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LIFE SUSTAINHUTS: SUSTAINABLE MOUNTAIN HUTS IN EUROPE

C7.2 Final guideline: "Implementation of renewable energies and hydrogen technologies to achieve SUSTAINHUTS"

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Executive Summary

LIFE SustainHuts is a demonstrative project which aims to reduce the environmental impact of the energy use in mountain huts by implementing renewable energy-based solutions, efficiency strategies and hydrogen technologies for storing renewable energy.

The aim of this guide is to present the technologies finally installed in the huts and the process that was followed from the initial idea of improving the sustainability of these facilities to the technologies finally installed, with the ultimate goal of promoting their reproducibility to other huts and similar isolated facilities. The process starts with a meeting between the technicians of the partners, the mountain federations and clubs, and the mountain hut keepers in which the potential improvements in the mountain huts are discussed and commented. The process ends with the installation of all the technologies, their testing and demonstration, the training that may be required by the keepers, and the monitoring protocol in place.

After the evaluation of the improvements, **30 technologies were finally selected, including renewable production and efficiency, hydrogen storage, and thermal insulation.** This guide presents the technologies related to **energy production and storage by means of hydrogen**, which are those highlighted in the next table.

ID	Hut	Technology	Guide	Comments
#1	Lizara	Advanced Automation	C7.3	
#2	**Lizara**	**PV**	**C7.2**	
#3	Lizara	Thermo-Chimney	C7.3	
#4	Bachimaña	Electrification	C7.3	
#5	Bachimaña	Micro-wind		Cancelled
#6	Bachimaña	Efficiency	C7.3	
#7	**Bachimaña**	**H2 Storage**	**C7.2**	
#8	Estós	Hydro		Cancelled
#9	Estós	Advanced Automation	C7.3	
#10	**Estós**	**PV**	**C7.2**	
#11	**Estós**	**Pellet Stove**	**C7.2**	
#12	Estós	Insulation	C7.3	
#13	**Llauset**	**PV**	**C7.2**	
#14	**Llauset**	**Pellet Stove**	**C7.2**	
#15	Llauset	Insulation	C7.3	
#16	Kočbekov	PV		Destroyed by fire
#17	**Pogačnikov**	**PV**	**C7.2**	
#18	**Pogačnikov**	**Micro-Wind**	**C7.2**	
#19	**Torino**	**PV**	**C7.2**	
#20	Torino	Water Plants	C7.3	
#21	Torino	Insulation		Cancelled
#22	**Montfalcó**	**PV**	**C7.2**	
#23	Montfalcó	Advanced Automation	C7.3	
#24	**Góriz**	**PV**	**C7.2**	
#25	**Dent Parracheé**	**PV**	**C7.2**	
#26	**Dent Parracheé**	**Hydro**	**C7.2**	
#27	**Dent Parracheé**	**Wood Stove**	**C7.2**	
#28	**Dent Parracheé**	**Solar Thermal**	**C7.2**	
#29	**Valentina dom**	**PV**	**C7.2**	
#30	**Valentina dom**	**Micro-wind**	**C7.2**	

This guide first presents the technologies implemented in the field of renewable energy production, describing the initial situation in each hut as well as the implemented solution.

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1 Introduction

LIFE SustainHuts is a demonstrative project which aims to improve the sustainability of mountain huts located in natural habitats by implementing novel and original solutions related to renewable energy and other eco-friendly technologies.

This report presents the implementation strategy followed in the huts to install the renewable energy technologies selected. The methodology developed to evaluate the microgrids and to propose the most optimal technologies to improve its work and sustainability was:

1) **Initial visit to the huts and initial status identification**. Interviews to hut keepers to understand the problems and necessities linked to the microgrids of the huts.

2) **Modelling**. Technical modelling of the micro-grids with the real data collected in the huts, as the diesel consumed by the facilities installed, monthly guests, etc. First ideas of how to improve the grids.

3) **Selection of the technologies**. The technologies were mainly proposed by hut keepers and SUSTAINHUTS technicians thanks to their wide knowledge of the huts and other European huts which are built under sustainable criteria.

4) **Final modelling of the huts**. SUSTAINHUTS technicians modelled the microgrids considering the improvement proposed and comparing them with the results obtained of the initial state of the hut. Considering the improvements achieved, the actions are definitively approved.

2 Starting configuration of the huts

This final guideline on the SustainHuts implementations presents all the **11 huts optimized during LIFE SUSTAINHUTS project**, located in four different European countries: Italy, Slovenia, France and Spain:

5 demo huts placed on Spanish Pyrenees and 1 in Sierra del Montsec.
3 demo huts placed on Slovenian Alps.
1 demo hut placed on Italian Alps.
2 demo huts placed on French Alps. Only one with a demo. Des Evettes is not included as "sustain hut" in the project, it is only the reference for Dent Parrachée, but not a hut included in the project. It is a little bit odd, but we consider only Dent Parrachée in the project.

FIGURE 1. LIFE SUSTAINHUTS PROJECT'S HUTS

Hut	Country	Altitude [m]	Capacity (beds)
Lizara	Spain	1650	78
Bachimaña	Spain	2200	80
Estós	Spain	1890	115
Cap de Llauset	Spain	2400	80
Torino	Italy	3375	160
Kočbekov	Slovenia	1808	100
Pogačnikov	Slovenia	2050	59
Montfalcó	Spain	800	45
Góriz	Spain	2200	80
Valentina Staniča	Slovenia	2332	99
Des Evettes	France	2594	64
Dent Parrachée	France	2520	42

TABLE 1. GENERAL HUTS' INFORMATION

3 Implementation of renewable energies

After the process of selection and analysis, **a final list of 30 technologies was selected**. The final list is formed of all actions proposed, including hydrogen and insulation, and those initially selected but finally not executed. This report does not cover the thermal insulation actions because they are covered in C7.3 "Energy efficiency and advanced materials applied to mountain huts".

