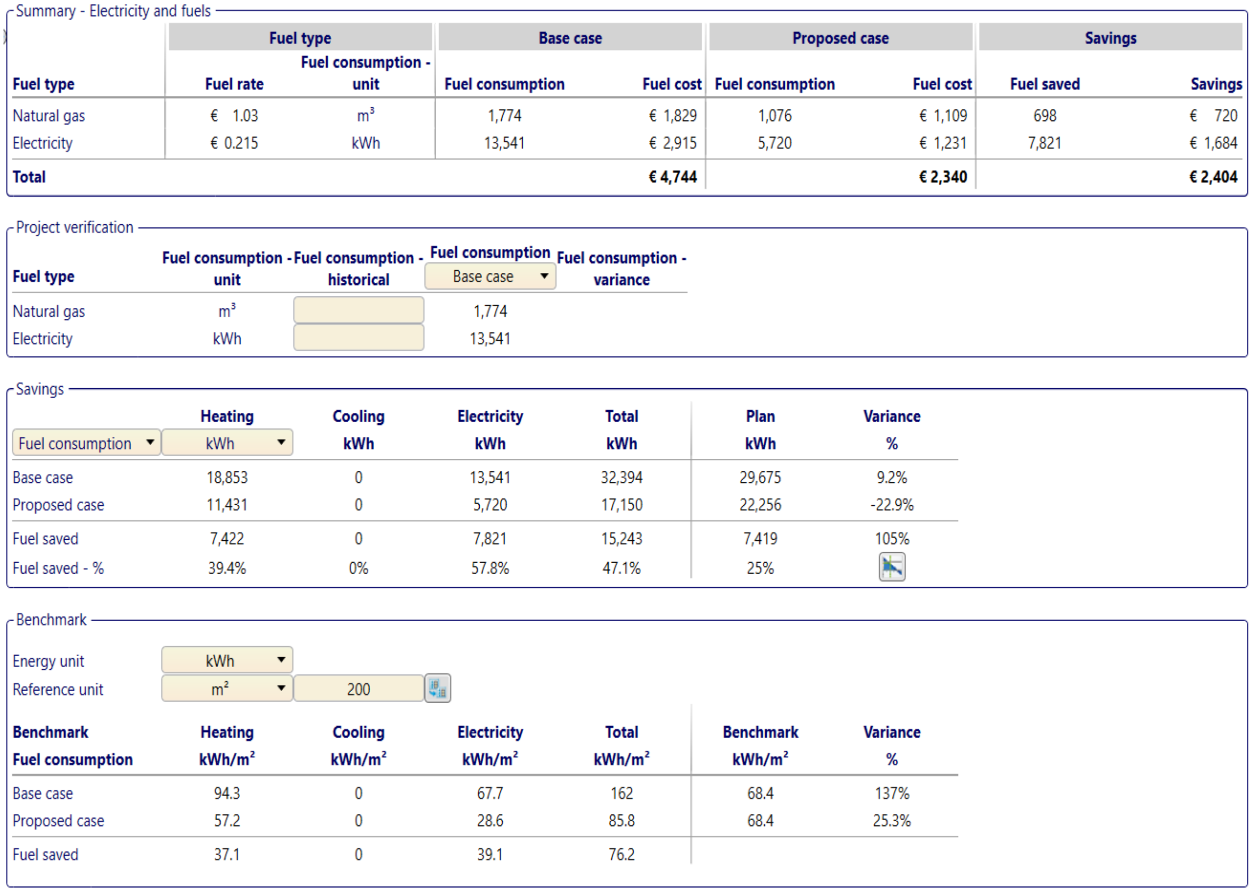
		Base case	Proposed case	Energy saved
☑ **Load type - calculator**		House		
Number of units	Occupant	3		
Occupancy rate	%	100%		
Daily hot water use - estimated	L/d	180		
Hot water use	L/d	250	150	
Temperature	°C	55	55	
Supply temperature method		Formula		
Water temperature - minimum	°C	8.8		
Water temperature - maximum	°C	16.8		
Operating hours	h/d	24	24	
Heat recovery efficiency	%	0%	0%	
☐ **Percent of month used**				
Incremental initial costs	€		210	
Incremental initial costs - other	€			
Incremental initial costs - total	€		210	
Incremental O&M savings	€		784	
Heating system		Domestic hot water	Domestic hot water	
Heating	kWh	4,487	2,692	1,795 40%

