Universidad de Oviedo

ESCUELA POLITÉCNICA DE INGENIERÍA DE GIJÓN.

MÁSTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

ÁREA DE ENERGÍA

ENVIRONMENTAL IMPACTS OF THE MOUNTAIN HUTS

IMPACTOS MEDIOAMBIENTALES EN LOS REFUGIOS DE MONTAÑA

LÓPEZ IGLESIAS, Paula
TUTOR: M.ª Manuela Prieto

FECHA: Junio 2018

Impactos Medioambientales en los Refugios de Montaña

1 Introducción

En la actualidad, el cambio climático, a nivel mundial, es una de las mayores preocupaciones de nuestros ciudadanos. En respuesta a esto, surge el "Acuerdo de Paris" más conocido como COP21, que busca un compromiso sobre la reducción de las emisiones de contaminantes a la atmósfera y que ha surgido con el objetivo de fortalecer la respuesta global al cambio climático, cuya aplicabilidad sería para el año 2020, una vez finalice la vigencia del Protocolo de Kioto. Entre los múltiples objetivos, se encuentra el de disminuir las emisiones de los gases de efecto invernadero casi por completo. Para ello, se debe reducir el uso abusivo de combustibles fósiles, ya que se estima que alrededor del 86 % de la demanda mundial de energía proviene de los mismos. Además, algunos problemas de contaminación están aumentando debido a las emisiones relacionadas con el proceso de combustión. Por lo que se debe promover la generación de energía a partir de energías renovables.

En base a esto, existen tanto lugares como actividades donde se pueden considerar algunas alternativas para disminuir las emisiones, como es el caso de las montañas con acceso limitado, en ellas hay construcciones aisladas llamadas cabañas o refugios. De manera que un refugio es generalmente una construcción aislada en la montaña, donde su funcionamiento afecta al medio ambiente como consecuencia de la generación de energía necesaria para el funcionamiento de la misma, así como las actividades relacionadas con la provisión de suministros tanto de combustible como provisiones que conllevan efectos negativos asociados.

Para que los refugios sean más sostenibles y con menos emisiones al medio ambiente, las fuentes de energía renovables deben implementarse en los refugios y las tecnologías actuales deben optimizarse para alcanzar la máxima eficiencia energética posible. Con estas acciones, todas las emisiones al aire, al agua y al suelo podrían reducirse a valores mínimos. Por tanto, el proyecto LIFE SUSTAINHUTS que puede traducirse como *Refugios Sostenibles*, surge con el objetivo de implementar soluciones sostenibles en las cabañas y disminuir las emisiones de CO_2 y NO_X

Para reducir la dependencia de los combustibles fósiles en los refugios y, promover la generación de energía renovable, se identificarán las tecnologías actuales presentes en las 9 cabañas que constituyen el proyecto, a fin de compararlas con las tecnologías alternativas tanto nuevas como ya instaladas, a fin de determinar los impactos ambientales y el potencial de las nuevas tecnologías instaladas.

Por lo tanto, la evaluación del ciclo de vida (ACV), en inglés Life Cycle Assesment (LCA), es la herramienta elegida para el estudio del impacto ambiental. Aunque, existen muchas maneras diferentes de estudiarlo, para el presente proyecto se ha escogido la metodología del método de evaluación del impacto CML 2001, en donde se estudiarán 12 indicadores de impacto ambiental. Los indicadores se clasifican en global, regional y local. Con el software Gabi Thinkstep se llevarán a cabo tres modelos numéricos, de manera que se hará un modelo numérico para la generación de electricidad y para la generación de calor, así como para las tecnologías de transporte. Para hacer una comparación más fácil entre las tecnologías eléctricas y también para las tecnologías de calor, la unidad funcional será de 1 kWh por energía generada. Mientras que para el transporte, la unidad funcional será de 130 km (1 hora) y 5.5 t.

