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LIFE SUSTAINHUTS: SUSTAINABLE MOUNTAIN HUTS IN EUROPE

C7.1 Final guideline: "Introduction to renewable energies and hydrogen technologies on extreme environments".

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Executive Summary

LIFE SustainHuts is a demonstrative project which aims to reduce the environmental impact of the energy consumption in mountain huts deploying renewable energy-based solutions, efficiency measures and renewable energy storage by means of hydrogen.

The aim of this guide is to present, on the one hand, the most common renewable energy production technologies in terms of their application to mountain shelters, complementing this description with renewable energy storage technologies, which is a very important aspect to take into account in this type of facility. In addition, and as a particular case of energy storage, the role that hydrogen can play as a seasonal storage of large amounts of renewable energy is described.

This guide also includes a section dedicated to the description of the methodology used in this project to carry out the energy analysis in the facilities.

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1 Introduction

Global warming has been for years one of the most important issues to be taken into high consideration, both in EU and internationally. In this regard, in order to keep the global temperature increase below 2 ºC by 2050, the EU has established the objective of reducing greenhouse gases emissions by 80 % taking as reference GHG levels from 1999, by 2050.

SustainHuts is well aligned with all these objectives. Measures to increase the energy resilience of mountaineering tourism infrastructure are vital for the development of mountainous regions. Recent studies show that the energy sector, notably the electricity sector, has a great impact on climate change, so it is suggested the need to adapt that sector.

Mountain huts are usually isolated from heating and electricity grids due to its location. Because of this, their energy supply mainly relies on fossil-fuel powered generators and boilers. Equipment and fuel are often supplied by helicopter, which is an expensive means of transport and another source of CO_2 emissions and pollution. In addition, the huts made of stone are often highly energy inefficient (due to lack of thermal insulation with the environment), so the energy consumption increases.

The development of energy-saving measures that significantly improve the sustainability and resilience of the off-grid mountain sector will contribute not only to the EU climate change mitigation strategy but also to nature conservation and biodiversity objectives. Achieving sustainable and nearly zero-emissions mountain huts will bring biodiversity benefits due to the natural zones where huts are located, including Natura 2000 network sites and biosphere reserves.

The document reports a brief introduction regarding renewable energies with the focus on innovative hydrogen energy storage applied in Bachimaña hut.

Then, an extended description of all steps necessary to carry out SUSTAINHUTS is clearly developed.

2 Mountain huts

A mountain hut is usually an isolated construction in the mountains with limited or difficult access. In addition to all general goods needed for mountain hut operation, one of the main challenges is the transport of the fuels for hut's energy supply from the valleys to the hut.

Nowadays systems providing energy (electricity, heat) in the mountain huts are mainly fossil fuel-based with diesel generator. Due to the difficult access, the fuel is supplied by helicopter in many cases, that means sky-scraping fuel consumptions (100 – 300 litres per hour) and high costs (30 €/minute). In addition, high production of GHG emissions occurs just with transportation. Moreover, huts are mainly located in natural parks where pollution is a critical factor, so policy makers look for the best measures to prevent deterioration and contamination of natural habitats and wild fauna and flora. The constructions of the huts are mainly stone-based well-prepared for the extremely snow conditions, but not energy-efficient buildings.

Measures to increase the energy resilience of mountaineering tourism infrastructure are vital for the development of mountainous regions. Recent studies suggest important impacts of climate change on the energy sector and underpin the need for adaptation, notably in the electricity sector. Mountain huts are usually isolated from heating and electricity grids. They depend on fossil-fuel powered generators and boilers. Equipment and fuel are often supplied by helicopter, a costly means of transport and another source of CO_2 emissions and pollution. The huts, being made of stone, are often highly energy inefficient.

LIFE SUSTAINHUTS aims to reduce CO_2 emissions sourced from buildings in isolated environments, such as mountain huts. According to this, the final objective of the project is to prevent air pollution, preserve mountainous forests, promote sustainable tourism and introduce environmentally friendly methods for the production, distribution and use of energy.

3 Renewable energies for mountain huts

This section reports the results of a survey which was conducted among hut's users in order to reflect their knowledge on renewable energy sources. After that a short view of the main renewable energy sources installed and applicable for off grid huts is reported.

3.1 Renewable energies knowledge survey

The chapter reports the survey's results on renewable energies knowledge. The survey was proposed during SustainHuts project, and it was useful to collect **"sentiment on green technologies" and renewable energies** (including hydrogen technologies, new insulation materials, energy efficiency plants, wind turbine,.) and so the level of knowledge from mountaineering associations, hut owners and related staff. The results coming from the survey will be useful to implement the technologies and to disseminate the green technologies installed and monitored in the huts.

The keys to collect information on sentiment on green technologies include: identification of the respondents, distinguishing between mountain tourism associations, members of mountaineering associations, hut owners and manager of the hut/internal staff of management.

Mountain tourism associations. This group includes mountain associations meant as entities offering leisure or sports activities. Networks of huts are usually managed by these associations, which are in charge of all the administrative and economic issues including new investments, energy supply, personnel contracts.

Members of mountaineering associations have access to the huts, can take part in the variety of mountaineering activities, use discounts on accommodation in mountain lodges, take out different types of insurance and enjoy benefits in the purchase of mountaineering equipment.

Huts owners and related staff manage and operate one or several huts in an isolated way without being part of a network in an association. Huts owners assume the same responsibilities as mountain associations.

Below the main results on different aspects.

The first part of the survey has been devoted to evaluate general knowledge on the sustainable **"green" technologies**, and the dependency between interest in sustainable technologies, climate actions and willingness to implement those solutions. The first parameter was the sentiment on climate change illustrating how much the correspondents are concerned about involved in the environmental and climate issues. It was measured on a scale from 0 to 10, where 0 means that the interviewee has no interest in climate change and 10 being very interested in the climate actions.

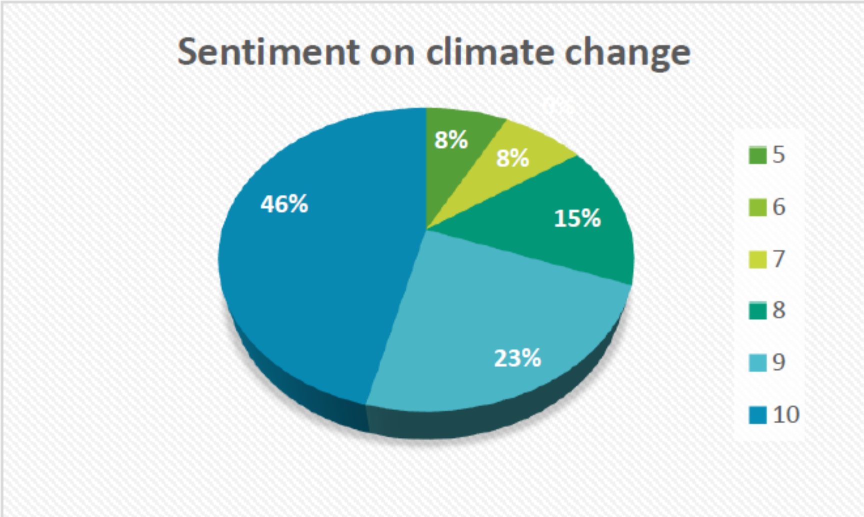


FIGURE 1. SENTIMENT ON CLIMATE CHANGE

The study has been based on the preliminary survey done at the beginning of the project in 2017 (see A1.3 report). Nevertheless, the sample and boundary conditions differ significantly, thus any reference done between those two studies might carry considerable measurement error and uncertainty. Although conducted on significantly reduced group of correspondents, with regard to initial survey, the results show that the investigated groups of stakeholders have some considerable interest in the climate change and almost half of the interviewed is very involved in the climate change issues (see Figure 1). This conclusion might come from the fact that the investigated group of various stakeholder is closely involved in the mountain hut life and thus has the sense of the importance of environment and nature preservation.

The following question served to evaluate the level of knowledge on various types of renewable technologies including photovoltaics (PV), micro wind turbine technology, hydrogen technologies, mini hydroelectric power, biomass for heating, and new insulating materials. To the question it has been assigned a reference scale from 0 to 10, respectively meaning no knowledge or very good knowledge regarding given type of renewable technology. The Figure 2 shows the average knowledge score assigned to each technology among all the respondents.

According to the results, it is concluded that the best known technology is PV, while the least known technology seems to be hydrogen technology. This phenomenon could be associated with the maturity of both technologies. On one side, PV technology and products were available on the markets for the first time some decades ago from now. On the other side, hydrogen technology for energy production is still under development and just entering the market.

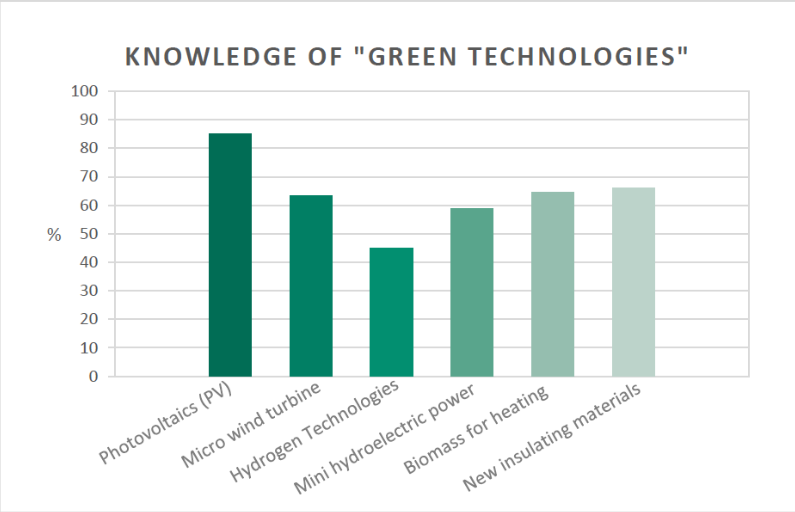


FIGURE 2. KNOWLEDGE OF "GREEN TECHNOLOGIES"

A similar trend is observed regarding the perception of the emissions reduction potential of each technology. Although many respondents selected PV as technology with considerable emissions reduction potential, the majority chose new insulating materials as best solution to curb emissions (see Figure 3).