Show: All Fuel saved	Heating kWh	Cooling kWh	Electricity kWh	Incremental initial costs €	Fuel cost savings €	Incremental O&M savings €	Simple payback yr	Include measure? ☑
Hot water								
Hot water	2,393			210	232	784	0.2	☑
Total	**2,393**			**210**	**232**	**784**	**0.2**	

Figure 34, 34: DHW improvements impact

7.4. Analysis of energy savings results

The plan as shown previously, is to reduce the energy consumption by at least 25%, but after increasing the energy efficiency of the building by the applications mentioned previously, there are heating energy savings of 39.4%, and electrical energy savings of 57.8% totaling of 47.1% of energy savings as shown in figure 38.



Summary - Electricity and fuels

	Fuel type		Base case		Proposed case		Savings	
Fuel type	**Fuel rate**	**Fuel consumption - unit**	**Fuel consumption**	**Fuel cost**	**Fuel consumption**	**Fuel cost**	**Fuel saved**	**Savings**
Natural gas	€ 1.03	m^3	1,774	€ 1,829	1,076	€ 1,109	698	€ 720
Electricity	€ 0.215	kWh	13,541	€ 2,915	5,720	€ 1,231	7,821	€ 1,684
Total				**€ 4,744**		**€ 2,340**		**€ 2,404**

Project verification

Fuel type	**Fuel consumption - unit**	**Fuel consumption - historical**	**Fuel consumption** Base case	**Fuel consumption - variance**
Natural gas	m^3		1,774	
Electricity	kWh		13,541	

Savings

Fuel consumption	**Heating** kWh	**Cooling** **kWh**	**Electricity** **kWh**	**Total** **kWh**	**Plan** **kWh**	**Variance** **%**
Base case	18,853	0	13,541	32,394	29,675	9.2%
Proposed case	11,431	0	5,720	17,150	22,256	-22.9%
Fuel saved	7,422	0	7,821	15,243	7,419	105%
Fuel saved - %	39.4%	0%	57.8%	47.1%	25%	