26 actions have been installed with technologies of energy production (either electricity or heat) like PV, micro-wind, pellet stoves, wood stoves, solar thermal panels, hydro-turbine, and several efficiency actions like improvement of batteries charge, electrification, changes of batteries, thermo-chimney, and improvement in the water pumping and water treatment. Some innovative technologies like storage of renewable energy by mean of hydrogen, and novel insulation materials are also considered. Table 2 reports the main technologies installed in each hut (those described in this guide are highlighted)

ID	Hut	Technology	Guide	Comments
#1	Lizara	Advanced Automation	C7.3	
#2	**Lizara**	**PV**	**C7.2**	
#3	Lizara	Thermo-Chimney	C7.3	
#4	Bachimaña	Electrification	C7.3	
#5	Bachimaña	Micro-wind		Cancelled
#6	Bachimaña	Efficiency	C7.3	
#7	**Bachimaña**	**H2 Storage**	**C7.2**	
#8	Estós	Hydro		Cancelled
#9	Estós	Advanced Automation	C7.3	
#10	**Estós**	**PV**	**C7.2**	
#11	**Estós**	**Pellet Stove**	**C7.2**	
#12	Estós	Insulation	C7.3	
#13	**Llauset**	**PV**	**C7.2**	
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#23	Montfalcó	Advanced Automation	C7.3	
#24	**Góriz**	**PV**	**C7.2**	
#25	**Dent Parracheé**	**PV**	**C7.2**	
#26	**Dent Parracheé**	**Hydro**	**C7.2**	
#27	**Dent Parracheé**	**Wood Stove**	**C7.2**	
#28	**Dent Parracheé**	**Solar Thermal**	**C7.2**	
#29	**Valentina dom**	**PV**	**C7.2**	
#30	**Valentina dom**	**Micro-wind**	**C7.2**	

TABLE 2. SUSTAINHUTS INSTALLATIONS IN STATE OF PLAY AT THE END.

The report includes only the description of "energy production" technologies those directly linked to renewable energy sources such as PV, wind, hydro and biomass. Whilst "energy efficiency" technologies (actions not directly involving RES, i.e. AAI-Advanced Atomation of Installation, electrification, thermo-chimney, water treatment) are discussed and described in C7.3 guidelines together with the advanced materials.

3.1 Spanish huts

3.1.1 Lizara

Status before SustainHuts. Lizara electric system is not as efficient as a usual off-grid system due to different reasons. The most remarkable fact observed is that the control and change between batteries, PV system and gensets operation is not automated, causing an inefficient use of the batteries which reduces their lifetime. This control is done manually by the hut keepers and frequently deep discharges of batteries occurred damaging them. This situation is also conditioned by the fact that all the elements of the microgrid (batteries, PV panels and gensets) are located in a dedicated shelter around 100 meters apart from the main building, situation which hampers its physical access in winter, making difficult the manual switching between diesel generators and batteries.

It has been found also that the system is quite inefficient, caused by different ageing of PV arrays and the bad condition of some of them. The panels are arranged in series of several units, so the total power is directly limited by the operation of the worst. Based on information provided by the PV arrays installers during the interviews done, only between 10% and 20% of the potential energy expected is generated. It implies that the useful power is extremely lower than the installed power, datum which has been taken into account during the assessment.

All the previous mentioned facts cause the gensets to work more frequently than expected, increasing the amount of fuel consumed and the environmental impact of the Lizara hut.

3.1.1.1 PV panels improvement (#2)

During the development of the project, the ***improvement and implementation of photovoltaic technology has been one of the main actions proposed for this hut since it has been detected that the photovoltaic panels that were already installed at the beginning of the project, located in the best position facing to the south, they are in a poor state of conservation due to their age, so their electricity production is much lower than expected in relation to their nominal power.***

As a specific action for Sustainhuts, it was decided to propose the replacement of the most deteriorated panels with new generation ones. Following the information provided by the installation and maintenance company of the photovoltaic installation, the performance of a part of the installation is especially low, so it is these elements that are going to be replaced, also installed a 60A photovoltaic charge regulator with capacity for the new panels.

This action produces an increase in the energy produced both by improving the condition of the panels and by increasing the efficiency of the new ones (as they are more modern), which will mean a notable increase in annual generation.

Regarding the batteries, throughout the execution of the project, 18 batteries have been replaced that presented poor behaviour and caused a bad operation of the entire set, which caused the diesel generators to work for longer than strictly necessary, increasing the environmental impact of the refuge. The 6 remaining batteries of the bench (which has 24 units) were replaced before the start of the project.

The new batteries are of the same characteristics as the previously installed ones, Hoppecke 8 OPzS 800 with 2 V output. This will not imply an increase in the capacity of the battery bank, only an improvement in the state of these, allowing the storage of energy is carried out in optimal conditions.

