# Toward sustainable mountain huts with environmental impact assessment of used technologies

Mitja Mori*, Rok Stropnik
Faculty of Mechanical Engineering
University of Ljubljana
Ljubljana, Slovenia
*mitja.mori@fs.uni-lj.si

Manuel Gutiérrez, Pedro Casero
Foundation for the Development of New Hydrogen Technologies in Aragon P. T. Walqa, Ctra. Zaragoza N330A km 566, 22197 Cuarte,
Huesca, Spain

***Abstract*— A mountain hut (MH) is usually located in very sensitive parts of the nature. Operation phase of the MH emits pollutants into environment, because of energy supply for electricity and heat and transport linked with MH operation. If energy carriers used are mainly fossil fuel based that can cause significant environmental impacts. One of the goals of the EU SustainHuts project (http://sustainhuts.eu) is identification of technologies used for heat and electricity generation in MH. Through environmental assessment, technologies are compared to show environmental impacts of each technology prior to make case studies of specific MH. Life cycle assessment (LCA) is the basic methodology used in the study. Functional unit is 1kWh of generated energy, heat or electricity. Gabi Thinkstep software was used for LCA modelling and in life cycle impact assessment CML2001 indicators were used with additional Sofi indicators. Generic data was used from Ecoinvent 3.5 and Gabi professional database. In all MH observed electricity is partly generated with diesel generators. On other hand it is good to realize that in many cases the photovoltaic (PV) is used at least to partially cover the electricity demand. In one case (Bachimaña, Pyrenes, Spain) there is small hydropower, but without optimal control. Wind turbine is a case in one MH but not working because of mechanical failure. For heat generation in many cases mixed wood is used as a main fuel source. In the case of Lizara hut propane-butane (natural gas) is used in gas heater, in the case of Bachimaña diesel heater is present and the Refugio Torino is connected to the electrical grid what makes this MH unique in the sense of environmental assessment. For transportation main technologies are minivans, ropeways with electricity or diesel generators and helicopters in the case of inaccessibility. For electricity generation it is showed that from environmental point of view diesel electricity generation is the worst case, but still used in many MH since it is simple to manage and control. In many MH PV with battery energy storage/buffer slowly takes over that is much better from environmental point of view. Wind and hydro electricity generation have the lowest environmental impact, but they are not applicable in all locations. The worst case in heat generation is diesel and electricity heat generation. Natural gas has much smaller environmental impact than diesel or electricity heat generation. Wood heat generation has quite low environmental impact in global environmental indicators, but quite high in local environmental indicators, where combustion process of wood contribute to photochemical ozone creation, toxicity of marine/fresh water and also human toxicity.**

***Keywords*— mountain huts, life cycle assessment, electricity, heat, transport, fossil fuels, renewable energy sources***

## I. INTRODUCTION

Europe depends strongly on fossil fuel import from foreign countries where around 80 % of all petroleum reserves are. This dependence is a clear weakness for Europe´s economy and a major problem to be solved in the future. EU document states: "*The electricity may play the most important role in order to reach the zero emissions by 2050, contributing to replace fossil fuels in transport and heating"*, [1]. In order to support this statement, electricity generation has to be switched from mainly fossil fuel based today, toward renewable based electricity generation.

A mountain hut (MH) is an isolated construction in the mountains, where not only the access to utilities is complicated, but it is also difficult to transport anything to the hut. MH's are usually built from wood and stone with not sufficient insulation material to maintain comfort and provide shelter for visitors, mountaineers and hut caretakers. In the operation of MH electricity and heat are needed as two main energy sources that provide comfort and are needed for basic operation. Nowadays systems providing energy are mainly fossil fuel-based. In addition fuel needed for the operation has to be transported to MH that additionally impact environment due to truck, car, ropeway or helicopter use.

EU Life project SustainHuts targets in lowering of MH emission in the operation phase with introducing more RES based technologies and proper regulation and storage of energy, where needed, possible or feasible, [2]. MH are located in natural parks, where pollution is critical factor and the different authorities look for the best measures to prevent deterioration, contamination and conservation of natural habitats of wild fauna and flora. MH's have different environmental impacts such as: wastewater, solid wastes (plastics, cans…) noise and energy generation. Especially energy generation for heat, electricity and transport are the key contributors to the environmental impact of MH during their operation. To conserve the natural habitats the integration of zero emission solutions for generating electricity and heat for remote located huts is necessary in the future. To evaluate the implementation of effective solutions life cycle assessment (LCA) has be applied before and after implementation actions, [3], [4]. In the original project nine huts from four different countries (Italy, Romania, Slovenia and Spain) were involved. After 3 years some changes were made and there are still 5 huts

978-1-7281-3923-4/19/$31.00 ©2019 IEEE

from Spain, 2 from Slovenia, 1 from Italy. In 2019 one hut in Spain (Refugio de Goriz) and one hut in France (Refugio Temple-Ecrins) will probably join in 2019 what makes the total number of 10 mountain huts. The technologies to be applied for electricity generation will be based on PV, micro hydro power and wind energy generation, fuel cells, electrolysers and hydrogen storage. For heat generation more wood will be used where possible and in cases of surplus electricity from RES also electricity will be used for heat generation. In all huts control systems will be installed to optimize energy consumption as well as new insulated materials which will minimize the heat losses and contribute to less energy demand for heat generation.