Benchmark

Energy unit: kWh

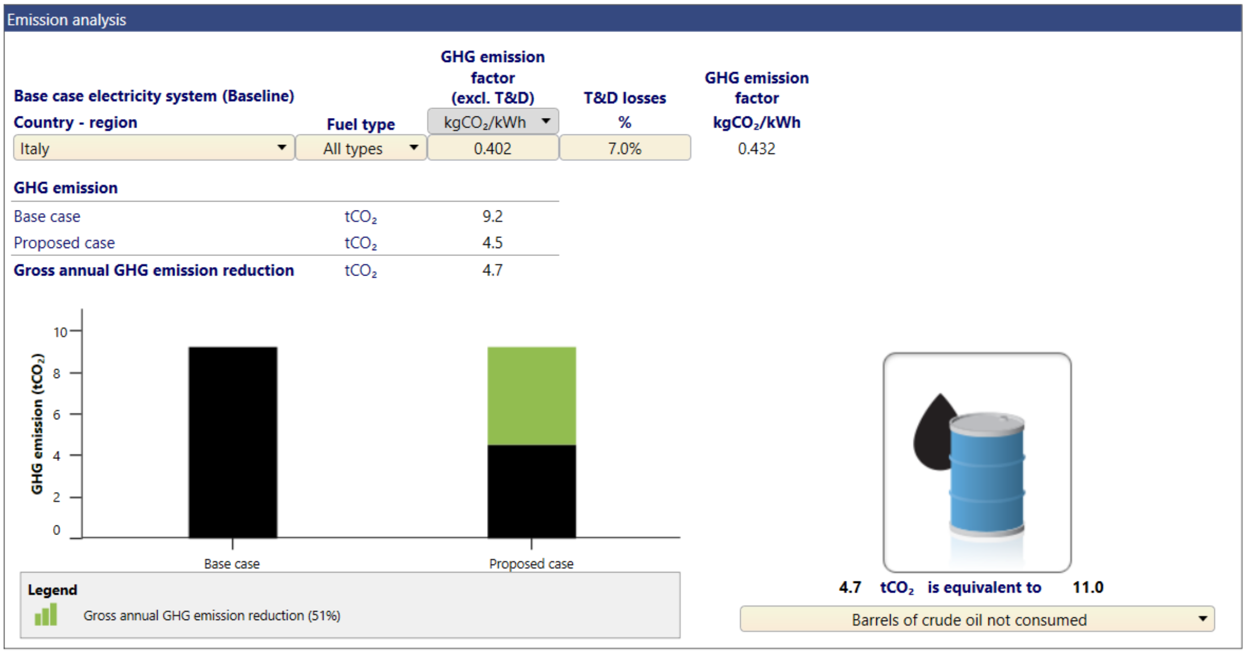
Reference unit: m^2 200

Benchmark **Fuel consumption**	**Heating** **kWh/m²**	**Cooling** **kWh/m²**	**Electricity** **kWh/m²**	**Total** **kWh/m²**	**Benchmark** **kWh/m²**	**Variance** **%**
Base case	94.3	0	67.7	162	68.4	137%
Proposed case	57.2	0	28.6	85.8	68.4	25.3%
Fuel saved	37.1	0	39.1	76.2		

Figure 35: Electricity and fuels savings

7.5. Emission analysis

With the energy savings, and shifting some of the energy used to renewable energies, the analysis shows that 4.7 tCO2 is prevented per year as a result of those applications, which is equivalent to 11 barrels of crude oil not consumed, as shown in figure 39.


Emission analysis

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) $kgCO_2/kWh$	T&D losses %	GHG emission factor $kgCO_2/kWh$
Italy	All types	0.402	7.0%	0.432

GHG emission		
Base case	tCO_2	9.2
Proposed case	tCO_2	4.5
Gross annual GHG emission reduction	tCO_2	4.7

4.7 tCO_2 is equivalent to 11.0

Barrels of crude oil not consumed

Figure 36: Emission Analysis

7.6. Economic analysis

This energy usage shift does not only benefit the community by reducing the harmful GHG emissions, but also directly profitable for the consumer. As the results show, there is financial profitability after applying these applications with a simple payback period of 6.4 years, net profit value of 17556 €, and annual life cycle savings of 1788 €/years. Figures 40 and 42 show the complete financial analysis made by the program with financial graphs of the yearly cash flow and the NPV.

Financial parameters

General		
Fuel cost escalation rate	%	2%
Inflation rate	%	1.79%
Discount rate	%	8%
Reinvestment rate	%	8%
Project life	yr	20
Finance		
Incentives and grants	€	
Debt ratio	%	70%
Debt	€	14,707
Equity	€	6,303
Debt interest rate	%	7%
Debt term	yr	15
Debt payments	€/yr	1,615
Income tax analysis	☐	

Annual revenue

GHG reduction revenue		
Gross GHG reduction	tCO_2/yr	5
Gross GHG reduction - 20 yrs	tCO_2	94
GHG reduction revenue	€	0
Other revenue (cost)	☐	

Costs | Savings | Revenue

Initial costs			
Incremental initial costs	100%	€	21,010
Total initial costs	**100%**	**€**	**21,010**
Yearly cash flows - Year 1			
Annual costs and debt payments			
O&M costs (savings)		€	-865
Fuel cost - proposed case		€	2,340
Debt payments - 15 yrs		€	1,615
Total annual costs		**€**	**3,090**
Annual savings and revenue			
Fuel cost - base case		€	4,744
GHG reduction revenue		€	0
Other revenue (cost)		€	0
Total annual savings and revenue		**€**	**4,744**
Net yearly cash flow - Year 1		**€**	**1,654**