3.1.2 Bachimaña

Status before SustainHuts. Bachimaña hut is a Spanish hut located in Spanish Pyrenees at 2200 meters. The electricity of this hut is generated using a 30 kW hydro turbine during about 9 months per year (except before snow melting, usually April-May), when enough water is available. Furthermore, two diesel generators of 25 and 8 kW are installed in order to provide electricity when no water is available. A rack of 24 batteries with a capacity of 73.1 kWh (2 V and 1523 Ah every battery) is installed too to be used in combination of the gensets. In relation to heat, a diesel boiler of between 73 and 178 kW is used.

The power produced in the hydro turbine during the most part of the year makes unnecessary to implement any other renewable power source like PV, apart from the fact that for the period when there is no renewable production, the hours of solar radiation are very low and the weather is not very favourable for PV production.

3.1.2.1 H2 storage (#7)

The hydrogen system consists in an electrolyser which consumes part of the surplus of electricity produced by the hydro turbine. The hydrogen produced is then stored as compressed gas during some months, and finally the hydrogen is consumed in a fuel cell to produce electricity when the hydro turbine is in standby due to lack of water. Figure 2 shows the electric system in Bachimaña including the implementation of the hydrogen technology.

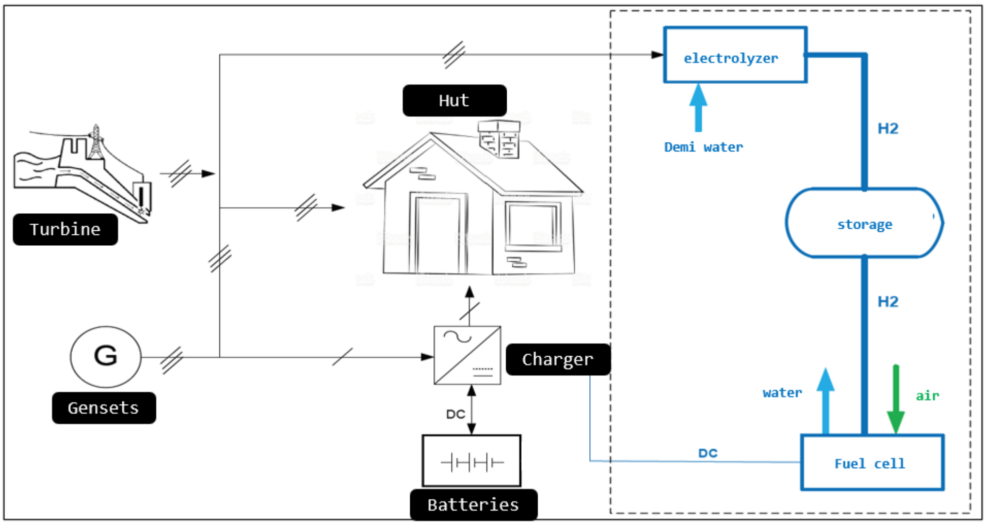

FIGURE 2: DIAGRAM OF HYDROGEN INSTALLATION CONFIGURATION.

Bachimaña is an interesting hut for integrating H2 technologies because surplus of RES electricity can be stored in summer and autumn for a subsequent used in spring.

- The total amount of H2 required to completely replace the operation of the diesel generators for 3 months is estimated in 100 kg. This value exceeds projects scope and budget.
- The H2 system is composed by an electrolyser, storage as compressed gas and a fuel cell that will charge the existing batteries in the hut.
- The electrolyser installed has a production of 0,25Nm3/h at 50 bars. It is fed by the micro-grid generated by the existing hydraulic turbine in the refuge, which generates surplus energy for 10 months a year.
- The storage consists of 18 cylinders of 50l@50bar capable of storing 4 kg of H2
- The fuel cell's output power is 1.2 kW(50.8V, 23.6A).
- The system is completed with all the gas detection and safety systems required for this type of installation.
- During the development of the project, a great variability has been observed in the period in which there is no renewable energy, with periods in which there has been no interruption in the production of the hydraulic turbine. The usefulness of hydrogen in these circumstances lies in the supply of electricity for short periods of time in which, due to turbine maintenance or some other incident, the hydraulic turbine is not available.

3.1.3 Estós

Status before SustainHuts. Estós hut is a Spanish hut located in the Aragonese Pyrenees at 1890 meters.
Estós is the oldest hut belonged to the project and was initially the hut with worst conditions in its micro-grid, so an ambitious plan to improve its generation was applied.

The electricity in this hut is generated using a genset of 24.8 kW. In addition, 2.9 kWp of PV are present, as well as a micro hydro turbine of 5 kW which provides electricity directly to some charges. 24 batteries with a capacity of 38.4 kWh (2V and 800 Ah every battery) are installed too. In relation to the heat, a diesel heater is installed in order to provide heat and hot water to the hut, although the hot water access is limited for the owners.

Regarding the ***electric system, it is not as efficient*** as it was expected at the beginning due to different reasons. The most remarkable fact identified is that the control and change between batteries, PV system and genset operation is not automated, causing an inefficient use of the batteries which reduces their lifetime. This control is done manually by the hut keepers and frequently deep discharges of batteries occurred, causing an accelerated damage and reducing their lifetime. Furthermore, the micro hydro turbine only provides energy to some small loads and, when there is an excess of energy, this is dissipated to the ambient, so the micro hydro turbine cannot charge the batteries when there is surplus of energy. On the other hand, the power of the genset is too high in relation to the electric demand of the hut, working always at low power and generating electricity in a low efficiency operation point.