In present paper all technologies used in mountain huts are evaluated in terms of life cycle assessment (LCA). Technologies at beginning state of play are compared with technologies at end state of play for generating 1kWh of electricity and heat. In addition some transport technologies are compared to get a basic knowledge regarding environmental impact of transport options.

## II. ENERGY GENERATION TECHNOLOGIES IN MOUNTAIN HUTS

First step is identification of all technologies used in MH for electricity, heat generation and transport. As a Basic output of life cycle inventory is LCI table with technologies and appropriate generic data from databases in Gabi software. LCI was made in all 9 huts and all technologies for energy generation and transport identified, [5]

### *A. Electricity generation*

In almost all huts diesel generator of different sizes are present for generation of electricity, [6]. In some MH PV is installed on the slanted roof and/or a facade, Bachimaña in Pyrenes has small hydropower-plant (30 kW) and in one MH small wind turbine is present but not working because of mechanical failure. Refugio Torino in Italy is connected to the grid and uses Italian electricity mix as electricity source.

Future technologies that will be installed for electricity are mainly mentioned above, in addition fuel cell and hydrogen technologies (FCH) will be installed in Bachimaña hut, but mainly as a midterm energy storage and not as main electricity generation technology. Therefore not direct comparison of the system comprised of polymer exchange membrane electrolyser, hydrogen tank and polymer membrane fuel cell is meaningful.

TABLE I. TECHNOLOGIES FOR ELECTRICITY GENERATION

| Technology | Data in Ecoinvent 3.5 | Output |
|---|---|---|
| **Diesel generator set** | GLO: diesel, burned in diesel-electric generating set, 18.5kW | 1 kWhe |
| **Photovoltaic on slanted roof** | ES: electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | 1 kWhe |
| **Photovoltaic on façade** | RoW: electricity production, photovoltaic, 3kWp facade installation, multi-Si, panel, mounted | 1 kWhe |
| **Small hydro power plant** | ES: electricity production, hydro, run-of-river | 1 kWhe |
| **Small wind turbine** | ES: electricity production, wind, <1MW turbine, onshore | 1 kWhe |
| **Electricity** | IT: Electricity grid mix ts | 1 kWhe |

Comparison in this case is better with battery storage at some point, but also not optimal since battery storage is used more for the short term and hydrogen storage for the midterm and possible long term storage.

To provide MH electricity within yearly operation time with dynamics within the typical day newly installed system with energy storage is of great importance

### *B. Heat generation*

Heat in MH is generated with hard wood and mixed logs in wood stoves, pellets, diesel heater, and butane-propane in gas heaters. In the case of Refugio Torino also electricity is used in electrical heater to heat the MH. In TABLE 2 all technologies used for heating are presented.

### *C. Transport*

The basic transport technologies used are mini truck, helicopter and ropeway. Ropeways are using electricity (Refugio Torino case) and diesel (Pogačnikov dom in Slovenia) as energy carrier. In the case of transport there is very challenging to make direct comparison of technologies normalized to one specific functional unit, because all mentioned technologies are used for specific cases of transport, where other technology couldn't be used. In the case of transport the comparison is possible just in the case of transport optimization in the case of specific hut, where specific measures can avoid extensive use of helicopter or ropeway that contributes to less energy use and avoided emissions to environment.

To make comparison of technologies we define two cases of transport:

a. To compare minivan with helicopter we define the transport of 3000 kg of goods to the hut of Lizara that is 74 km from Huesca for helicopter (1 hour) and 111 km for minivan.

TABLE II. TECHNOLOGIES FOR HEAT GENERATION

| Technology | Data in Ecoinvent 3.5 | Output |
|---|---|---|
| **Mixed logs** | RoW: heat production, mixed logs, at furnace 30kW ecoinvent 3.5 | 1 kWh |
| **Hardwood chips** | CH: heat production, hardwood chips from forest, at furnace 50kW ecoinvent 3.5 | 1 kWh |
| **Softwood chips** | RoW: heat production, softwood chips from forest, at furnace 50kW ecoinvent 3.5 | 1 kWh |
| **Pellets** | RoW: heat production, wood pellet, at furnace 25kW ecoinvent 3.5 | 1 kWh |
| **Diesel** | Europe without Switzerland: heat production, light fuel oil, at boiler 10kW, non-modulating ecoinvent 3.5 | 1 kWh |
| **Gas - low temperature boiler** | EU-28: Gas low temperature boiler < 20 kW (use) ts | 1 kWh |
| **Gas - natural gas, at boiler** | Europe without Switzerland: heat production, natural gas, at boiler atmospheric non-modulating <100kW ecoinvent 3.5 | 1 kWh |
| **Gas – central / small-scale** | Europe without Switzerland: market for heat, central or small-scale, natural gas ecoinvent 3.5 | 1 kWh |
| **Electricity - water heater** | EU-28: Electric instantaneous water heater (use) ts | 1 kWh |
| **Electricity - grid mix ts** | IT: Electricity grid mix ts | 1 kWh |

b. To compare ropeway with helicopter we need to transport 5000 kg of water approx., 1500 m in height. From the data of Refugio Torino we need 79,63 kWh electricity or 2 h of helicopter from Torino.