Financial viability

Pre-tax IRR - equity	%	30.9%
Pre-tax MIRR - equity	%	15.4%
Pre-tax IRR - assets	%	9.5%
Pre-tax MIRR - assets	%	8.7%
Simple payback	yr	6.4
Equity payback	yr	3.5
Net Present Value (NPV)	€	17,556
Annual life cycle savings	€/yr	1,788
Benefit-Cost (B-C) ratio		3.8
Debt service coverage		2.1

Yearly cash flows

Year	Pre-tax	Cumulative
#	€	€
0	-6,303	-6,303
1	1,718	-4,585
2	1,783	-2,802
3	1,849	-954
4	1,916	962
5	1,985	2,947
6	2,055	5,002
7	2,126	7,128
8	2,199	9,327
9	2,273	11,600
10	2,349	13,949
11	2,426	16,374
12	2,504	18,879
13	2,585	21,463
14	2,666	24,130
15	2,750	26,879
16	4,449	31,328
17	4,536	35,864
18	4,624	40,488
19	4,714	45,202
20	4,806	50,008

Figure 37: Financial parameters and results with the yearly cash flow graph

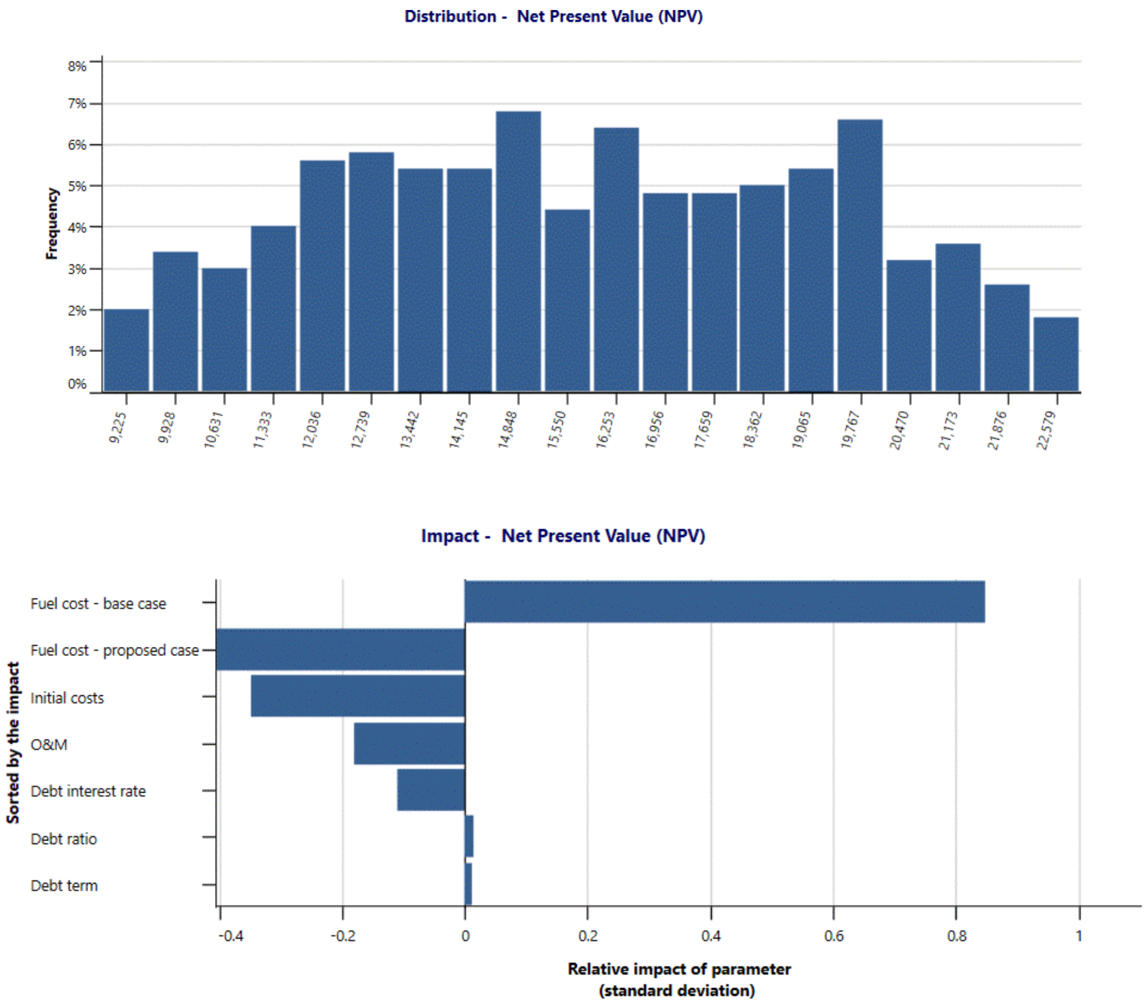


Figure 38: NPV graphs

7.7. Over all energy consumption reduction in the Energy Community

By applying these changes in all the one and two dwelling houses in Piadena (1301 dwellings out of the 1561 dwellings) which are responsible for 83.34% (1779608 m^3) of the overall residential energy consumption in the town, an overall reduction in the natural gas demand would reach to 1269276 m^3 instead of 1970442 m^3 (701166 m^3 of reduction), that means that almost 40.67% of the overall demand has decreased (also after reducing the AD productivity) by these applications, and the electrical consumption would decrease dramatically from 21.14 GWh per year to 8.93

GWh per year (completely covered with the PV systems production with excess fed to the grid) as the electrical changes are appliable on all the 1561 dwellings not only the one and two dwelling houses.

A further analysis was made using excel spreadsheet for the electrical consumption using the different consumptions in the four seasons of the year, as still the electrical consumption results from RET screen are relatively high. The results as shown in the appendix were that the electrical consumption would decrease to 2553.499 kWh per year per dwelling if only the essential electrical devices were used. Thus, the overall electrical consumption may be reduced to 3.99 GWh which is only 65.49% of the energy produced by the PV systems in the city.