It has been found ***also that the PV system is very inefficient due to the different ages of the arrays and the bad conditions of some of them***. The panels are arranged in series of several units, so the total power is directly limited by the operation of the worst. Only among 10% and 20% of the potential energy expected is generated. It implies that the useful power achieved is much lower than the installed power, a fact that has been taken into account during the assessment.

Regarding ***the micro hydro turbine, it was installed many years ago and it works out of optimal condition because of a bad water collection system***.

All the previous mentioned conditions cause the genset to work more frequently than desired, increasing the amount of fuel consumed and the environmental impact of the Estós hut.

3.1.3.1 PV panels substitution (#10)

During the project, it is proposed to replace the existing PV panels with 20 150W panels without increasing the surface occupied by them; going from 1920 Wp to 3000Wp, thus increasing its production capacity by 56%.

This gives the advantages to:

- Increase in energy produced both by improving the condition of the panels and by the increased efficiency of the new panels (as they are more modern), which will mean a notable increase in annual generation.
- Remarkable increase in power since, due to the development of technology in recent years, the same catchment area leads to an increase in installed power. In addition, the installation of new locations is planned, which will also increase the installed power.

Regarding the batteries, throughout the execution of the project, 16 batteries have been replaced. The new batteries have the same characteristics as the previously installed ones, Hoppecke 8 OPzS 800 with 2 V output. This will not imply an increase in the capacity of the battery bank, but rather an improvement in their condition, increasing the real storage capacity as well as the energy efficiency of the shelter.

3.1.3.2 Pellet stove (#11)

Regarding the pellet stove action, it has been proposed by the hut owners like a way to reduce the amount of diesel consumed, increasing the biomass consumption. Pellet is a resource which does not involve CO2 emissions (considering the carbon neutrality). Furthermore, the new stove proposed is not a usual pellet stove because the new one allows the recirculation of the hot gases through some rooms, increasing the energy efficiency of the hut.

Regarding for the SOPE (State of Play at the End.) exclusively, an increase of 15078 kWh per year generated from renewable sources is attached, expecting that more than 53% of the energy produced at the end comes from them. In relation to the CO2 emissions, a reduction of 9943 kg every year is expected after the implementation of the improvements, near from 70% of the initial emissions of the initial situation.

So, in conclusion, the actions proposed will introduce an important improvement in Estós hut, increasing its sustainability and resilience and reducing their environmental impact.

3.1.4 Llauset

Status before SustainHuts. Cap de Llauset hut is a Spanish hut located in Spanish Pyrenees at 2450 meters. It is very new, being inaugurated at the same time as SUSTAINHUTS begun. The electricity in this hut is generated using two gensets of 12 and 36 kW. In addition, 4.0 kW of PV are present as well and 24 batteries with a capacity of 57.6 kWh (2V and 1200 Ah every battery). In relation to the heat, biomass stoves are in the hut in order to provide heat to the hut, whereas the hot water is provided through a diesel heater.

3.1.4.1 PV panels (#13)

During the development of the project, the implementation of photovoltaic technology has been the main action proposed for this refuge since a potential energy use of solar radiation has not yet been exploited.

The considered panel installation is made up of 20 panels of 200 W each one. PV modules are installed on the building's roof, in such a way that generation loss due to shading is minimized.

Along with the installation by the 4 kW of power already mentioned, the installation of 4 kW of power by the FAM is foreseen (not included in the budget), so that a greater use of solar radiation by increasing installed power.

3.1.4.2 Pellet stove (#14)

Related to the pellet stove action, this has been proposed by the hut owners with the aim of reducing the diesel consumption, increasing the biomass consumption, because pellet is a resource which does not involve CO2 emissions (considering the carbon neutrality).

There are three the pellet stove installed in different parts of the shelter in order to ensure the correct heating of the building.

The heat produced by the pellet stoves suppresses the use of the diesel heater for space heating (domestic hot water will be still supported by the heater), supposing that the heat produced in the hut at the end of the project will be the same than at the beginning, so, in order to keep consistency, heat profiles has not been changed.

PV and pellet stove are expected to provide almost all the energy required during winter months. This fact is interesting to be considered during the monitoring protocol because, if this is accomplished, Llauset hut will be near zero emissions during half year approximately. The actions proposed will introduce an important improvement in Cap de Llauset hut, increasing its sustainability and reducing their environmental impact.

3.1.5 Montfalcó

Status before SustainHuts. Montfalcó hut is a Spanish hut located in the Spanish range of Sierra del Montsec, at 790 meters. The electricity in this hut is generated by means of a 50 kW genset. In addition, 5.7 kWp of PV are installed and 24 batteries with a total capacity of 109.5 kWh (2V and 2280 Ah every battery) are installed as well. The PV arrays present inefficiency.

One diesel heater is installed too in order to provide heat and hot water to the hut.

Furthermore, another genset of 12 kW is used only for pumping water from a natural spring to the water tank located in the hut. This diesel generator is located close to the natural spring, which is far away from the hut and about one hundred meters down in altitude. Therefore, the genset function is to pump the water from the natural spring to the water tank, which is located in the hut, where the water is consumed. This genset only works one hour per day approximately (when it is necessary to pump water), being turned off during the rest of the time.

3.1.5.1 PV panels substitution and implementation (#22)

Since some of the PV panels previously installed are inefficient, part of them were replaced and the total power installed in the shelter reached the 6.84 kWp, close to that installed in other huts such as Lizara or Llauset.