TABLE III. TECHNOLOGIES FOR TRANSPORT

| Technology | Data in Ecoinvent 3.5 | Description |
|---|---|---|
| **Mini truck** | EU28 Transport, van (up to 7,5 t total cap., 3.3t payload) (A4) | Units: kg/km |
| **Helicopter** | GLO transport, helicopter | Units: hours of flying |
| **Ropeway electrical** | - | Electricity use: kWh |
| **Ropeway diesel** | - | Diesel fuel use: kg |

## III. LCA METHODOLOGY USED FOR ENVIRONMENTAL IMPACTS

The life cycle assessment methodology applied in this study follows the ISO 14040 and 14044 standards [7], [8]. The LCA software Gabi Thinkstep has been used to model the processes, [9]. The impacts have been evaluated according to the CML 2001 method [10]. This is a problem oriented method, often referred to as a 'midpoint' approach, because it considers environmental burdens at an intermediate point between the point of intervention (extraction of resources or emissions to the environment) and the ultimate damage caused by that intervention. This method has been chosen here as one of the most commonly used by other studies [11].

In CML2001 methodology there are 12 environmental indicators that can be sorted in global, regional and local environmental indicators. In global indicators are abiotic depletion (ADP elements and ADP fossil), global warming (GWP 100 years and GWP 100 years excluding biogenic carbon) and ozone depletion (ODP). Among those indicators the most popular in general public is GWP, but it is just the indicator that shows us how intense the technology/process uses fossil fuels. So more fossil fuels indicates in higher GW, [12].

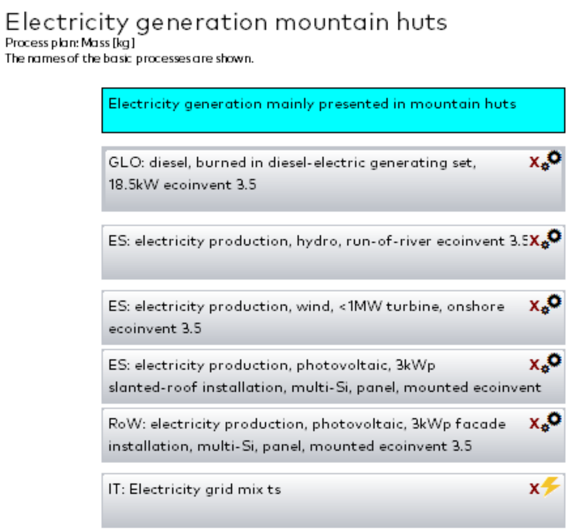


*Fig. 1. LCA model electricity generation technologies*

In addition $CO_2$ is not pollutant according to EU legislation, so it is very important to analyze other indicators more in detail too. In category of regional indicators acidification (AP), fresh water eco toxicity (FAETP) and marine water eco toxicity (MAETP) are discussed. In category of local environmental impact indicators eutrophication (EP), human toxicity (HTP), photochemical ozone creation (POCP) and terrestrial eco toxicity (TETP) are discussed.

In addition to CML2001 environmental impacts are evaluated with mass emissions to environment according to SOFI, [13]. Mass emissions to environment are one of the requirements to monitor in the LIFE SustainHuts project [2].

### *A. LCA models and functional units*

LCA models for electricity and heat generation technologies are simple when all data are available from generic databases, [14], [15]. In Fig. 1, technologies used for electricity generation in are presented as used in LCA model. Functional unit in all cases is 1 kWh of generated electricity.

LCA model of heat generation technologies is presented in Fig. 2, where all technologies present in MH are included. Heat is generated with diesel, natural gas, electricity, wood, pellets. In LCA model different sizes of appliances are included to see what the influence of device size on environmental impact is. Processes of heat generation on bigger scale (EU28 Thermal energy from natural gas, lignite, LFO, hard coal and biomass) are included for comparison.

LCA model for transport to MH is presented in Fig. 3. As explained before transport technologies in the case of transport to MH is not possible in all transport cases. Where ropeway is used the only comparison possible is helicopter.