The following table summarizes all the energy demand needed from outside the community (energy demand differences), and the total CO2 emissions avoided after applying the different technologies throughout this project.

ENERGY SOURCE	BASE CASE	AFTER EXPLOITING THE RES	AFTER APPLYING ENERGY MANAGEMENT TO THE BUILDINGS	AFTER ONLY USING ESSENTIAL ELECTRICAL DEVICES	DEMAND REDUCTION (%)
NATURAL GAS (M3)	2789529	1970442	1269276	1269276	54.5
ELECTRICITY (GWH)	21.14	6.77	-5.44	-10.38	81.13

Table 12: Overview of the Energy demand improvement

ENERGY SOURCE	BASE CASE	AFTER EXPLOITING THE RES	AFTER APPLYING ENERGY MANAGEMENT ON THE BUILDINGS	AFTER ONLY USING ESSENTIAL ELECTRICAL DEVICES	CARBON NEUTRAL (%)
CO_2 EMISSIONS AVOIDED (TON CO_2)	10035	5261	1219	87	99.13

Table 13: CO2 reduction

8. Conclusion

Energy communities applicability is still under research and analysis, this thesis helped in proofing that with the current conditions of energy pricing, it is technically, and financially applicable to make an energy shift towards renewables available in every city, or even set of buildings compound. The luxury of being energy independent is now a necessity, and the aim of this project was to see the technical, economic, and environmental impact of applying all the possible energy technologies available in one town to extract as much energy as possible from it. After the results shown in the thesis, it is proven that the dependency of the available energy sources in a certain community is not always completely possible (maybe possible in other location with more energy sources or less inhabitance), but, this transition may shift a town to a carbon-neutral community, and may also attract more inhabitance to live and work in this community. Thus, an increase in agricultural activities would occur that may lead in increasing the productivity of biomass production, especially by cultivating specific crops with high biomass yield. Furthermore, there is still a possibility of adding further PV installations built on the ground (which could partially decrease the agricultural production), but with a well-structured study, the optimum balance between agriculture, and energy production may occur.