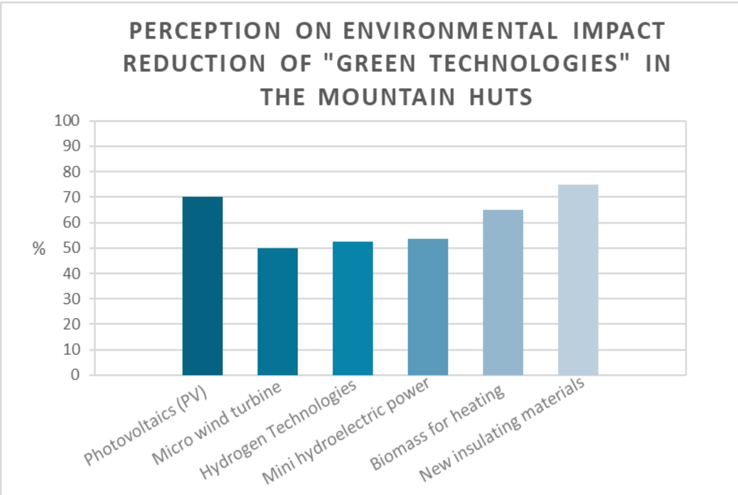


FIGURE 3. PERCEPTION ON ENVIRONMENTAL IMPACT REDUCTION OF "GREEN TECHNOLOGIES"

The last part of the section faces the willingness to deploy each technology. The results reflect the dependency between level of knowledge on given technology and the tendency to implement the considered technology. The better is a technology known, the more prone to implement it the correspondents are. In this ranking the preferred choice was the PV technology while the least voted technologies were hydroelectric and hydrogen technologies (see Figure 4). These results show the importance of disseminating the results and raising awareness and level of knowledge on innovatory sustainable solutions.

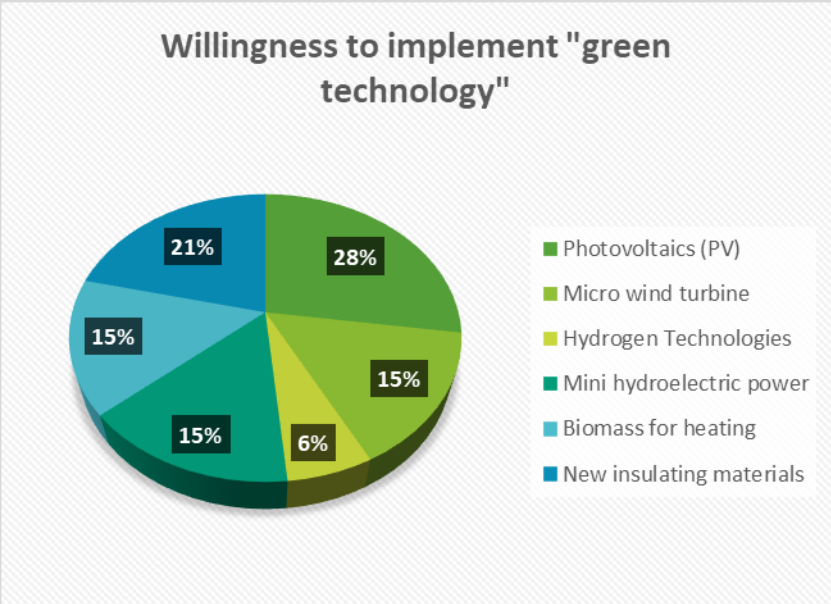


FIGURE 4. WILLINGNESS TO IMPLEMENT "GREEN TECHNOLOGY".

3.1.1 Socio-economic assessment

The aim of the socio-economic assessment is to evaluate the social and economic benefits that SustainHuts project implemented measures brough to the hut community. It consists of three main sections distinguishing the social benefits, environmental benefits, and economic benefits that the LIFE SustainHuts Project brought to the investigated mountain huts.

In this context, the term social benefit can be understood as an improvement in the conditions related to broadly understood social area owing to the actions taken under the SustainHuts project. For the sake of this study, the potential social improvements occurring in the mountain hut environment have been selected and presented in Table 1. The second column shows the percentage of people surveyed that perceive an improvement thanks to measures deployed.

The study on social benefits shows the improvements in almost all the investigated aspects, as the percentage of responders agreed has been 50% or higher. The highest consensus has been observed in the energy access improvement (83.3%), which could be a reason for a higher comfort living perception (75%). The least improved sub-category was the maintenance time of energy equipment (41.7%). The remaining indicators have been subjected to slight advance. However, this minor improvement might be explained for the fact that initial conditions of the investigated areas were very satisfactory before the introduction of SustainHuts Project. The overall improvement on the social background was on average of 61.9%.

Social Benefits of LIFE SustainHuts project	
Potential improvement	*Percentage of responders agreed*
2.1 Increased efficiency in domestic work	66.7%
2.2 Improved hygiene and health conditions	58.3%
2.3 Reduction of maintenance time of energy equipment	41.7%
2.4 Increased comfort of living in the shelter	75.0%

2.5 Increased time of operation of the hut over the year	50.0%
2.6 Improved access to energy	83.3%
2.7 Improved access to water	58.3%

TABLE 1. SOCIAL BENEFITS OF LIFE SUSTAINHUTS PROJECT.

Regarding the environmental benefits of SustainHuts Project, the most scored indicator was observed in the reduction of fossil fuel consumption (83.3%), which corresponds to main purpose of the Project being fulfilled. It can also be observed that the reform conducted in the huts had a positive impact (58.3%) on the decrease of the overall energy consumption, which results from the actions introduces in each hut which aimed at microgrid optimization. A considerable positive impact of 75% has been observed regarding the reduced need for fuel and water transport, which is strongly connected with the previously mentioned indicators. This aspect is of great importance, since transport of energy resources such as diesel fuel and access to water were a major problem in many huts, which generate high costs and emissions resulting from the need of transport of those resources to the hut. The reform had rather marginal impact on the wildlife and biodiversity of the mountain huts, which at the same time indicates the conservation of natural habitats and minor impact coming from the reduction of fossil fuels usage and introduction of renewable, environmentally friendly solutions. The low noise reduction percentage as well results from the initial huts conditions and regulations in the nature reserves. The overall, average improvement of the environmental impact corresponds to 58.3%.

Environmental Benefits of LIFE SustainHuts project	
Potential improvement	*Percentage of responders agreed*
3.1 The consumption of fossil fuels in the hut has decreased	83.3%
3.2 The reform had a positive impact on the visual aspect of the environment.	50.0%
3.3 The reform had a positive impact on wildlife and biodiversity.	41.7%
3.4 Energy consumption for heating has decreased.	58.3%
3.5 The need for fuel/water transportation has decreased or has been reduced completely.	75.0%
3.6 Noise level has been reduced	41.7%

TABLE 2. ENVIRONMENTAL BENEFITS OF LIFE SUSTAINHUTS PROJECT.

Last section has been devoted to economic benefits of LIFE SustainHuts Project on the mountain huts in Europe. This category has been limited only to the expenditures and tendency to invest in renewable technologies inside the hut community. The results show (see Table 3) that the reduction in expenditures is strongly connected with the actions undertaken in the SustainHuts project and are linked with the environmental and social benefits. The highest improvement has been observed on the energy background while water resources would require further improvements as it was also visible on example of previous categories. The positive phenomenon has been observed, as the users are now more prone to invest more in renewable technologies. This fact results from the higher knowledge regarding green technologies which improved significantly in comparison with the status before the Project´s introduction. Concerning the economic benefits, the Project brough to the hut community, the overall weighted impact is equal to 50%.

Economic Benefits of LIFE SustainHuts project	
Potential improvement	*Percentage of responders agreed*
4.1 Energy expenditures have decreased	58.3%
4.2 Water expenditures have decreased	25.0%
4.3 Willingness to invest in green technologies	66.7%

TABLE 3. ECONOMIC BENEFITS OF LIFE SUSTAINHUTS PROJECT.

In the light of the socio-economic study results, the greatest SustainHuts Project's positive impact was on the social scope, since the overall agreement score is 61.3%. The least impacted category was the economic aspect of the mountain huts community. Nevertheless, in each category a positive impact and improvement of at least 50% has been achieved. This indicates the importance and beneficial impact of the renewable, sustainable technologies being introduced in isolated facilities such as mountain huts. Moreover, the role of dissemination and promotion of the actions undertaken over the LIFE SustainHuts Project has been visible as the general knowledge of renewable technologies and climate actions has improved among the hut community. However, future dissemination actions and promotion are of paramount importance in order to increase the awareness of the benefits and importance of hydrogen technology and other emerging sustainable solutions. Although the main objective of the Project was to curb emissions from fossil fuels, it is undeniable that the Project also brought other side benefits to the hut community on various levels. The introduced actions contributed to the increase of comfort and quality of living, at the same time upgrading the status of mountain huts, which will contribute to greater interest from the user side and raised frequency of visits.

3.2 Renewable energies applied on off-grid installations

Remote off-grid mountain huts are specific microgrid systems which are usually located in sounder environment. As they are not connected to utility grids, they require own energy supply for both heat and electricity. While heat is typically provided by fossil fuels and/or biomass, electricity is mainly provided by fossil fuels, since the most widely used devices are diesel generators. The Figure 5 reports the main technologies applied in off-grid applications and applied in SustainHuts.

Renewable technologies are PV, mini-hydraulic, mini-wind, solar thermal and pellet stove, since they are powered by renewable energy sources such as solar radiation, water, wind and biomass. It must be noted that biomass is a renewable source if it is exploited in a sustainable way. Hydrogen is not an energy source, but an energy carrier (such as electricity). If it is obtained by means of one of the renewable technologies mentioned, it can deliver renewable energy. The most common way of producing renewable hydrogen is by water electrolysis, which requires electricity supplied by PV, hydropower or wind-power. Regarding novel insulation, it is a technology that reduces thermal losses and, therefore, improves building efficiency decreasing its thermal energy demand.