After the execution of PV action, the diesel consumed by the genset decreases 2078 litres per year, avoiding the emission of near of 6000 kg of CO2 per year approximately. Regarding PV technology, the energy generated by PV modules increases from 5304 kWh to 8892 kWh per year.

3.1.6 Góriz

Status before SustainHuts. Góriz hut is a Spanish hut located in the Aragonese Pyrenees at 2200 meters. The electricity in this hut is generated through two gensets of 25.0 kVA (20.0 kW) and 11 kVA (8.8 kW). In addition, 3.0 kWp of PV are present as well as 24 batteries with a capacity of 72.0 kWh (2V and 1500 Ah every battery). In relation to the heating system, a diesel heater is installed in order to provide heat and hot water to the hut, although its use is limited as far as is possible. The gensets deliver energy to meet the direct energy demand and to charge the batteries. When batteries are fully charged and the energy demanded is low, the genset stops and electricity is supplied by the batteries.

3.1.6.1 PV panels implementation (#24)

It has been considered the enlargement of the PV arrays. The total PV power installed will increase from 3.0 kWp to 21.1 kWp.

The actual batteries were replaced with new ones with higher energy capacity, accomplishing two objectives: to renew an old and not completely efficient string and to enlarge the energy storage capacity according to the new renewable power installed.

An increase of 23691 kWh per year generated from renewable sources is calculated, although not all the renewable energy is leveraged. Related to the CO2 emissions, a reduction of 8646 kg every year is expected after the implementation of the improvements, near 50% of the initial emissions.

So, in conclusion, the action proposed will introduce an important improvement in Góriz hut, increasing its sustainability and reducing its environmental impact.

3.2 Italian hut

3.2.1 Rifugio Torino

Status before SustainHuts. The Torino Hut (Rifugio Torino) is a high mountain refuge in The Alps in the northwestern Italy. Located near the border with France, it is about 15 km southwest of Mont Dolent, the tripoint with Switzerland. The refuge is in the Mont Blanc massif above the town of Courmayeur in the Aosta Valley. It can be most easily accessed from the Italian side by the Skyway Monte Bianco cable car from La Palud in Courmayeur, with a change at the Pavilion du Mont Fréty. It can also be reached from Chamonix via the Aiguille du Midi, either by cable car which crosses the massif, or by a long crossing of the Glacier du Gèant. The refuge lies nearly directly above the 11.6 km Mont Blanc Tunnel, which passes deep underground, and connects Courmayer to Chamonix.

The hut is the only in SustainHuts grid connected, the electrical system is powered by the Low Voltage 230V three-phase power supplier (connected to electrical grid, MT), with a delivery point near the beginning of the connecting staircase between Rifugio Vecchio and Nuovo. The Rifugio has a counter of 70kW. Rifugio Torino had in 2016 an electrical energy consumption of 96155 kWh/year.

The Rifugio Torino gets most of the heat from electricity with different devices (electric heater, electric fan, etc.). Other heat sources are:

- 2 diesel fans with a modulated output from 20-60 kW (located one in the drying room and one in the self-service room)
- 2 pellet stoves, located one in the room bar (room area 88 m2) and one in the lunchroom (room area 53 m2)

A big problem due to the high hut's altitude is the water supply for culinary uses and for toilets.

3.2.1.1 PV panels (#19)

Although the hut has enough electricity thanks to the grid connection, CAI decided to install some new-generation photovoltaic panels as an experimental way to monitor their operation and efficiency, aiming to gain knowledge and some lessons learned for other Italian huts not connected to the grid. Due to the huge amount of snow accumulated in the roof during the winter, the panels were installed in vertical position in the south façade.

The panels are 30 modules of Enemoc HF-130 (130 Wp), installed in 10 fix structures that vertically fix the panels to the wall. Besides, 8 batteries of 205 Ah were installed to stock up the PV production together with the charger and the inverter.

The modules are fixed on Aluzinc plate glued to the surface. The panel is fixed to the plate with a screw and a stud. The plate is fixed to the cover by gluing or mechanical fixing. Furthermore, protection against over-currents ensured by circuit breakers were installed as well as a crimping power of the device placed at the energy delivery point. Protection against direct contacts made of insulating materials and casings with suitable protection degree was installed too.

After the implementation of PV action, the energy is used to heat the drying room, with a reduction of diesel consumed by the diesel fan.

3.3 Slovenian huts

In Slovenia at the *state of the beginning* there were planned to include two mountain huts: Kocbekov dom na Korošici and Pogačnikov dom na Kriških podih. Unfortunately, Kocbekov dom was destroyed by a fire in autumn 2017 just after new equipment installation. After this incident, the new hut Dom Valentina Staniča was included and additionally financed.

3.3.1 Pogačnikov dom na Kriških podih

Status before SustainHuts. Pogačnikov dom is located in Triglav national park less than 4 km from Slovenia's highest mountain Triglav. It is seated at the altitude of 2050 m on the peak of Kriški podi and is surrounded by peaks of Bovški Gamsovec, Stenar, Razor and Pihavec. Like Kocbekov dom it is typically opened during summer season from June to September and is uninhabited during winter. The hut has a low flow of people and only opened during the summer. The idea was to install a hybrid system (solar and wind generation) with a storage system of batteries. It was evaluated that the combination between two technologies might provide the hut with a robust and reliable system for reducing a high amount of diesel fuel. Since the heat is already generated by the mixed wood, modifications in heat generation system were not foreseen.