It is necessary to work on the demand side to reach to a complete or near state of independency. With no incentives taken from the government, the project was proven to be financially applicable and profitable, but to be fair, the CAPEX, and the operation of these projects is still not completely possible to be handled only by the members of the community especially for the bigger projects such as anaerobic digestors. Thus, the government should help in the funding and the supervision of these projects while making the priority of employing, and training people within the community to work on these projects. Furthermore, the thesis showed the importance of managing the energy from the demand side, as there is a lot of wasted energy from really simple household equipments that may lead to an increase in the consumption dramatically. As shown with the energy management chapter made by the RETscreen tool, more than 40% of the energy consumed from the grid can be simply avoided by the installation of some technologies that are economically feasible for the consumer with a short payback period of 6.4 years, that may lead to the complete residential independency of energy from outside the community, or at least will make the community produce as much energy as it consumes, although the systems with no electrical storage would need the help of the grid to still sell the excess electrical energy produced to other commercials, agriculture or industrial institutes, or even nearby towns, as a substitute of the expensive electrical storage systems.

Appendix

Electrical load demand per dwelling

WEEKDAY SPRING/ AUTUMN					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Device Name	Place	Number	Stand-by Condition [W/ unit]	Working Condition [Watts/ Unit]																										
Washing machine	Kitchen	1	0	500																				500						
Microwave	Kitchen	1	0	1500							300									600										
Fridge	Kitchen	1	225	225	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75		
Light bulb	Bathroom	1	0	9							9												9							
Flat screen TV	Living	1	0	60																	60	60			60					
Light bulb	Bedroom	2	0	9																				18	18	18	18	18		
Light bulb	Kitchen	1	0	9							9										9	9								
Light bulb	Livingroom	4	0	9																	36	36	36							
Mobile		4	0	6	24																						24	24		
Wifi Adabtor		1	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5		
Labtop		4	5	50																		1500	200		1500	200				
Hair drier		1	0	1500						900																				
					104	80	80	80	80	980	398	80	80	80	80	80	80	80	80	680	185	1685	325	598	1658	298	122	122		8.115
					8123.12																									

WEEKEND SPRING/ AUTUMN					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Device Name	Place	Number	Stand-by Condition [W/ unit]	Working Condition [Watts/ Unit]																										
Washing machine	Kitchen	1	0	500																				500						
Microwave	Kitchen	1	0	1500									300							1500										
Fridge	Kitchen	1	225	225	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75		
Light bulb	Bathroom	1	0	9							9												9							
Flat screen TV	Living	1	0	60												60	60	60			60	60			60	60	60	60		
Light bulb	Bedroom	2	0	9	18	18																		18	18	18	18	18		
Light bulb	Kitchen	1	0	9																9	9	9	9							
Light bulb	Livingroom	4	0	9																36	36	36	36	36	36	36	36	36		
Mobile		4	0	6																							24	24		
Wifi Adabtor		1	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5		
Labtop		4	5	50											200					200	200						200			
Hair drier		1	0	1500											450	450														
					98	98	80	80	80	80	89	80	380	80	730	590	140	140	80	1825	385	185	134	634	194	194	418	218		7012

WEEKDAY WINTER					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Device Name	Place	Number	Stand-by Condition [W/ unit]	Working Condition [Watts/ Unit]																										
Washing machine	Kitchen	1	0	500																				500						
Microwave	Kitchen	1	0	1500							300									600										
Fridge	Kitchen	1	225	225	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75		
Light bulb	Bathroom	1	0	9						9	9												9							27
Flat screen TV	Living	1	0	60																	60	60			60					180
Light bulb	Bedroom	2	0	9																18	18	18	18	18	18	18	18	18		162
Light bulb	Kitchen	1	0	9						9	9									9	9	9	9							54
Light bulb	Livingroom	4	0	9																36	36	36	36							144
Mobile		4	0	6																	24	24	24							72
Wifi Adabtor		1	0	5																							5	5		10
Labtop		4	5	50	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5		120
Hair drier		1	0	1500																					1500	1500				3000
Hair drier		1	0	1500						150																				150
					80	80	80	80	80	248	398	80	80	80	80	80	80	80	80	743	227	227	176	598	1658	1598	103	103		7.119