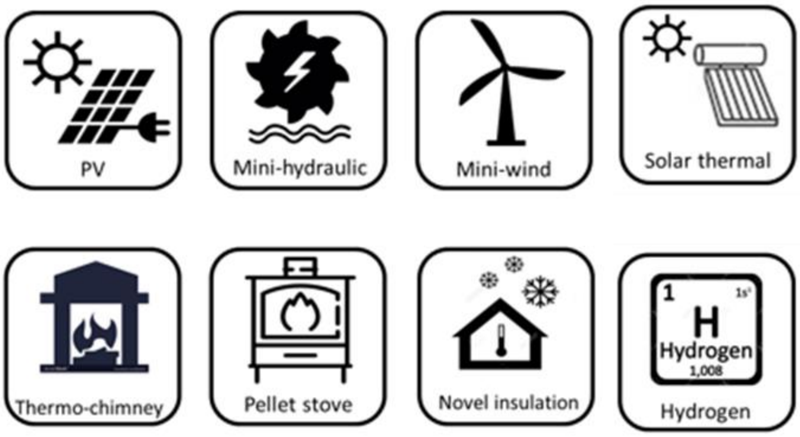
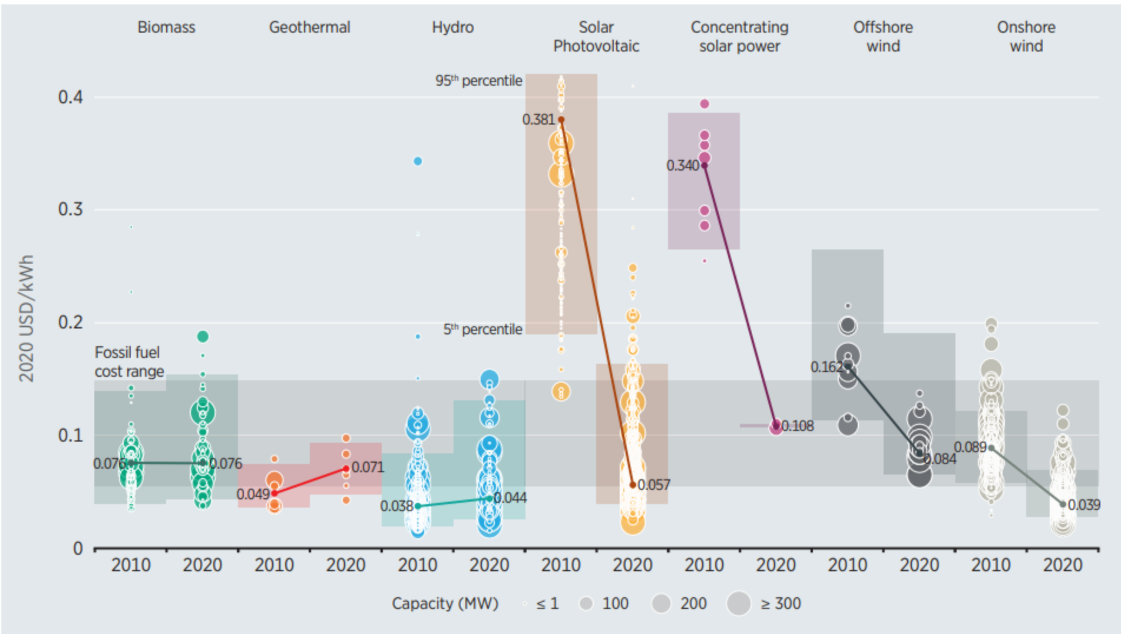


FIGURE 5. TECHNOLOGIES APPLIED IN SUSTAINHUTS.

A short explanation of each technology and the current status in Europe[1]. Figure 6[2] shows price trend of renewable power generation. Although is referred to a scale higher than the scale required in mountain huts, it gives a comprehensive insight of the current status.



Source: IRENA Renewable Cost Database

Note: This data is for the year of commissioning. The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y-axis. The thick lines are the global weighted-average LCOE values for plants commissioned in each year. Real WACC was 7.5% in 2010 and 5% in 2020 for OECD countries and China, and 10% in 2010 and 7.5% in 2020 for the rest of the world. The single band represents the fossil-fuel fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

FIGURE 6. GLOBAL LEVELIZED COST OF ENERGY FROM NEWLY COMMISSIONED, UTILITY-SCALE RENEWABLE POWER GENERATION TECHNOLOGIES, 2010-2020.

[1] EurObserv'ER. (2019). *The State of Renewable Energies in Europe.* From https://www.eurobserv-er.org/19th-annual-overview-barometer/

[2] https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020

3.2.1 Photovoltaic

PVs panels use solar electric cells that convert solar radiation directly into electricity. Individual PV cells are arranged into modules (panels), and they can be connected in series (to increase output voltage) or in parallel (to increase output current). The output is DC (Direct Current) power; therefore, an inverter (DC/AC converter) must be installed if AC (Alternating Current) power is needed.

High temperatures have a negative impact on PV efficiency. Figure 7[3] shows the evolution of the output power at different temperature and radiation conditions. For the same radiation, the electric production is lower when the temperature is higher.

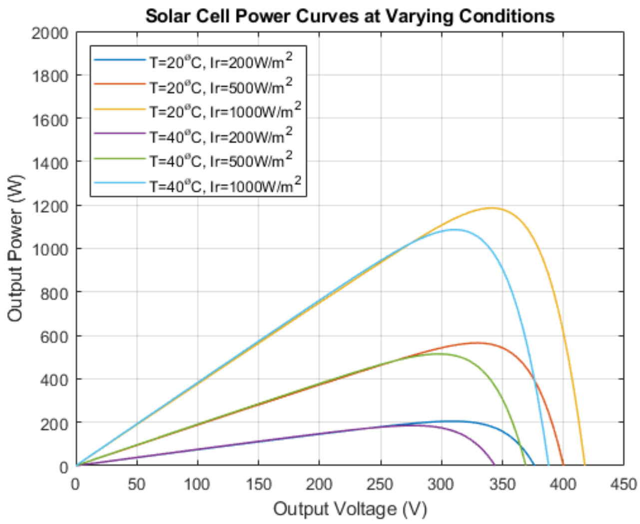


FIGURE 7. EFFECT OF TEMPERATURE AND RADIATION IN PV CELLS PRODUCTION

Renewable energy sources like solar PV and wind are intermittent sources, depending on daily and seasonal weather. Although they can be forecasted with some precision, they are not manageable, so the installation of energy storage technologies is usually required in off-grid systems, such as mountain huts. Batteries are the most widely used type of electric storage in this kind of applications. Batteries can charge during off-peak periods and be discharged at times of peak demand a few hours later, using stored energy from either the grid itself or supplemental energy sources to respond to demand increases.

With the growing deployment and development of PV technologies in the last years, new PV technologies have emerged. Those are bifacial and hybrid modules.

Bifacial modules are provided with photovoltaic cells in both faces of the panel, so they are able to collect the direct radiation coming from the sun, but also the ground-reflected radiation. Thus, the output power per square meter is greater, what makes it suitable for limited-space

[3] https://es.mathworks.com/help/physmod/sps/ug/solar-cell-power-curve.html

situations. However, they are more expensive than conventional modules and the backside face's production is lower than the frontside, since energy potential of reflected radiation is lower.

A hybrid solar panel is capable of simultaneously generating electricity and hot water. It achieves this by having photovoltaic cells that produce electricity and, on the same panel, a hydraulic system that heats the water. The global efficiency of hybrid panels is greater than conventional panels, since the same radiation received from the sun produces two types of energy: electric and thermal. Moreover, the electric efficiency of PV cells is improved because the hydraulic system removes the heat released by PV cells and keeps them cooler.

When a solar system is designed, the optimal position of the panels depends on the location. The main position parameters that must be selected are azimuth and tilt angles (see Figure 8[4]). For example, if the facility is located in the northern hemisphere, the panels should be oriented to the south. Sometimes there are restrictions, for example, when the panels are installed on the top of a roof, the tilt angle may be fixed previously.

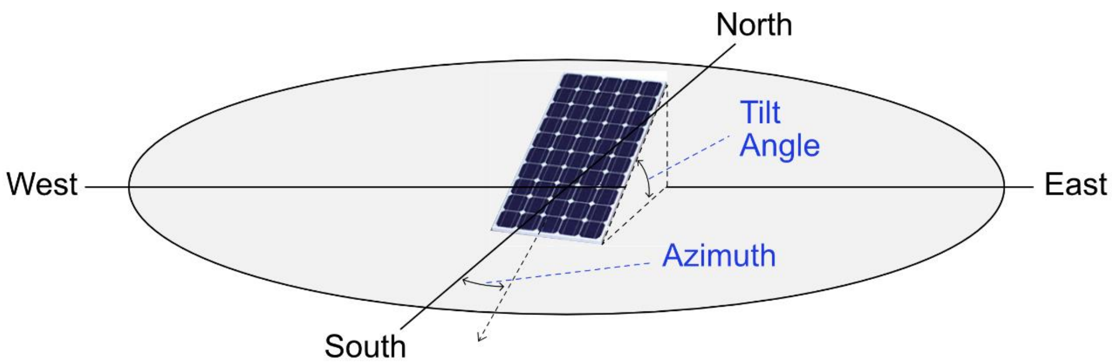


FIGURE 8. TILT AND AZIMUTH ANGLES.

The PV production is maximized with a solar tracking system that allows to change the angles in order to track the sun trajectory (see Figure 9). There are 3 possible angles that can be modified and, thus, 3 possible rotation axes, which are depicted in Figure 10. The first one is a vertical axis and allows to change the azimuth angle; the second one enables tilt-axis modification and the third one allows to track the East-West daily trajectory of the sun. Tracking systems can be single- axis or dual-axis. However, tacking systems are expensive and require more maintenance than fixed installations, so the fixed solution is usually preferred in off-grid systems.

[4] https://solardesignguide.com/solar-panel-tilt-and-azimuth/

PV systems are suitable for mountain huts because the peak demand occurs during lunch time hours and coincides with PV generation period. Nevertheless, huts are usually surrounded by mountains that shade the panel array and diminish PV power.

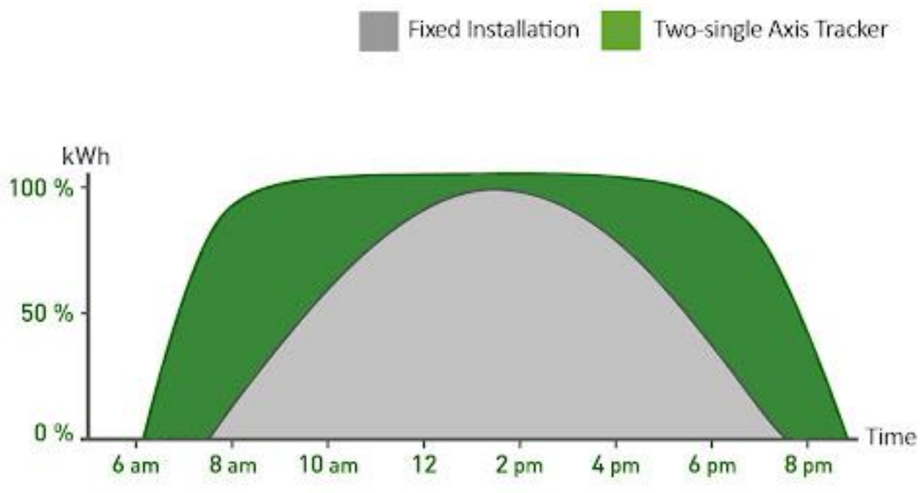


FIGURE 9. FIXED AND TWO-AXIS TRACKER PV PRODUCTION COMPARISON.