*Fig. 2. LCA model for heat generation technologies*

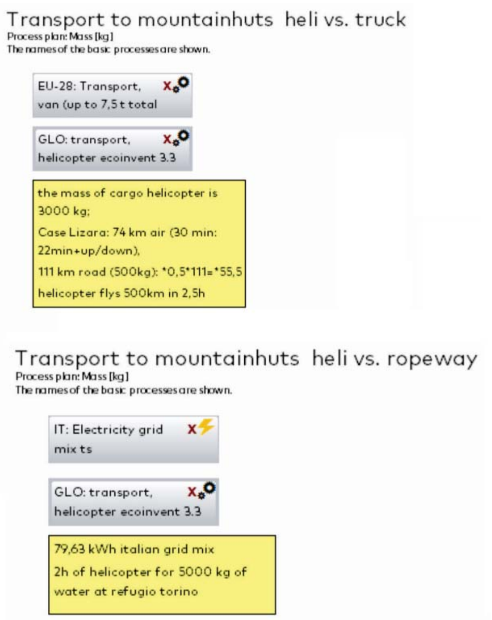


*Fig. 3. LCA model for used transport technologies*

## IV. RESULTS

Results are divided in three parts covering technologies for electricity generation, heat generation and transport.

### *A. Electricity generation environmental results*

Absolute values of CM2001 environmental impact indicators for electricity generation technologies are presented in TABLE IV, where relative comparison of environment impacts for all identified technologies is made. The biggest impact to environment has 1kWhe generated from diesel electric generator. Looking at $CO_2$ emissions and global warming potential (GWP) diesel generated electricity and electricity from Italian grid mix are the worse cases.

TABLE V. MASS EMISSIONS TO AIR FOR DIFFERENT ELECTRICITY GENERATION TECHNOLOGIES PER 1KWH IN MH

| | Hydro (run of river) | PV (slanted roof) | PV (facade) | Wind (onshore) | Diesel generator | Electricity grid mix (IT) |
|---|---|---|---|---|---|---|
| **$CO_2$ [kg]** | 3,8E-03 | 5,3E-02 | 9,3E-02 | 1,1E-02 | 8,9E-01 | 3,8E-01 |
| **$NO_x$ [kg]** | 1,5E-05 | 1,5E-04 | 2,6E-04 | 3,3E-05 | 1,5E-02 | 5,0E-04 |
| **$SO_x$ [kg]** | 7,0E-06 | 2,5E-04 | 4,4E-04 | 4,4E-05 | 1,7E-03 | 3,4E-04 |
| **VOC [kg]** | 5,9E-06 | 1,8E-04 | 3,0E-04 | 3,9E-05 | 5,6E-04 | 1,1E-03 |
| **PM [kg]** | 5,2E-06 | 6,4E-05 | 1,1E-04 | 1,6E-05 | 1,8E-03 | 1,3E-05 |

The best technology environmentally wise is electricity from hydropower and wind.

For small PV power plant global indicators are in the line with hydro and wind generated electricity, but in the case of regional MAETP, FAETP and local HTP and TETP small slanted roof and facade PV installation have relative big environmental impact in comparison even with electricity mix from Italian grid mix that comes 33,5 % of natural gas, 21,5 % of hydro, 15,2 % of hard coal and 8 % of photovoltaic. The reason for that is manufacturing process of PV systems and the fact that small systems on the roof are not optimized in position toward the sun and therefore produce less electricity per surface unit than big PV systems.

If we access the environmental impacts with mass emissions (TABLE V) we can see that results are more in the line of expectations with diesel engine being the worst case and Italian electricity mix environmentally worse case as small PV system. Nevertheless it is visible that PV on the facade is not as optimal as in the case of slanted roof. The reason for that is that in the case of facade the position of panels is not optimal relatively to the sun and therefore the electricity generation is smaller for the same surface.

TABLE IV. ENVIRONMENTAL IMPACT INDICATORS FOR 1KWH FOR ELECTRICITY GENERATION IN MH

| | ES: electricity production, hydro, run-of-river ecoinvent 3.5 | ES: electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted ecoinvent 3.5 | RoW: electricity production, photovoltaic, 3kWp facade installation, multi-Si, panel, mounted ecoinvent 3.5 | ES: electricity production, wind, <1MW turbine, onshore ecoinvent 3.5 | GLO: diesel, burned in diesel-electric generating set, 18.5kW ecoinvent 3.5 | IT: Electricity grid mix ts |
|---|---|---|---|---|---|---|
| **ADP elements [kg Sb eq.]** | 1,97E-08 | 2,48E-06 | 4,36E-06 | 1,97E-07 | 1,29E-06 | 4,01E-07 |
| **ADP fossil, [MJ]** | 3,59E-02 | 6,72E-01 | 1,17E+00 | 1,44E-01 | 1,32E+01 | 5,19E+00 |
| **AP, [kg SO2 eq.]** | 1,77E-05 | 4,06E-04 | 7,07E-04 | 7,25E-05 | 9,37E-03 | 9,51E-04 |
| **EP, [kg Phosphate eq.]** | 7,52E-06 | 2,50E-04 | 4,37E-04 | 4,58E-05 | 2,37E-03 | 1,11E-04 |
| **FAETP inf., [kg DCB eq.]** | 0,00247 | 0,163 | 0,285 | 0,0525 | 0,104 | 0,000691 |
| **GWP 100 years, [kg CO2 eq.]** | 0,00404 | 0,0599 | 0,104 | 0,0126 | 0,926 | 0,419 |
| **GWP 100 years, excl biogenic carbon [kg CO2 eq.]** | 0,00402 | 0,06 | 0,104 | 0,0126 | 0,926 | 0,42 |
| **HTP inf., [kg DCB eq.]** | 0,00722 | 0,142 | 0,249 | 0,0695 | 0,17 | 0,0299 |
| **MAETP inf., [kg DCB eq.]** | 4,4 | 208 | 363 | 39,3 | 199 | 34,8 |
| **ODP, steady state, [kg R11 eq.]** | 3,16E-10 | 6,17E-09 | 1,08E-08 | 6,88E-10 | 1,66E-07 | 5,25E-13 |
| **POCP, [kg Ethene eq.]** | 2,00E-06 | 3,52E-05 | 6,15E-05 | 8,50E-06 | 0,000906 | 6,10E-05 |
| **TETP inf., [kg DCB eq.]** | 0,000194 | 0,00075 | 0,00134 | 0,00179 | 0,00187 | 4,56E-05 |