WEEKEND Winter					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Device Name	Place	Number	Stand-by Condition [W/ unit]	Working Condition [Watts/ Unit]																										
Microwave	Kitchec	1	0	1500										150				150	150							150				600
Fridge	Kitchec	1		225	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75		1800
Light bulb	Bathroo	1		9										9									9	9						27
Flat screen TV	Living	1		60											60	60	60			60	60	60			60	60	60	60		600
Light bulb	Bedroom	2		9	18	18														18	18	18	18	18	18	18	18	18		198
Light bulb	Kitchen	1		9																9	9	9	9							36
Light bulb	Livingroom	4		9	36															36	36	36	36	36	36	36	36	36		360
Mobile		4		6																							24	24		48
Wifi Adabtor		1	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5		120
Labtop		4	5	50											200					200	200						200			800
Hair drier		1	0	1500											450	450														900
					134	98	80	80	80	80	80	80	80	239	790	590	140	230	230	403	403	203	152	143	194	344	418	218		5.489

WEEKDAY Summer					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Device Name	Place	Number	Stand-by Condition [W/ unit]	Working Condition [Watts/ Unit]																										
Washing machine	Kitchen	1	0	500																				500						
Microwave	Kitchen	1	0	1500							300									600										
Fridge	Kitchen	1	225	225	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75		
Flat screen TV	Living	1		60																	60	60			60					180
Light bulb	Bedroom	2		9																		18	18	18	18	18	18	18		189
Light bulb	Kitchen	1		9						9	9										9	9								36
Light bulb	Livingroom	4		9																	36	36	36							108
Mobile		4		6																							24	24		48
Wifi Adabtor		1	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5		120
Labtop		4	5	50																		200	200			200				600
Fan	Living	1	35								35										35	35	35	35	35					210
Fan	Bedroom	2	35		70	70	70	70	70	70																70	70	70		945
Hair drier		1	0	1500						300																				300
					150	150	150	150	150	459	424	80	80	80	80	80	80	80	80	680	220	438	369	633	193	368	192	192		5.558

WEEKEND Summer					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Device Name	Place	Number	Stand-by Condition [W/ unit]	Working Condition [Watts/ Unit]																										
Microwave	Kitchen	1	0	1500										150				150	150							150				
Fridge	Kitchen	1		225	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75		
Light bulb	Bathroom	1		9										9									9							
Flat screen TV	Living	1		60											60	60	60				60	60			60	60	60	60		24.618
Light bulb	Bedroom	2		9										18								18	18	18	18	18	18	18		
Light bulb	Kitchen	1		9																	9	9								
Light bulb	Livingroom	4		9																	36	36	36	36	36	36	36	36		
Mobile		4		6																							24	24		
Wifi Adabtor		1	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5		
Labtop		4	5	50											200					200	200						200			
Fan	Living	1	35								35	35	35	35	35	35	35	35	35	35	35	35	35	35	35					
Fan	Bedroom	2	35		70	70	70	70	70	70																70	70	70		
Hair drier		1	0	1500											450	450														900
					150	150	150	150	150	150	115	115	115	292	825	625	175	265	265	315	420	238	178	169	229	414	488	288		6431

Yearly	112.5	101.357	97.5	97.5	97.5	504.107	315.571	82.5	125.357	106.5	276.786	228.214	99.6429	112.5	103.929	808.964	259.679	778.464	256.107	546.25	980.607	539.357	220.679	163.536		2560514.107
Yearly Average Consumption	40950	36894	35490	35490	35490	183495	114868	30030	45630	38766	100750	83070	36270	40950	37830	294463	94523	283361	93223	198835	356941	196326	80327	59527	0	2553499