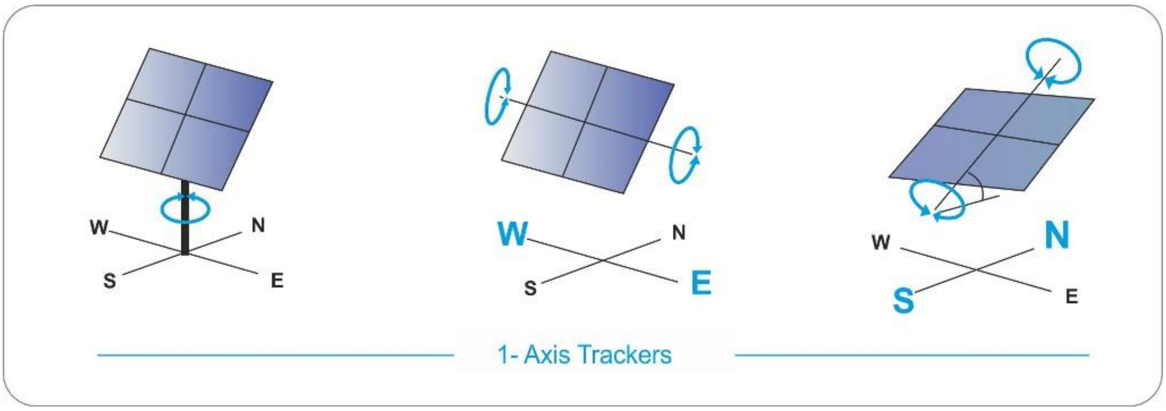


FIGURE 10. PV ROTATION AXES.

3.2.2 Windpower

Wind turbines use blades to collect the wind's kinetic energy. Wind flows over the blades creating lift, which causes the blades to turn. The blades are connected to a drive shaft that turns an electric generator, which produces electricity. The output is AC power; thus, a rectifier (AC/DC converter) must be installed if DC power is needed.

Wind energy is a reliable and well-known technology, since is one of the main sources of power generation in several European countries. Wind resource distribution is more homogeneous in space and time than solar but is less predictable.

It is desirable to find places like plains to avoid wind flow disturbances (for this reason offshore wind is interesting) or to install wind generators at the top of hills where wind speed is higher. Wind velocity also increases in valleys. The higher is the hub of the wind turbine from the ground, the higher is the wind speed, since the air close to the ground is slowed down due to the friction. In Figure 11 is shown that, in a plain terrain like open lands, the maximum speed is reached at a lower height than in a place with obstacles like a city core. When installing several wind turbines in the same place, there must be a minimum distance (usually 8-12 times the rotor diameter) behind one wind turbine and the following to avoid the turbulence created by the rotation of the blades. Turbulent flow compromises wind generator's mechanical stability.

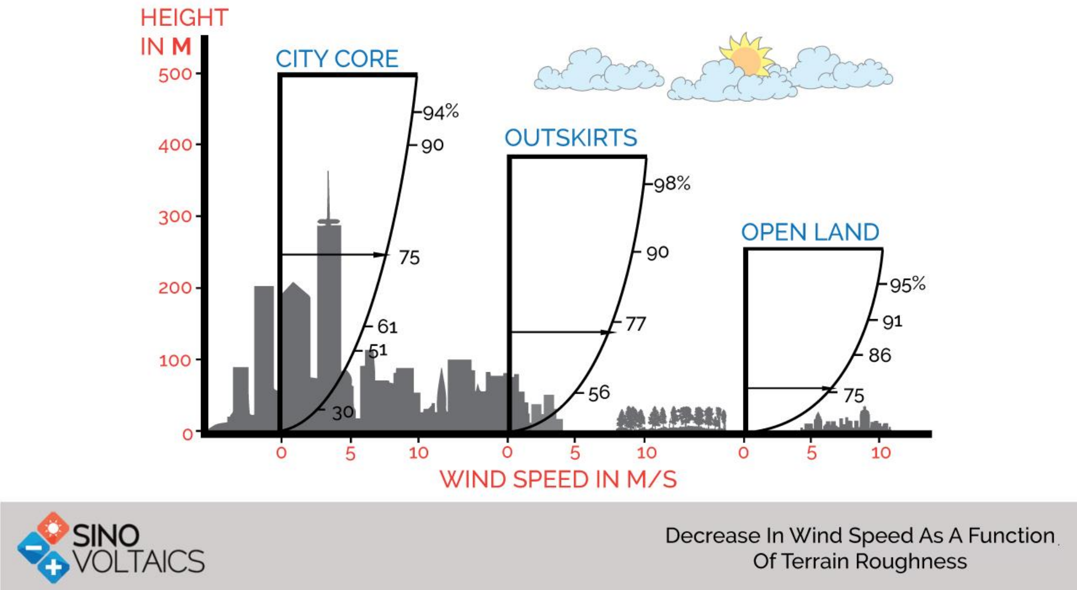


FIGURE 11. WIND SPEED PROFILES AS A FUNCTION OF TERRAIN ROUGHNESS AND HEIGHT.

In order to assess the wind power potential of a place, a data collection campaign is needed, otherwise, wind data from near places is used. Some of the measuring instruments are:

- Anemometer to measure wind speed.
- Wind vane to collect wind speed direction.
- Thermocouples to measure air temperature and estimate air density.
- Barometer to register the atmospheric pressure and estimate air density.

The higher is the air density, the higher is the wind potential. Air density increases with atmospheric pressure and decreases with temperature and those parameters change with altitude. At higher altitude, pressure and temperature decrease.

There are two main groups of wind turbines: horizontal-axis wind turbines and vertical-axis wind turbines (see Figure 12[5]). Vertical-axis are simpler because do not need a device to point the axis toward the wind, but they are less efficient than the horizontal-axis ones, however, Windside turbines -thanks to their aerodynamic design- reach efficiency values close to horizontal-axis. At high scales (MW), three-blade horizontal-axis turbines are the most common.

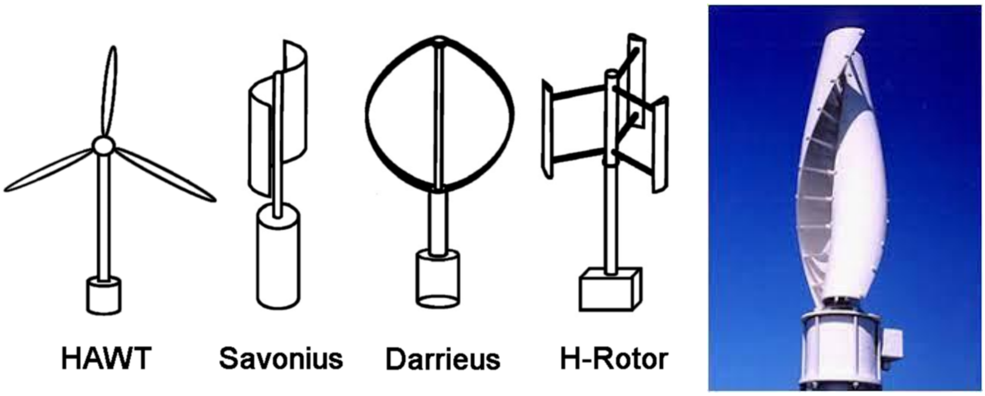


FIGURE 12. SCHEMATIC OF HORIZONTAL-AXIS AND VERTICAL AXIS (SAVONIUS DRAG-BASED, DARRIEUS CURVED-BLADE, GIROMILL H-ROTOR AND WINDSIDE) WIND TURBINES.

Wind turbines include a generator that transforms mechanical energy into electricity. The most used are AC three-phase generators, but low power wind turbines also use DC generators.

Manufacturers provide the power curve which relates the power output to the wind speed. As can be seen in Figure 13, power is not produced until the cut-in speed is reached (usually 3-5 m/s) and the wind turbine stops when the speed surpasses the cut-out speed in order to avoid mechanical strain.

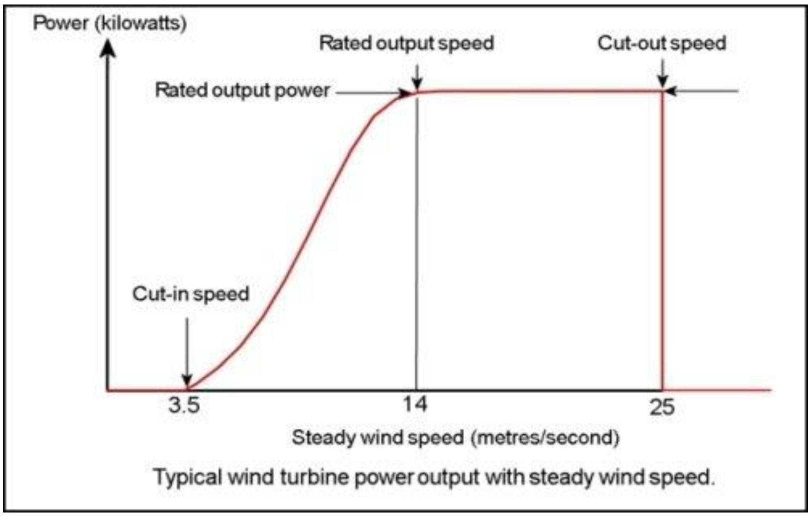


FIGURE 13. WIND TURBINE POWER CURVE.

[5] Mehrpooya, Payam. (2014). IMPROVEMENT OF VERTICAL-AXIS WIND TURBINE PERFORMANCE VIA TURBINE COUPLING. 10.13140/RG.2.2.13616.76808.

In off-grid facilities, mini or micro wind turbines are used. Some manufacturers are given below:

- Primus Wind Power
- Bornay
- Enair
- Bergey
- China Hummer

Micro wind turbines	< 1 kW
Mini wind turbines	< 10 kW
Midi wind turbines	< 100 kW

TABLE 4. WIND TURBINE CLASSIFICATION BY POWER RANGE.