TABLE VI. ENVIRONMENTAL IMPACT INDICATORS FOR 1KWH OF HEAT GENERATION WITH DIFFERENT TECHNOLOGIES IN MH

| | electricity | | gas | | | diesel | wood | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EU-28: Electric instantaneous water heater (use) ts | IT: Electricity grid mix ts | EU-28: Gas low temperature boiler < 20 kW (use) ts | Europe without Switzerland: heat production, natural gas, at boiler atmospheric non-modulating <100kW ecoinvent 3.5 | Europe without Switzerland: market for heat, central or small-scale, natural gas ecoinvent 3.5 | Europe without Switzerland: heat production, light fuel oil, at boiler 10kW, non-modulating ecoinvent 3.5 | CH: heat production, hardwood chips from forest, at furnace 50kW ecoinvent 3.5 | RoW: heat production, mixed logs, at furnace 30kW ecoinvent 3.5 | RoW: heat production, softwood chips from forest, at furnace 50kW ecoinvent 3.5 | RoW: heat production, wood pellet, at furnace 25kW ecoinvent 3.5 |
| **ADP elements [kg Sb eq.]** | 2,2E-07 | 4,0E-07 | 1,7E-08 | 9,4E-08 | 9,5E-08 | 2,0E-07 | 6,4E-08 | 1,1E-07 | 6,3E-08 | 1,7E-07 |
| **ADP fossil, [MJ]** | 4,42 | 5,19 | 4,61 | 3,92 | 3,82 | 4,87 | 0,18 | 0,38 | 0,35 | 0,69 |
| **AP, [kg SO2 eq.]** | 1,2E-03 | 9,5E-04 | 1,5E-04 | 2,5E-04 | 2,6E-04 | 8,4E-04 | 4,3E-04 | 3,9E-04 | 4,2E-04 | 4,5E-04 |
| **EP, [kg Phosphate eq.]** | 1,1E-04 | 1,1E-04 | 2,2E-05 | 5,3E-05 | 6,4E-05 | 2,1E-04 | 1,7E-04 | 1,6E-04 | 1,6E-04 | 1,9E-04 |
| **FAETP inf., [kg DCB eq.]** | 9,0E-04 | 6,9E-04 | 9,3E-05 | 1,2E-02 | 1,5E-02 | 2,1E-02 | 1,1E-02 | 1,5E-02 | 1,7E-02 | 2,8E-02 |
| **GWP 100 y [kg CO2 eq.]** | 0,42 | 0,42 | 0,28 | 0,27 | 0,26 | 0,34 | 0,12 | 0,04 | 0,08 | 0,36 |
| **GWP 100 y ex. [kg CO2 eq.]** | 0,42 | 0,42 | 0,28 | 0,27 | 0,26 | 0,34 | 0,02 | 0,04 | 0,03 | 0,06 |
| **HTP [kg DCB eq.]** | 0,02 | 0,03 | 0,02 | 0,04 | 0,04 | 0,05 | 0,05 | 0,05 | 0,05 | 0,07 |
| **MAETP [kg DCB eq.]** | 49,7 | 34,8 | 1,3 | 33,7 | 39,3 | 53,0 | 13,3 | 31,6 | 36,4 | 84,4 |
| **ODP [kg R11 eq.]** | 1,8E-12 | 5,3E-13 | 3,8E-14 | 2,4E-08 | 2,3E-08 | 6,2E-08 | 2,8E-09 | 3,4E-09 | 2,6E-09 | 3,6E-09 |
| **POCP [kg Ethene eq.]** | 7,4E-05 | 6,1E-05 | 2,0E-05 | 5,2E-05 | 5,1E-05 | 6,6E-05 | 1,6E-04 | 2,8E-04 | 1,4E-04 | 7,1E-05 |
| **TETP [kg DCB eq.]** | 3,0E-04 | 4,6E-05 | 1,8E-05 | 2,7E-04 | 2,9E-04 | 7,4E-04 | 2,3E-03 | 2,1E-03 | 1,8E-03 | 1,4E-03 |

## B. *Heat generation environmental results*

Heat generation processes used in MH are presented in TABLE II and the LCA model in Fig. 2. Some processes are added to the model for easier evaluation of results. In TABLE VI environmental indicators for all possible technologies for heat generation in MH are presented.