3.3.1.1 Photovoltaic and batteries (#17)

Photovoltaic system consists of 34 pcs. Of Bisol PV modules of 285 W Wp. The total power of the PV system is 8 kWp Wall panels are placed at the north-east side of the hut whereas roof panels are placed on the south-east side of the roof (on the part which is lower of the rest of the roof). All existing PV panels remain in the PV system because they are still in good operating condition.

New PV panels were located on the south-east side of the roof. The inclination of the roof is around 20° but with the direction to the south-east, so it is expected a good output of PV panels.

For energy storage all the existing batteries were replaced by new ones with increased capacity, with higher voltage to provide better overall system efficiency and with LiFePo4 technology which is environmentally less hazardous: 8 pcs., 12 V, 2.4 kW - 2.4kWh, LiFePo4 set, 4x 200Ah cells + BMS monitoring.

3.3.1.2 Micro-wind (#18)

Micro wind turbine was also installed at Pogacnikov hut, presenting some added supply to the electricity system. Originally it was planned to install a 2.5 kW power micro wind turbine, but the market did not offer proper wind turbine with such size, so it was decided to install a micro wind turbine with power of 1 kW (wind turbine HY-1000) and horizontal axis.

Considering the whole hybrid system, the power supply system proposed for Pogacnik hut also includes a data acquisition system. The provided data is used for system monitoring and for detecting possible deviations in operation. Furthermore, the collected information is used for subsequent detailed analysis of system performance.

All measured data are constantly transferred to the control unit via internet connection. Since the existing internet connection is weak and cannot support sufficient connectivity, an upgrade of the internet connection is also foreseen.

3.3.2 Dom Valentina Staniča pod Triglavom

Valentina Staniča hut was joined to the project after the Kocbekov hut destruction and after Pogačnikov installation, so the technologies to implement were easy to be chosen: the same than in Pogačnikov. The impact in Pogačnikov dom using a hybrid system was fantastic (and the good results of hybrid systems in isolated micro-grids are widely supported by bibliography), so the idea was to adapt and replicate the successful work done in Pogačnikov. Thus, a hybrid system (PV-wind) supported with a batteries bank system has been installed in Valentina Stanica hut.

3.3.2.1 Photovoltaic (#29)

Photovoltaic system consists of 20 roof panels Luxor EcoLine 300, monokristal, Non Reflect. 10 panels (3 kWp) were mounted on the southern side of the main building roof and 10 panels (3 kWp) on the eastern side of the auxiliary building roof. Existing panels on the auxiliary building roof were partly removed (old panels) and partly integrated into the new PV system (panels from 2017). Summing it, a total gross power of PV installation is 6 kWp of new installed system added to 600 Wp that was installed in 2017.

Regarding the electricity storage, all existing batteries (6pcs of 12V OPZS 1500 Ah capacity) were replaced by 12 units of new ones TAB OPZV 1500 Ah 24V (gel technology). The system was upgraded to 24 V voltage, therefore, control system, inverters and all balance of plant components were installed or replaced.

3.3.2.2 Micro-wind (#30)

A micro-wind turbine with the power of 600 W was already installed in Valentina hut. Due to malfunction, the generation of the electricity with the wind turbine was very limited, so the plan was to remove it and install a new micro-wind turbine with the power of 1 kW from the StormyWings 1000-24 manufacturer (HYE 1000-24).

In Table 3, all data regarding the upgrade of energy system in Slovenian mountain huts is presented.

	Kocbekov dom na Korošici	**Pogačnikov dom na Kriških podih**	**Dom Valentina Staniča pod Triglavom**
Year of investment	2017	2018	2020
PV	18 kosov, Luxor: Secure line P60/250W	34 kosov, PV moduli Bisol, polikristal 285 W	20 kosov, Luxor EcoLine 300, monokristal, Non Reflect
PV system, power	4,5 kW (+ 0,6 kW current)	8 kW	6 kW (+ 0,6 kW current)
Inverter DC/AC	Vicron Multiplus 48/5000/70-100 MK3-USB	3 kos, Inverter 5kVA - 4kW	Victron MultiPlus C24-5000-120-50
Charger	Charger Victron smartSolar MPPT 150/100-MC4 Charger Victron smartSolar MPPT 150/35 (for current PV)	50 A solar charger, 50 A charger from gen-set	2 kos, Victron SmartSolar MPPT 250-100
Data acquisition	yes	yes	yes
Data transfer	yes	yes	yes

Batteries	24 kos, TAB 10 OPzV 800 – 2 V 800 Ah (gel technology)	8 pcs., 12 V, 2.4 kW - 2.4kWh, LiFePo4 set, 4x 200Ah cells + BMS monitoring	12 pcs., TAB OpzV 1500 – 2 V 1500 Ah (gel tehnologija)
Wind turbine	-	turbine HY-1000	turbine HYE 1000-24
System voltage	48 V	48 V	24 V

TABLE 3. TECHNOLOGIES FOR ELECTRICITY GENERATION INSTALLED IN SLOVENIAN MOUNTAIN HUTS.

3.4 French hut

3.4.1 Dent Parrachée

Dent Parrachée is the last hut joined to the project, although no technologies have been financed by the project budget. The hut was refurbished in 2018, installed new renewable technologies in order to turn the hut into a more sustainable one. Considering it, no technologies are defined here, because the methodology (visit to the hut, hut keepers' proposition, assessment of technologies, purchase, and installation) has not been applied in this hut, only the monitoring protocol affects it, which is based on the comparison of this hut with Evettes, which is a very similar hut without recent refurbishment. Even so, it is possible to declare that 4 renewable technologies have been installed in the hut: solar thermal panels (#28), a hydro-turbine (#26), a wood stove (#27), and PV panels (#25).