When the batteries (or other kind of energy storage as hydrogen) are full, they should be disconnected to prevent overcharging and damage. However, if the batteries are the only load and they are disconnected, the wind turbine will start running at high-speed freewheeling and will cause high voltages because it is working without a load (open circuit). The mechanical load that an alternator puts on the shaft depends on the current taken from the alternator. If there is no current (open circuit), then the alternator spins more freely, with only a bit of friction. This can cause mechanical damage since the turbine is spinning too fast without restrictions, and especially when the charge controller reconnects the wind turbine to the battery to recharge it. Sudden changes in the electrical load cause mechanical shocks in wind turbines, thus, they should be avoided.

Therefore, it is needed to divert the excess power not absorbed by the batteries to a separate load, so the wind turbine will not go into high-speed freewheeling in heavy winds. That is where a dump load (also called a divert load) comes in. The charge controller will switch from battery charging to sending power to the dump load to keep the wind turbine under load.

Not using a reliable dump load, or no divert load at all, can cause serious heat buildup in the wind turbine motor which could ultimately cause the motor to overheat, seize up, and burn out the stator. Dump loads are usually electrical resistances that convert excess electricity into heat. If the heat is not used, energy will be wasted, however, it is worth it because avoids possible damages.

To protect the wind turbines from heavy winds, a break switch is usually installed as well. This switch causes a short-circuit and avoids the turbine from spinning. It is important to note that the switch should only work if the turbine is in stop mode. If the switch turns off while the turbine is working, the short-circuit will cause a high current that could damage the facility. Therefore, the break switch should be used when a storm is forecasted or during maintenance labors as a prevention measure, not as a correction measure.

3.2.3 Hydropower

Hydropower is electricity produced from flowing water. There are two general types of hydropower: **Conventional hydropower** uses water in dams or flowing in streams and rivers to spin a turbine and generate AC power. **Pumped storage systems** use electricity (renewable energy surplus or electricity from the grid during cheap hours) to pump water from a reservoir to another reservoir at higher elevation.

The key component of a hydropower facility is the turbine. There are different kinds of turbines and each type is capable of handling different flow rates and pressure heads. In fact, turbines are selected according to those two parameters, as can be seen in Figure 14.The main types of turbines are Kaplan, Francis and Pelton.

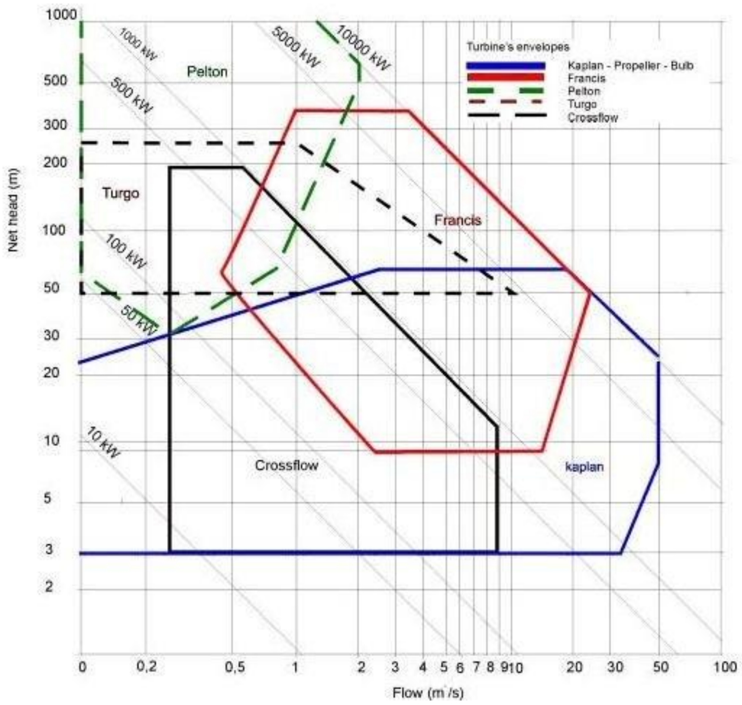


FIGURE 14. TURBINE SELECTION CHART BASED ON HEAD AND FLOW RATE.

In order to estimate the electricity that can be produced in a place through a hydropower facility, flow duration curves are used, like the one depicted in Figure 15. It shows the number of days that the mean daily flow rate is above a certain value and it can be seen that the available flow rate does not match the usable flow rate. The reason is that there must be always a minimum flow to preserve biodiversity (called ecological flow). Furthermore, the turbine can operate between two flow values: the nominal flow and the minimum flow (see red stripped region in Figure 15). The lower threshold (minimum flow) is usually expressed according to the nominal flow $Q_{min} = k \cdot Q_{nom}$ where k is a constant that depends on the kind of turbine:

- Pelton: k = 0.10
- Kaplan: k = 0.25
- Francis: k = 0.40

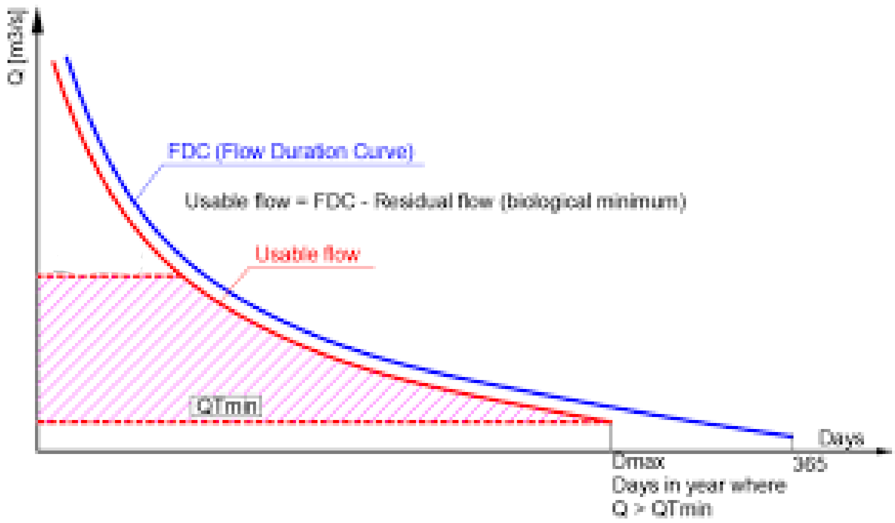


FIGURE 15. FLOW DURATION CURVE.

3.2.4 Solar thermal

Solar thermal systems use radiation from the sun to produce heat. They can be classified into two wide groups. **Solar thermal systems** use solar collectors to absorb solar radiation to heat water or air for space heating and water heating. **Solar thermal power plants** use concentrating solar collectors (parabolic collectors or solar towers with a mirror field) to focus the sun's rays to heat a fluid to a high temperature. This fluid generates steam which is expanded in a turbine and produces mechanical work that is converted into electricity by means of and alternator. The concept is like a conventional steam cycle, but the heat is supplied from the sun in spite of being supplied from fossil fuel combustion. This kind of plants usually store thermal energy by means of molten salts in order to provide electricity during the night. Solar thermal power plants are used in large-scale energy production to deliver energy into the grid, so they are not the aim of this study, just are mentioned for the reader's information.

Solar thermal systems provide low-temperature heat (max 90ºC), so they are useful for space heating or domestic hot water demands. A water tank is installed to store thermal energy. Nevertheless, an auxiliary boiler is needed to support system and ensure the energy supply.

Solar collectors include an absorber that collects the sun's radiation and heats a fluid (energy carrier) inside a hydraulic circuit. The fluid (which is mainly water) transfers energy to the storage tank by means of a heat exchanger. If the weather is cold, the water of the hydraulic circuit is blended with an antifreeze to avoid water freezing. A diagram of the hydraulic circuit is shown in Figure 16.

Although is not depicted in Figure 16, solar thermal facilities require a dump load that protects the system, just like the case of wind turbines. If this heat is not removed, the hydraulic circuit will heat up and core components of the system (such as solar collectors) could break. The dump load consists of a heat exchanger that releases the excess heat to the environment. They usually include a fan that enhances the heat transfer power.

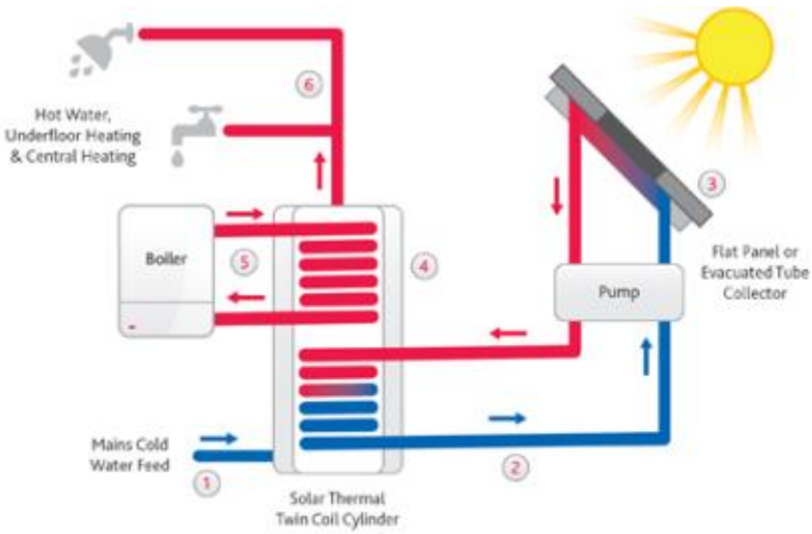


FIGURE 16. SOLAR THERMAL DOMESTIC HOT WATER SYSTEM.

There are two main groups of solar collectors for residential/commercial applications: flat-plate collectors and evacuated-tube collectors. To understand their benefits and drawbacks, a brief description of the possible energy losses is given below. There are two types of losses in a solar collector: optical losses and thermal losses. The first ones are related to the amount of radiation that the absorber receives. Since a collector includes several covers or layers that are not transparent, the sun's light that reaches the collector is reduced and this entails an energy loss. Thermal losses are linked to convection and radiation heat transfer between the collector and its surroundings. Flat-plate collectors have lower optical losses than evacuated-tube collectors but higher thermal losses. The reason is that evacuated-tube collectors consist of a set of modular tubes, where convective heat losses are minimized thanks to the vacuum in the tubes. Flat-plate collectors are the most used, but evacuated-tube collectors provide higher temperatures and are recommended if the weather is cold, thanks to their reduced convective losses.