TABLE VII. EMISSIONS TO AIR FOR 1 KWH OF HEAT GENERATED WITH DIFFERENT TECHNOLOGIES IN MH

| | $CO_2$ [kg] | $No_x$ [kg] | $SO_x$ [kg] | VOC [kg] | PM [kg] | |
|---|---|---|---|---|---|---|
| Electric water heater | 0,39 | 5,9E-04 | 6,4E-04 | 7,1E-04 | 1,9E-05 | **Electricity** |
| Electricity grid mix (IT) | 0,38 | 5,0E-04 | 3,4E-04 | 1,1E-03 | 1,3E-05 | |
| Gas: low temperature boiler | 0,26 | 1,6E-04 | 5,9E-05 | 6,3E-04 | 3,3E-06 | **Gas** |
| natural gas, at boiler atmospheric | 0,24 | 1,3E-04 | 1,5E-04 | 1,2E-03 | 1,0E-05 | |
| central or small-scale, natural gas | 0,23 | 1,3E-04 | 1,5E-04 | 1,2E-03 | 1,1E-05 | |
| light fuel oil, at boiler | 0,33 | 2,8E-04 | 5,7E-04 | 1,9E-04 | 2,8E-05 | **Diesel** |
| hardwood chips at furnace | 0,01 | 7,1E-04 | 3,4E-05 | 5,3E-05 | 4,7E-04 | **Wood** |
| mixed logs at furnace | 0,03 | 5,4E-04 | 8,3E-05 | 7,8E-05 | 2,6E-04 | |
| softwood chips at furnace | 0,03 | 6,0E-04 | 7,7E-05 | 7,5E-05 | 4,9E-04 | |
| wood pellets at furnace | 0,05 | 4,5E-04 | 1,6E-04 | 1,6E-04 | 2,9E-04 | |

Green color represents low environmental impacts and red color high environmental impacts. In general it is evident that heat from diesel and electricity is not a good choice from environmental point of view. Gas and wood in general are good choices of heat generated, but in the case of pellets impacts are higher since pellets have to be manufactured and that require some energy.

In TABLE VII emissions to air for all technologies for 1 kWh of heat generation is presented. $CO_2$ emissions are high in the case of heat from electricity and diesel, and very low in the case of heat from wood. $NO_X$ are high in the case of heat from electricity and wood (mixed logs, hard and soft wood). In the case of wood the combustion is not controlled in the stove resulting in higher $NO_X$ and also particulate matters. Volatile organic compounds are higher in all technologies linked with fossil fuels.

From Fig. 4, it can be concluded that every technology used for heat generation has some plusses and some minuses. In general bigger surface means higher environmental impact of technology, but to understand better, we have to look more in details:

- In almost all global indicators (ADP, GWP) heat from electricity from Italian grid mix has the biggest environmental impact.
- In the case of ODP heat from diesel has the biggest impact because of processes at refinery, where they use some chemicals that influence ozone layer.
- Heat from natural gas seems in the middle in almost all criteria.