The hydro-turbine is a small (micro) turbine which leverages a small water flow close to the hut. Although only 600 W are installed, it is enough due to the reduced hut's consumption. Regarding the PV panels, 8 panels of 300 Wp each are installed with 30º south orientation and 90º of slope (vertical). During winter, the vertical ones receive more solar irradiation than the others, therefore, PV production is increased during this period. Furthermore, 38.4 kWh of lead-acid batteries (12 batteries of 2 V) are installed to store electric energy. Finally, a stove with recirculation, which uses wood as fuel, is used to heat the main room.

3.5 Transport plan

The transport plan is strictly connected to the hut altitude, typology of accessibility, climatic conditions. As reported below, it is necessary for each hut to distinguish the different stages of transport: (1) inspection phase, (2) procurement's material phase, (3) installation phase and (4) execution phase.

Below two huts are reported as examples:

1. **Kocbek hut** is located in the coral area of mountain range Kamnik-Savinja Alps (Kamniško-Savinjske Alpe) at an altitude of 1808 meters. The hut is not accessible by road. All main transportations of material and goods are done by helicopter. The transport plan is adapted to helicopter transport. Due to sustainability and general efficiency, the number of helicopter flights has been minimized as much as possible. Helicopter that is planned for the transport of the material, can normally carry up to 1.200 kg. All the materials are prepared and packed in the way. The transport consists of 5 helicopter flights from the loading point to the hut. Helicopter base point is at

Airport Jožeta Plečnika Brnik, which is placed 23 km away (straight airline) from the loading point. Two transportations via truck are used to bring all material to the loading point on the public roads. One truck transport is planned from the Battery Factory (85 km one way) and one for all other material from the Installation Company (85 km one way). Concerning the transport of the installation staff, a van is used from the Company (85 km one way), which also transported all the tools back to the Company (85 km).

2. **The Torino Hut (Rifugio Torino**) is a high mountain refuge in The Alps, in the northwestern Italy. Located near the border with France, it is about 15 km southwest of Mont Dolent, the tripoint with Switzerland. The refuge is in the Mont Blanc massif above the town of Courmayeur in the Aosta Valley. It can be most easily accessed from the Italian side by the Skyway Monte Bianco cable car from La Palud in Courmayeur, with a change at the Pavilion du Mont Fréty. It can also be reached from Chamonix via the Aiguille du Midi, either by cable car which crosses the massif, or by a long crossing of the Glacier du Gèant. The refuge lies nearly directly above the 11.6 km Mont Blanc Tunnel, which passes deep underground, and connects Courmayer to Chamonix. The transport of all materials follows different phases, in each of them there are different transports:
    a. Inspection visits using the cableway;
    b. Procurement's phase using a van mainly used for the transport of bulky and heavy material and after helicopter; a mini-van used for transport any other workers during the procurement stage.
    c. Installation phase structured using car and cableway. A number of 52 visits are considered.
    d. Execution phase during SustainHuts project is structured using car and cableway, considering 4 visits per years in 2 years of demonstration period. In total 8 visits are considered.

Linked to what reported on, it is also necessary to consider:

- **Climatological estimation**: transport by helicopter can be done the whole year. But for the installation of equipment is determined to the no-snow condition and to the opening season of the hut. Helicopter transport requires a clear weather. Transport tasks are subject to delay if foggy/cloudy weather takes place, since that transport cannot be restarted for one week or even more.
- **Economic criteria**: transport represents a high cost, mainly due to the use of helicopter.
- **Sustainability criteria**: The criterion of sustainability and low environmental impact, which is embedded within the SustainHuts project, has been essential during the development of the transport plan. Given that there is no other possibility but helicopter, the transport plan foresees the minimum number of helicopter flights to transport needed material.

4 Conclusions

Mountain huts are located at various altitudes and regions and are provided with different available technologies. Analysis of installed technologies for electricity generation at mountain huts reported in this document shows that consumption analysis and the identification of the correct technology are strictly connected:

- operation months/year of the hut;
- number of visits;
- average accommodation;
- energy availability
- grid-connection or off-grid;
- altitude;
- climatic conditions (wind, sunshine, snow, etc.);
- dimensions of the buildings;
- new or old hut.

Slovenian mountain huts in the project are very specific because they are located in high mountains and are therefore open just 3-5 months during the year. They are not easy to access and usually helicopter or ropeway is used to transport energy carriers and good to the hut.

Huts need electricity mainly for lights, kitchen appliances, charging of electronic devices, and other small devices. Heat is mainly for heating.

Huts are located in the area with good weather (sunshine) and also constant wind, so the combination of PV and wind turbine was the best choice to implement. System was oversized, so when renewable energy sources are available there is excess of electricity. The storage should be short to midterm, so battery was a logical choice. Heat distribution system was not upgraded since heat in Slovenian huts is mainly generated through mixed logs, which is already a reliable and sustainable option. In Valentina hut, liquefied petroleum gas still remains for now because of cooking and refrigerators, but in next steps refrigerators could be replaced with electrical ones since there is enough electricity generated with PV and wind system.