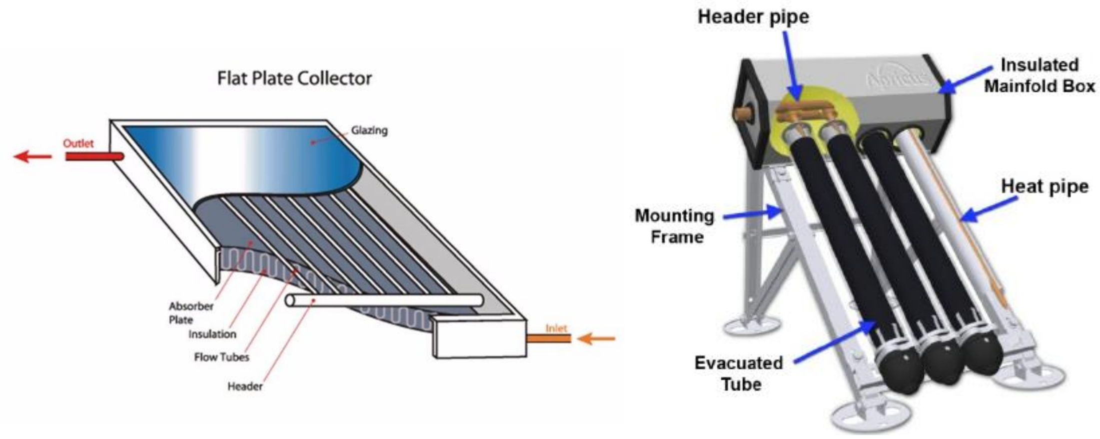


FIGURE 17. FLAT-PLATE COLLECTOR AND EVACUATED-TUBE COLLECTOR

3.2.5 Biomass

Biomass energy is produced from organic matter that comes from plant sources or animal sources. The biomass term is usually referred to plant sources since wood and wood waste are the best-known sources of biomass, but the cattle industry waste and municipal waste contain biomass from animal sources that is used to produce energy. However, these kinds of biomass are usually consumed in large-scale power plants or in the same place that is produced (in the case of cattle waste). Thus, regarding mountain huts, the most suitable kind of biomass is from plant sources.

Biomass is a clean energy source because the CO_2 that emits when burned has been previously captured by the plants from the atmosphere, so the net balance emissions is equal to zero. The only emissions that must be counted are those related to biomass managing processes such as cleaning, gathering, drying, transport etc. Biomass is a renewable source of energy provided that plant sources are sustainably exploited. Furthermore, the use of biomass could bring additional environmental benefits, for instance, the cleaning of forests avoids fire propagation and sometimes agricultural waste is burned on site to remove pruning waste so it could be used instead. Biomass consumption also enhances reforestation and forest care.

The European Union's solid biomass energy consumption trend is driven by its two main outlets – the supply of heat and the supply of electricity. The trend in heat supply, which is the main biomass energy recovery form, is particularly climate-sensitive during the heating season. There are different ways to use biomass: direct combustion in boilers, synthesis gas production through partial combustion, biofuels production… Nevertheless, the most common way in mountain huts is the supply of heat by means of direct combustion in boilers.

The main drawback of biomass is the supply chain. The energy density of biomass is low and usually contains high moisture levels, what increases transport and storage costs. Therefore, it must be dried and densified before it is delivered to the customer. Biomass is usually supplied in pellet or wood chips form especially at residential or commercial scale.

Figure 18[6] shows that biomass could be cheaper than fossil fuels like gasoil.

FIGURE 18. PRICE PER ENERGY UNIT COMPARISON BETWEEN GASOIL AND DIFFERENT TYPES OF BIOMASS (PELLET, OLIVE STONE AND WOOD CHIPS).

6 https://www.avebiom.org/biomasanews/avebiom/espana-tiene-biomasa-para-calentar-muchos-hogares-de-forma-segura-economica-y-limpia

3.3 Electricity storage

Electric energy cannot be stored by itself, since it must be consumed at the same time that is produced. This is the great drawback of electricity and renewable energies intermittency. Thus, electric energy must be converted into other type of energy (chemical, mechanical, thermal) to be stored. Below some examples are given, but there are others approaches [7] [8].

- Electrochemical
  - Lithium-ion: lithium-ion iron phosphate (LFP) batteries:
  - Lithium-ion: lithium-ion nickel manganese cobalt (NMC) batteries
  - Lead-acid batteries
  - Redox flow batteries (ZnBr, VRB and PSB)
  - Sodium-sulphur batteries (NaS)
  - Nickel-cadmium batteries (Ni-Cd)
  - Hydrogen energy storage system (electrolyzer + storage + fuel cell)
  - Supercapacitors
  - Metal-air batteries
- Electromechanical
  - Pumped storage hydro (PSH)
  - Compressed-air energy storage (CAES)
  - Flywheels

At large-scale, the most frequently kind of storage is electromechanical though PSH followed by CAES. However, they are limited to specific areas. Currently, the most suitable storage technologies for residential, commercial or industrial applications are Li-ion, Ni-Cd or lead-acid batteries. Nevertheless, they are used in short-term storage (like daily periods of time), but they are not recommended in long-term storage (like seasonal) due to they suffer from self-discharge. Moreover, they have short life-times due to fast degradation with the number of cycles. Hydrogen storage overcomes those issues but has a low efficiency in comparison.

3.3.1 Electric batteries

During the charging process of an electric battery, an electrochemical reaction takes place and electric energy is transformed into chemical energy to store it. To deliver electricity, batteries are discharged through the reverse reaction.

In the last years, Li-ion batteries are gaining importance. However, lead-acid are the most robust and the most used in PV off-grid systems. Batteries are usually characterized by two parameters that manufacturers provide in technical datasheets: energy capacity (kWh) and power or rate of charge/discharge (kW).

[7] Mongird, K., Viswanathan, V., Alam, J., Vartanian, C., Sprenkle, V., & Baxter, R. (2020). *2020 Grid Energy Storage Technology Cost and Performance Assessment*.

[8] Dufo-López, R., & Bernal-Agustín, J. L. (2014). *Techno-economic analysis of grid-connected battery storage*. https://doi.org/10.1016/j.enconman.2014.12.038

The most important concern for batteries is their cycle life. Each charging and discharging cycle has negative effects on the life. In order to extend the battery life, manufacturers provide a technical parameter called "Deep of Discharge" (DoD). This parameter describes the maximum allowed discharge level from a fully charged battery. For example, a battery with a capacity of 150 kWh and a DoD of 80% can deliver 120 kWh when it is fully charged. Therefore, the useful capacity is less than the purchased capacity. The higher the DoD is, the shorter the cycle life is (see Figure 19). To protect the battery from overcharging and over discharging, a charge regulator must be installed. The charge regulator manages the energy and decides whether battery is charged or discharged. Lead-acid and Li-ion properties are summarized and compared in Table 5.

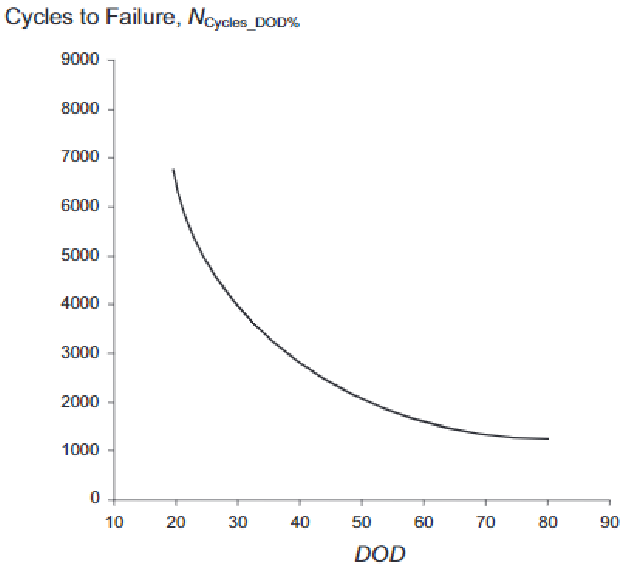


FIGURE 19. CYCLES TO FAILURE VERSUS DOD.

Performance parameters	Li-ion (Average value)	Lead-acid (Average value)
Specific Energy (Wh/kg)	151	30.58
Specific Power (W/kg)	229	181
Round trip Efficiency (%)	87.37	76.36
Service Life (Years)	12.67	8.75
Daily Self Discharge Rate (%)	0.17	0.2666
Energy density (kWh/m^3)	311.67	65.00
Power Density (kW/m^3)	1250.00	75.00
Environmental Impact	Medium/Low	High

TABLE 5. TECHNICAL CHARACTERISTICS COMPARISON OF LI-ION AND LEAD-ACID BATTERIES.[9]

[9] Kebede, A. A., Coosemans, T., Messagie, M., Jemal, T., Behabtu, H. A., van Mierlo, J., & Berecibar, M. (2021). Techno-economic analysis of lithium-ion and lead-acid batteries in stationary energy storage application. Journal of Energy Storage, 40, 102748. https://doi.org/10.1016/J.EST.2021.102748

Li-ion batteries have advantages of high power and energy density, low maintenance requirement, a high number of cycles as compared to lead-acid battery technology. Therefore, Li-ion is a better solution in situations that demand fast charging/discharging cycles (high power) and have space restrictions (high energy density), for instance, in mobility. However, PV systems have less restrictions than mobility, so lead-acid are usually good enough. Furthermore, lead-acid batteries are cheaper, what makes them an attractive solution. In fact, lead-acid is the most used technology in PV off-grid facilities.

It must be noted that temperature has a great impact in batteries. At low temperature, the battery performance is clearly reduced, which will limit their use in cold climates and high-altitude places. At high temperature, there are several adverse effects such as capacity/power fade and self-discharge. Therefore, a thermal management system may be needed to keep the battery temperature in the range of 20-30 ºC. Moreover, a uniform temperature distribution in the battery cells must be kept, because the worst-state cell limits the operation of the whole battery, so it is desirable to achieve the same degradation rate in each cell of the battery[10].

3.3.2 Hydrogen technologies

The renewable hydrogen technology consists in three parts: hydrogen production, hydrogen storage, and hydrogen consumption.

There are many ways to produce hydrogen, nevertheless, only a few are truly exploited. According to International Energy Agency[11], 90 Mt H_2 were produced in 2020 worldwide, with 59% coming from natural gas, 21% from industries as a by-product (mainly refineries), 19% from coal and only 0.03% from water electrolysis. Therefore, the current approach of hydrogen production is mainly based on fossil fuels.

Renewable or "green" hydrogen is known to be produced by electrolysis of water using electricity generated from renewable energy sources. But there are alternative approaches such as biomass gasification, biogas reforming, photoelectrocatalysis and others. A representative summary of hydrogen production routes is provided by Hydrogen Europe[12]. Regarding the SustainHuts Project, the electrolsysis approach is considered the most suitable to mountain shelters, since it is mature and allows to store surplus renewable energy, so the document will focus on electrolysis.