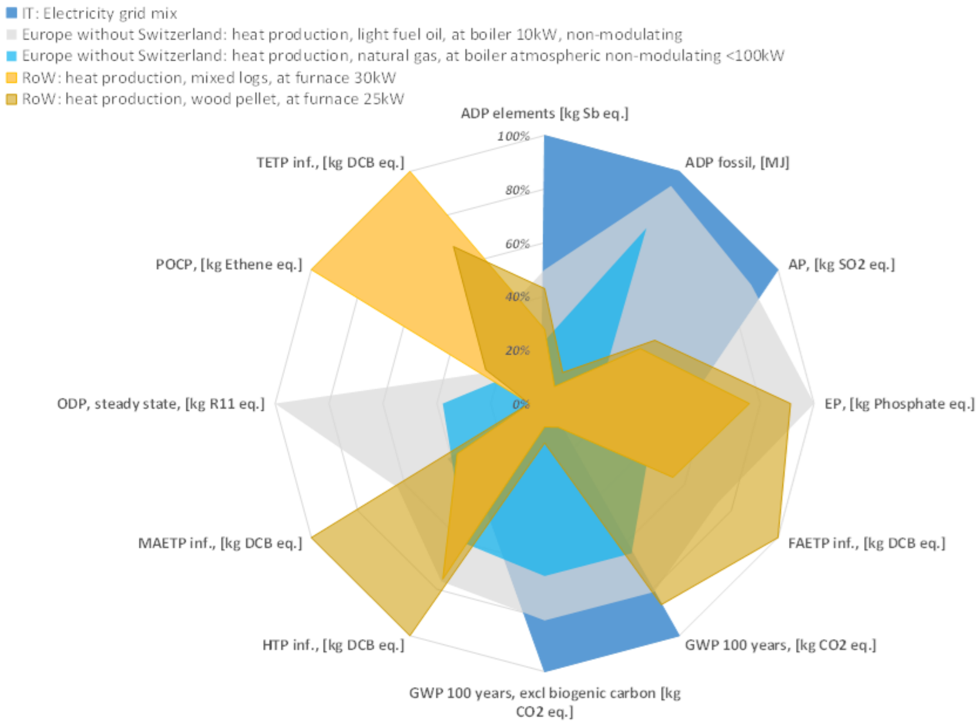


*Fig. 4. Comparison of environmental impacts of heat generation technologies in MH*

- Heat from the mixed logs is ok from global and regional criteria point of view, but has high impact in local criteria (POCP, HTP; TETP). The reason for that is that the process is linked with combustion process that in the case of mixed logs is not ideally controlled and emissions because of that can be high.

Heat from pellets has even bigger environmental impact in local criteria that heat from mixed logs. Pellets have to be manufactured and that require additional processes and energy.

## C. *Transport environmental results*

In transport the comparison between minivan and helicopter was made for Spanish hut Lizara (Fig. 5.) and between transport with ropeway with electricity drive and helicopter for Refugio Torino (Fig. 6.), where transportation of water is done daily. Comparing environmental impacts of transport technologies it is evident that helicopter has the biggest impact, so careful planning of transports has to be done in order to minimize the impact of the transport.

In the case of ropeway in Refugio Torino water is transported on daily basis with electrically driven ropeway that needs 79,63 kWh of electricity for 5000 liters of water that is needed for hut operation. To transport water with helicopter would be very expensive on one side and also not environmentally sound. In order to lower environmental impacts of transport all huts have to be assessed individually. For example in the case of Refugio Torino transport of water could be partly avoided if water management on the hut location is done with appropriate water collection from snow and rain.

In the case of ropeway in Refugio Torino water is transported on daily basis with electrically driven ropeway that needs 79,63 kWh of electricity for 5000 liters of water that is needed for hut operation. To transport water with helicopter would be very expensive on one side and also not environmentally sound. In order to lower environmental impacts of transport all huts have to be assessed individually. For example in the case of Refugio Torino transport of water could be partly avoided if water management on the hut location is done with appropriate water collection from snow and rain.

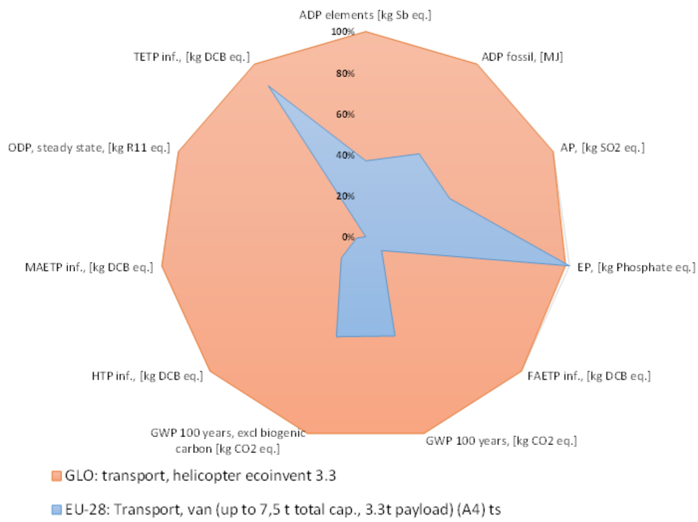


*Fig. 5. Comparison of environmental impacts of transport with minivan and helicopter for Lizara hut*

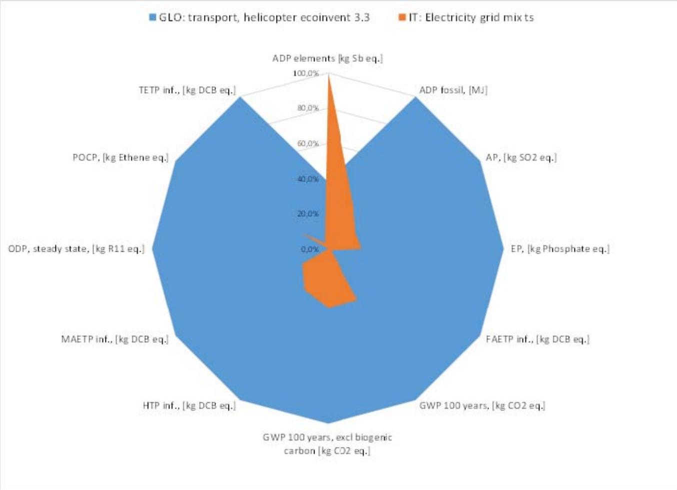


*Fig. 6. Comparison of environmental impacts of transport with electricity drived ropeway and helicopter for Refugio Torino*