Spanish huts are different than Slovenian huts. They are big buildings, with several services (café, showers, restaurant, etc.) and they are opened during all the year. It implies a huge amount of energy needed, especially during the winter when the heating system is working but few people visit the huts. Considering it, the main actions implemented in Spanish hut were focused on increasing the renewable production, integrating new technologies with the previously installed (diesel generators). The idea of achieving a zero-emission huts, like happens in Slovenian cases, is completely difficult because of the operation of the huts and the services provided. Even so, it has been demonstrated that a higher range of renewable technologies is possible, especially when the natural resources are available.

In general, PV technology is a cheap, easy to install and easy to manage technology, so it is always a good possibility for huts. Apart from it, a heating system based on pellet or wood from the surroundings can be a positive option. Regarding other possibilities, hydro turbines are a robust, easy to manage and a high productive technology, although it is difficult to install, requires difficult permits and the CAPEX is expensive. Micro-winds turbine is also difficult, especially in Natural Parks where this technology is banned.

Finally, the reduction of 27,383 litres of diesel and 9,207 kg of propane gas are declared in Spanish hut during the monitoring protocol, reducing 94.99 tonnes of CO_2 emitted to the atmosphere (the calculation include also the Energy efficiency actions).

Italian hut in the project is totally different from the others. The Rifugio di Torino Hut situation is special because is connected to the grid, so the methodology implemented is not the same as the rest. The CO2 emissions have been calculated using the generation electric mix of Italy and the unit emissions in kind of technology, so, knowing the electrical consumption of the hut, it has been possible to calculate the total amount of CO2 emissions in the hut (*state at the beginning* CO2 ton/year = 74,68; *state at the beginning* NOx ton/year = 0,14),

The choice of photovoltaic panels is derived taking into account that the part of the Refuge used as a winter shelter is always open and without custody for the winter months, therefore with the need to have an energy "reserve" for heating the dormitory rooms and the room for drying clothes and storage for boots and materials. This solution allows you to have energy resources even in the absence of electricity from the general system.

Finally, **Table 4 summarises the main reasons** why a particular technology has been installed in a hut as well as other observations that are considered to be of interest in this respect.

ID	Hut	Country	SH Technology	Reason for implementation
#2	Lizara	Spain	PV	The electric generation was PV based and with good operation, but it was old with unsatisfactory energy production.
#7	Bachimaña	Spain	H2 Storage	The storage of renewable energy in the form of hydrogen had already been identified from the proposal phase of the project due to the particularities of the shelter in terms of availability of excess renewable energy source during most of the year, and specific needs in the rest of the year.
#10	Estós	Spain	PV	The hut had a PV system with good operation, but it was old and with unsatisfactory energy production.
#11	Estós	Spain	Pellet Stove	Pellet stoves were previously used in other huts, with successful operation. This option was evaluated considering the needs of Estós, and the evaluation was positive.
#13	Llauset	Spain	PV	The hut was new, so no demand came from previous experiences of the hut in terms of energy management. Considering the good operation of the PV in many huts, it was decided that PV was the best "first" option to introduce in this new hut.

#14	Llauset	Spain	Pellet Stove	The hut was new, so no demand came from previous experiences of the hut in terms of energy management. Considering the satisfactory operation of the pellet stoves in other huts, it was decided that it was the best “first” option to introduce in a new hut.
#16	Kocbekov	Slovenia	PV	The project partners made a search for huts where the actions could be carried out. This shelter was selected because its existing photovoltaic system was small and rather old.
#17	Pogačnikov	Slovenia	PV	PV was already installed at this hut, so the keepers were familiar with how to operate this technology. In addition, the location of this shelter is ideal for installing photovoltaics.
#18	Pogačnikov	Slovenia	Micro-Wind	ue to relatively good location for winds there was a common decision to include also Micro-Wind of 1000 W. This will also serve as a test if micro-wind turbine is appropriate technology for Slovenian high mountains.
#19	Torino	Italy	PV	CAI decided to install some new-generation photovoltaic panels as an experimental way to monitor their operation and efficiency, thinking in obtaining some lessons learned for other Italian huts not connected to the grid. The panels were installed in the south façade due to the huge amount of snow accumulated in the roof during the winter, so they were installed in a vertical position in the south wall.
#22	Montfalcó	Spain	PV	Montfalcó had previous PV installation with good operation. After joining this hut to the project, the keepers identified unsatisfactory electricity production from the PV operation. Once the system was analysed, it was decided to replace the old PV panels.
#24	Góriz	Spain	PV	The keepers demanded to enlarge the PV installation. FHa and FAM assessed the proposal from technical and financial aspects and assessment and the conclusion was positive.
#25	Dent Parracheé	France	PV	FFCAM joined the project in 2019: not enough time to implement renewable energies but to compare the renewable energies recently refurbished.
#26	Dent Parracheé	France	Hydro	

#27	Dent Parracheé	France	Wood Stove	
#28	Dent Parracheé	France	Solar Thermal	
#29	Valentina Stanica	Slovenia	PV	Regarding destroy of Kocbekov hut because of fire the Project looked for another hut in Slovenia. We made an inquiry for another hut and there was the most interest of Stanic hut. Their PV system was old and not sufficient to meet the electricity demand of the hut.
#30	Valentina Stanica	Slovenia	Micro-wind	Regarding destroy of Kocbekov hut because of fire the Project looked for another hut in Slovenia. We made an inquiry for another hut and there was the most interest of Stanic hut. They already had installed Micro-wind in the past but it was small scale and old, damaged and with very low efficiency.

TABLE 4. REASONS FOR TECHNOLOGY IMPLEMENTATION.