The electrolysis is an electrochemical reaction which splits the molecules of water into H_2 and O_2 thanks to electricity. The reaction is also called "redox" and is divided into two sub reactions: the oxidation (an element releases electrons) and the reduction (an element receives those electrons). This reaction takes place in an electrolysis cell. According to thermodynamics, a cell requires a minimum voltage of 1.5 V to split a H_2O molecule, but a higher voltage is required due

[10] Wu, W., Wang, S., Wu, W., Chen, K., Hong, S., & Lai, Y. (2019). A critical review of battery thermal performance and liquid based battery thermal management. *Energy Conversion and Management*, *182*(January), 262–281. https://doi.org/10.1016/j.enconman.2018.12.051
[11] https://www.iea.org/reports/global-hydrogen-review-2021
[12] https://hydrogen.revolve.media/

to energy losses. Cells are grouped into stacks. Finally, an electrolyzer is a group of stacks that can be connected in series or in parallel. There are different kinds of electrolyzers depending on the cell technology. Figure 20[13] shows the reactions involved in each kind of electrolysis. However, all of them have similar components:

- Two electrodes: the anode (oxidation reaction) and the cathode (reduction reaction).
- Electrolyte: this component provides ion conductivity.
- DC generator: this component provides the electricity needed to carry out the reaction.

The main difference between electrolysis technologies is the type of ion transported from one electrode to the other and, therefore, different materials are required in each case. For instance, alkaline electrolyzers use a liquid electrolyte, while PEM and AEM use membranes and SOE use a solid oxide. Not only the electrolyte changes, but also the anode and cathode materials. The most mature technology is alkaline, followed by PEM.

Electrolysis technologies also have different properties; thus, they are suitable for different applications. For instance, SOE operate at high temperatures so industrial applications where high temperature waste heat is available are a good choice. However, they have a slow response time, so they are not a good solution to follow the production of renewable energies. Instead, PEM electrolyzers run at low temperatures and have a flexible operation, so they seem to be suitable for renewable energy production in mountain huts.

[13] https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

In addition, an electrolysis facility needs an auxiliary system called the **"balance of plant"**. It comprises a range of system elements such as cooling, purifiers, thermal management, water treatment and others.

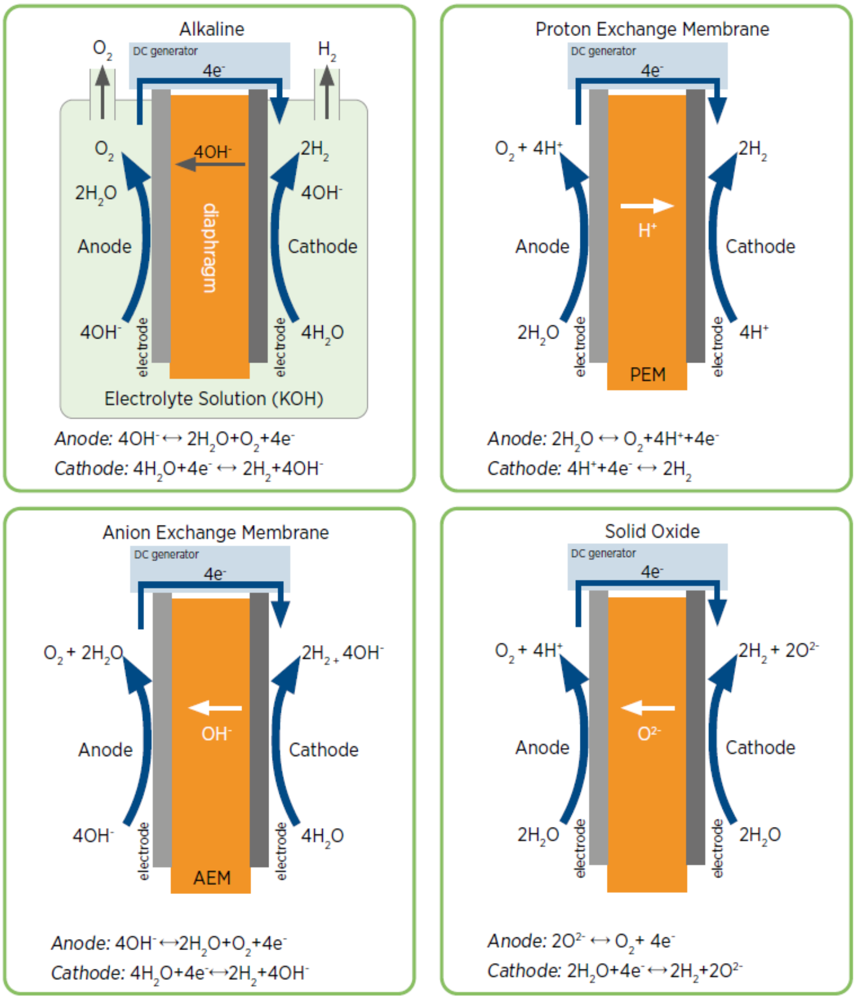


FIGURE 20. DIFFERENT TYPES OF COMMERCIALLY AVAILABLE ELECTROLYSIS

The main concern with hydrogen safety is flammability, and hydrogen has, after acetylene, the widest explosive/ignition mix range with air of all gases. This is, however, mitigated by the fact that hydrogen, due to its low atomic weight, rapidly rises and disperses before ignition. Unless accumulated in an enclosed, unventilated area, hydrogen is very unlikely to induce serious risks.

A storage step is usually required between production and use of hydrogen. The hydrogen molecule has some characteristics (small size, lower molecular weight compared to all compounds and its high reactivity) that give it a high-energy density in mass, making it extremely interesting as energy storage in applications where low weight is required. In contrast, hydrogen density is low (0.0899 kg/Nm^3), which leads to an energy density per volume lower than other common fuels. This behavior is depicted in Figure 21[14]. The main objective of the storage system is to increase its density so as the greatest amount of mass of hydrogen is stored in the lowest volume. The most common method of hydrogen storage is compressed gas. The storage pressure level will depend on the final application and the space available. Other technologies like liquid hydrogen, metal hydrides or synthetic fuels are storage options to consider depending on the final application requirements.

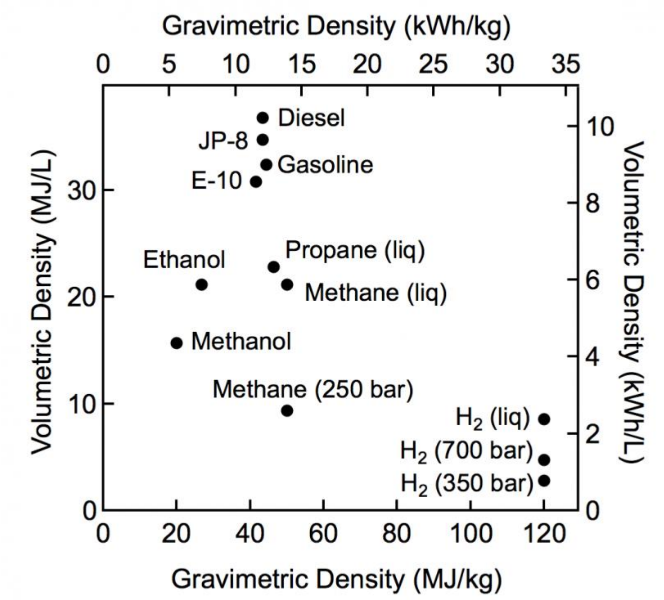


FIGURE 21. COMPARISON OF SPECIFIC ENERGY (ENERGY PER MASS) AND ENERGY DENSITY (ENERGY PER VOLUME) FOR SEVERAL FUELS BASED ON LOWER HEATING VALUES.

The final step of the technology is the use of hydrogen. Hydrogen can be used in fuel cells, where a redox reaction takes place to produce electricity, or in combustion devices like burners, boilers to produce heat. However, electricity and heat can be obtained simultaneously by means of fuel cells if the temperature of the heat released is high enough to use it or by means of gas turbines. The cleaner option is fuel cells, since water steam is the only subproduct emitted, while combustion processes emit NOx. Thus, fuel cell technology will be explained.

A fuel cell is an electrochemical reactor where hydrogen is continuously converted into electrical energy. It can be understood as the reverse reaction of the electrolysis. The anode of the cell is fed with hydrogen (fuel), where it is oxidized on the platinum catalyst (diffuser/catalyst layer), and produces electrons and protons when dissociates, H^+. The electrons flow through an

[14] https://www.energy.gov/eere/fuelcells/hydrogen-storage

external electrical circuit and are used to power the loads connected. The protons are transported from the anode to the cathode through the electrolyte. The cathode is fed with oxygen, which reacts with the protons transported across the membrane and electrons via the electrical circuit. The final product of the reaction occurring at the cathode is steam. The electrical power output of the fuel cell depends on the demanded load.

Like in the electrolyzers case, there are different types of fuel cells:

- Alkaline
- Polymer electrolyte membrane (PEM)
- Phosphoric acid
- Molten carbonate
- Solid oxide fuel cells

4 SUSTAINHUTS' Methodology

The section reports the methodology used in SustainHuts project useful to replicate it in other huts.

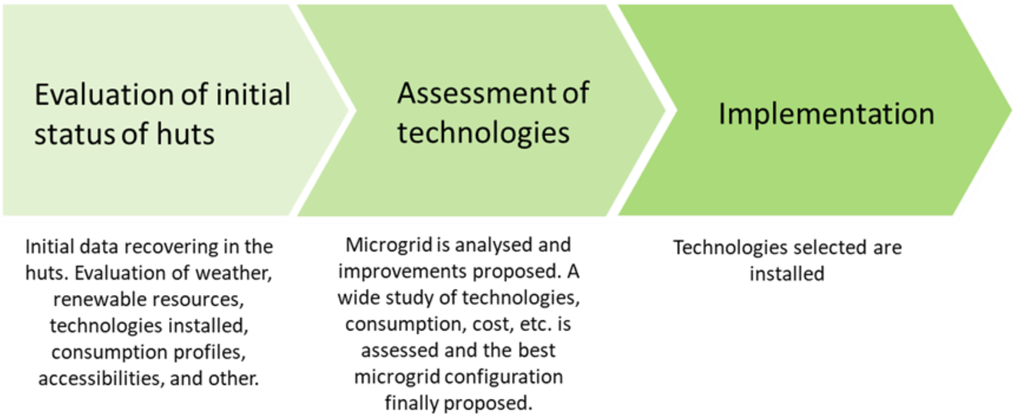


FIGURE 22. STEPS TO CARRY OUT SUSTAINHUTS.