## V. CONCLUSION

In the paper technologies for electricity and heat generation in mountain huts within Life SustainHuts project are identified and assessed with LCA methodology. The case is built on nine huts Spain, Italy, Slovenia and France. The goal was to make environmental impact assessment of single technology per 1 kWh of electricity or heat. Those results will serve as a basic input of life cycle assessments that will be done for each mountain hut in the project where we will compare environmental impact of MH before and after modifications of installations. From results of this study can be concluded:

- Electricity generated from diesel generators has the biggest environmental impacts in all criteria.
- Electricity from Italian grid mix (Refugio Torino case) has big environmental impact in global environmental criteria, but lower environmental impact from small PV systems in regional and local criteria.
- Small PV systems mounted on the slanted roof are environmentally better that PV systems mounted to facade. But both have bigger impacts than wind and hydroelectricity that turns out to be environmentally top technologies.
- Heat generation from diesel is also the worst case, followed by heat generated with electricity.
- Nevertheless that natural gas is worse from wood technologies in global environmental criteria (GWP, ODP and ADP) is better when talking about some regional and local indicators.
- In the transport technologies the approach has to be very target oriented with optimization criteria on place. Helicopter is not environmentally sound technology but the only possibility in some locations. The same goes for ropeways, so every hut will have to be considered separately.

In the case of electricity generation the best technologies are wind and hydro in the case of heat generation mixed logs are sustainable solution, but where fossil fuels are still the fact natural gas is good choice.phase.

## ACKNOWLEDGMENT

The work was accomplished in the scope of SustainHuts Life project funded from Programme for the Environment and Climate Action (LIFE) and repealing Regulation (EC) No 614/2007.

## REFERENCES

[1] European Commission, “COMMUNICATION FROM THE COMMISION: A Roadmap for moving to a competitive low carbon economy in 2050,” *COM(2011) 112 Final*, vol. 34, no. March, pp. 1–34, 2011.

[2] “EU project: SustainHuts - Demonstrative project which aims to reduce CO2 emissions in natural environments acting in huts; G.A. LIFE15 CCA/ES/000058,” 2016. [Online]. Available: http://sustainhuts.eu/. [Accessed: 03-Oct-2018].

[3] Z. Günkaya, A. Özdemir, A. Özkan, and M. Banar, “Environmental Performance of Electricity Generation Based on Resources: A Life Cycle Assessment Case Study in Turkey,” *Sustainability*, vol. 8, no. 12, p. 1097, 2016.

[4] C. Smith *et al.*, “Comparative Life Cycle Assessment of a Thai Island’s diesel/PV/wind hybrid microgrid,” *Renew. Energy*, vol. 80, pp. 85–100, Aug. 2015.

[5] M. M. Lotrič A., Stropnik R., Drobnič B., Sekavčnik M., “LIFE15 CCA / ES / 000058 LIFE SUSTAINHUTS : SUSTAINABLE MOUNTAIN HUTS IN EUROPE C5 Life cycle assessment and environmental analysis C5 . 1 Identification of technologies used in mountain huts and specifications of huts construction in Pyrenees , Alps and,” pp. 1–34, 2017.

[6] M. M. Lotrič A., Stropnik R., Drobnič B., Sekavčnik M., “LIFE15 CCA / ES / 000058 LIFE SUSTAINHUTS : SUSTAINABLE MOUNTAIN HUTS IN EUROPE, C5 Life cycle assessment and environmental analysis, C5.2 Life cycle inventory analysis (LCIA): Mass and energy balances of mountain huts,” pp. 1–34, 2017.

[7] International Organisation for Standardisation, “ISO 14040 (2006a): Environmental management - Life cycle assessment - Principles and framework,” 2006.

[8] International Organisation for Standardisation, “ISO 14044: Environmental management - Life cycle assessment - Requirements and guidelines,” 2006.

[9] M. Baitz *et al.*, “GaBi thinkstep: Database & Modelling Principles,” *PE International*, no. November. pp. 1–178, 2017.

[10] Thinkstep, “Life Cycle Impact Assessment (LCIA) methods: GaBi Software,” 2018. [Online]. Available: http://www.gabi-software.com/uk-ireland/support/gabi/gabi-5-lcia-documentation/life-cycle-impact-assessment-lcia-methods/.

[11] D. García-Gusano, D. Garraín, and J. Dufour, “Prospective life cycle assessment of the Spanish electricity production,” *Renew. Sustain. Energy Rev.*, vol. 75, pp. 21–34, 2017.

[12] R. Turconi, A. Boldrin, and T. Astrup, “Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations,” *Renew. Sustain. Energy Rev.*, vol. 28, pp. 555–565, 2013.

[13] Thinkstep, “Corporate Sustainability Software - SoFi | thinkstep.” .