4.1 Evaluation of the initial status of the hut

Firstly, an assessment of each hut's situation is needed. The evaluation can be done with an initial visit to the huts and initial status identification. Interviews with hut keepers must be conducted in order to understand the problems and necessities linked to the microgrids of the huts. During the visit, the hut is checked visually, statistics are gathered (people attending yearly; operation months/year…) and needs of the hut manager are collected. The monitoring allows to understand how much energy is demanded. If there are not monitoring devices or previous data collections, data loggers are installed if required.

The collected data also include:

- Typology of installed technologies.
- Identification of energy sources already installed.
- How energy is managed.
- Hourly load profile.
- Baseload and peak power.
- Annual consumption of electricity.
- Accessibility to the shelter.
- How to reach the shelter.
- Methods of water supply.
- Methods of fuels supply.
- Weather assessment.
- Space available.

4.2 Technology assessment.

Once the key data is collected, the aim of the second step is to assess which technologies are most suitable to achieve supply, cost and environmental targets, according to the data provided. Moreover, a detailed plan for transport and installation is developed. A microgrid evaluation is needed.

In order to develop the microgrid model of the hut, different software can be used. In this project, HOMER has been used to obtain a detailed calculation, but depending on the level of detail, good results can be obtained through a spreadsheet. The aim is to assess the economic and environmental cost of different scenarios where different technologies and sizes are installed. As a result, the software reports the most cost-efficient combination of technologies and helps to decide the final design of the microgrid. Thus, the decision-making process is more comprehensive, since several selection criteria can be considered.

The main input parameters needed to obtain economic and environmental results are given below:

- Electric and thermal load profiles of the hut (1 hour or 15 mins intervals), which should be provided by the hut manager during the Evaluation of the initial status of the hut.
- Energy sources availability: such as solar radiation, wind speed, water head and flow, amount of fuel.
- Technical data of each component: mainly nominal power and efficiency.
- Economic data of each component: CAPEX (Capital Expenditure), fixed OPEX (Operational Expenditure), variable OPEX (mainly fuel and commodity costs), lifetime, interest rate.
- Carbon footprint of each component.
- Project restrictions or targets: such as minimum PV contribution, maximum fuel consumption or CO_2 emissions, space available.

4.2.1 Micro grid models

European huts generate, mainly, electricity using diesel generators, causing different consequences like CO_2 emissions or diesel dependence, creating the necessity of providing the main energy resource.

Renewable energy sources are installed in some huts too, but, in most cases, backup generation is required to guarantee energy supply. Therefore, diesel generators are still needed.

To estimate the amount of energy that could be produced by a renewable energy facility not only weather data (collected in the first step) is needed, but also technical information of the technologies that will be installed. This data is provided by manufacturers.

4.2.1.1 Microgrid models input

In order to assess the microgrid models of the hut, some inputs must be demanded in order to model the grid. The input data depend on the characteristics of each hut and the facilities installed. Thus, the characteristics of the facilities must be taken into consideration, including the batteries (energy storage capacity, connection way, etc.), electric converters, power of the generators, etc.

Technology	Main technical information from manufacturer	Resource availability
PV	• Efficiency curves • Size • Thermal coefficients • Derating factor	• Radiation: depends on location, slope, azimuth, solar tracking. • Ambient temperature affects PV's performance.
Solar thermal	• Efficiency curves • Size • Thermal coefficients • Derating factor	• Radiation: depends on location, slope, azimuth, solar tracking. • Ambient temperature affects collector's performance.
Hydropower	• Efficiency curve • Nominal flow rate	• Water flow rate. • Water head.
Windpower	• Power curves	• Wind power: depends on location, hub height, temperature.
Biomass	• Power of the boiler. • Efficiency • Type of biomass.	• The resource is purchased so it depends on the availability of the provider. • Supply cost. • Technical properties (density, heating value)
Diesel engine	• Power • Efficiency	• The resource is purchased so it depends on the availability of the provider. • Supply cost. • Technical properties (density, heating value)
Batteries	• Energy capacity (kWh) • Power (kW) • Efficiency. • Deep of discharge (%)	• Resource data is not needed. • Ambient temperature affects battery's performance.
Electrolyzer	• Nominal input power • Efficiency	• Electricity supplied by the devices mentioned above. • Demineralized water production or purchase. • Ambient temperature affects electrolyzer's performance.

TABLE 6. MAIN TECHNICAL AND RESOURCE DATA REQUIRED TO SIMULATE EACH TECHNOLOGY.

Looking at renewable sources, different information must be considered. For PV systems, slope, azimuth positioning, lifetime and derating factor of the panels as well as tracking system and the effect of the temperature is necessary to know. In relation to hydro generation, available head of the flow, design flow rate and the efficiency of the turbine must be considered. Regarding wind turbines, hub height and lifetime must be included as well as the power curve of the wind turbine. Most of these data come from information from hut owners and, in some cases, the bibliography referenced.

In relation to PV and solar thermal, PVGIS database is useful to estimate solar potential of a given location, since it provides accurate temperature data and solar radiation according to azimuth and tilt angles. It is recommended to compare the data from PVGIS with data from national meteorology agencies if possible.

For hydro resource, the information demanded about the water flow normally is not easy to get due to the lack of measurements. So, in these cases, the available data such as the owner's information or the percentage of energy produced by the turbine can be used in order to estimate the water flow available.

Regarding the wind resource, it can be obtained from Renewables Ninja database (which is based on NASA and EUMETSAT databases) and, from its data, daily average value, Weibull constants and other values can be calculated.

Biomass is purchased, so a shortage of resource is not expected. Biomass' properties like density and heating values should be given by the biomass supplier. However, if the decision-making process is in an early stage such that the supplier has not been selected yet, information could be obtained from several references, such as Phyllis database which is a trusted one.

In relation to diesel, the amount used may not be limited because it is supposed that diesel fuel is always available. Its cost may not get relevance in the study (it is not the aim of this assessment) so a standard value can be introduced.

Another important point for the simulation is the electric consumption profile of the huts. These data can be obtained using different ways like the installation of data loggers in the huts, the knowledge of the loads installed in them or the calculation of the consumption profiles using a well-known profile of a standard European hut and interpolating using the relation of overnights hosted per month; the way in each hut must be selected depending on the data available. These profiles are needed to obtain the amount of energy which is demanded per hour and to calculate the energy flows in the hut in an average year. The electric profile introduced reproduces the average hourly consumption in a day of each month, taking like the medium hourly data the average value of every hour in the month.

In relation to the heat consumption profiles, different bibliography[15] and information provided by the hut owners can be followed due to the lack of experimental measurements. So, a general consumption profile which has been individually adapted to each hut must be developed.

Finally, the connections of loads and generators, in DC or AC and the characteristics of the converters must be considered.

[15] Albert, A. y Rajagopal, R., «Building Dynamic Thermal Profiles of Energy Consumption for Individuals and Neighborhood», *IEEE*, p. 9, dic. 2013

4.2.2 Inefficiencies of the Electric System

Regarding the electric systems of the huts, it is important to consider possible inefficiencies that lead to a non-optimal operation. These inefficiencies are different depending on the hut but all of them entail that the generators must work more time than it was initially expected.

These inefficiencies might be the incorrect PV panels operation (conditions apart from the derating factor), the age deterioration of some elements, the inability of the renewable sources for charge the batteries or the low batteries lifespan. Batteries' problems are especially important because they have optimal operation conditions like the charge rate or the depth of discharge and, when they work out of these parameters, it drastically reduces their utility and lifespan. All of these situations create the need to introduce these inefficiencies in the microgrid simulation in order to adapt the final results to the real situation.

4.3 Technology implementation & maintenance

This step is focused on the installation of the selected technologies. The implementation must take into account:

- Good choice of materials suitable for the altitudes, that avoid breakage or degradation because they are subjected to extreme climatic conditions for a long period, for instance, water/glycol blends to avoid pipe break due to water freezing.
- The means of transport and the difficulties associated with reaching a remote area.
- Choice of companies with experience and suitable for working at high altitudes and in climatic conditions.
  Stipulation of an insurance of the installed energy system to be done prior to installation procedure or parallel to installation procedure.
- Preparation of a working plan.
- Weather conditions forecast.

The maintenance must take in consideration mainly the availability of the hut owner and the ageing of the materials, but also how much the hut is opened and the period.

4.4 Regulation assessment

During the design phase the hut owners need also to check which kind of permits and licenses for the installation are necessary, mainly linked to the area of the installation. Specially in those cases located in Natural Parks, where the restrictions are harder.

SustainHuts project involved 4 EU-Countries, for each of them the partners contacted the Regional Administrations to follow the correct processes; the main conclusions of the report are:

- In Spain, FAM has made a review of the existing regulation and no additional authorisation is needed to implement the chosen technologies. The special case of hydrogen has been revised by FHA and there is no need to ask for any special license. In spite of this, a fluent contact is established between FHA and the Regional Administration on these matters and special care is taken due to the novelty of installing this technology in an isolated environment. It is no possible to install wind turbines in

Natural Parks, whatever the power. The permit needed is focused on the civil works done in the huts, ensuring the correct security of gases.

- In Italy, CAI has obtained the corresponding authorisation for the PV installation. Regarding Energy Efficiency Actions, the establishment of an agreement with the entity proprietary of the soil where it is installed requires a special action. Water recovered via snow dissolution: this is an intervention inside the CAI private property, that does not create any environmental impact on landscape, so it was not necessary to require special permissions. Waste water recovering: spaces are not in CAI private property; it was necessary to include an agreement with "Società Funivie del Monte Bianco".
- In Slovenia, PZS has reviewed the regulatory framework, and only one hut requires asking for special authorisation as it is placed in a Natural Park. This authorisation has not been asked yet because of the forced replacement of the original Slovenian huts during the first stage of the project delayed it. It will be done as soon as possible, and no problem is expected in obtaining it.
- In France the installation of solar arrays (thermal or photovoltaic) requires an authorization from the Municipality, because it may affect exterior appearance of the building. In general, modifications which take place inside a building without modifying exterior appearance does not require a Municipality authorization. For instance, internal insulation can be done without permit. But an exterior insulation which will change exterior wall aspect, requires a permit. For water turbine, the authorization process has been simpler than general case because the power station took place on a water drain deviation which has been previously authorized for human water consumption. The only authorization needed was from the Vanoise National Park because the hut is inside this natural protected area.