2 Refugios de Montaña Presentes en el Proyecto

En este capítulo, se detallan los nueve refugios de montaña asociados al proyecto. Los refugios se encuentran localizados en 4 países europeos diferentes. En concreto, dos refugios se encuentran ubicados en Eslovenia (Kocbekov dom and Pogačnikov dom); 5 en España, de los cuales 4 se encuentran actualmente involucradas en el proyecto (Bachimaña, Llauset, Lizara y Estós) y otra se incluirá próximamente (Montfalcó); 1 en Italia (Refugio de Torino) y por último, 1 en Francia (Refugio de D’Ayous).

A continuación cabe destacar las altitudes de cada uno de los refugios de montaña:

En Eslovenia, los 2 refugios se encuentran ubicados en los Alpes eslovenos con una altitud de:

- Kocbekov dom (1808 m)
- Pogačnikov dom (2050 m)

En España, hay 5 refugios demo ubicados en los Pirineos:

- Montfalcó (790 m)
- Lizara (1540 m)
- Estós (1890 m)
- Bachimaña (2200 m)
- Cap de Llauset (2450 m)

En Italia, un refugio demo ubicado en los Alpes italianos:

- Refugio de Torino (3375 m)

En Francia, hay un reciente refugio demo ubicado en los Pirineos Atlánticos:

- Refugio de Ayous (1980 m)

A lo largo de este capítulo, se detallan los datos sobre las especificaciones de cada uno de los refugios presentes en este estudio junto con una tabla en donde se listan las tecnologías que hay en cada cabaña, diferenciadas acorde a su función (generación de electricidad o calor). Además, se diferenciarán dos estados de los refugios; uno, en donde se detalla el estado actual de cada cabaña (ubicación exacta, dimensiones, promedio de visitas por día, capacidad de alojamiento, así como una breve descripción de los alrededores en los que se encuentran ubicadas y el modo de acceso a los mismos), y en el otro, un estado de las futuras actividades.

Basándose en parámetros tan importantes como la demanda del turismo, la ubicación y el clima en cada refugio; así como el aspecto económico en cada cabaña se encuentran instaladas diferentes tecnologías, las cuales serán analizadas en detalle en el próximo capítulo.

3 Inventario: Balance de Masa y Energía

En este capítulo se encuentran detalladas las especificaciones técnicas de cada uno de los refugios de montaña del presente proyecto, a continuación se resumen las características más destacables con el objetivo de analizar la posibilidad de mejorar las tecnologías actuales y/o instalar nuevas.

KOCBEKOV DOM

El refugio se encuentra abierto de junio a octubre (4 meses/año). La instalación del refugio consta de 1 generador diésel, paneles fotovoltaicos para la generación de electricidad con equipos compatibles como baterías y convertidores. Además, consta de una estufa de leña que funciona con biomasa (leña) y también un horno de leña para la generación de calor.

Generación de electricidad y calor

La electricidad se proporciona utilizando un generador diésel con 5 kW de potencia nominal y produce 1500 kWh de electricidad al año, paneles fotovoltaicos instalados en la pared (12 x Siemens SM50) de 600 W de potencia y de 700 W en el tejado (10 x Siemens SM70), baterías de 1200 Ah (12 x 2 V) y tres controladores de carga, por lo que la cabaña no está conectada al sistema de red (fuera de red). En el sistema de la cabaña hay un inversor de 1500 W CC/CA.

La generación de calor se basa solo en la biomasa, la estufa de leña es la tecnología actualmente instalada.

Transporte

Para acceder al refugio Kocbekov, el único medio posible es caminado. Sin embargo, tanto los bienes y provisiones como el combustible requieren de un helicóptero para ser transportados hasta el refugio.

Estado futuro

Una solución para mejorar la sostenibilidad de la cabaña de montaña es incrementar la capacidad de los módulos fotovoltaicos.

Pogačnikov dom

Pogačnikov se encuentra abierto 3 meses al año. Las tecnologías instaladas para la generación de electricidad son un generador diésel y otro de gasolina. Además, tiene instalado paneles fotovoltaicos, baterías y alternadores. Para la generación de calor, se usa tanto estufas de madera como hornos.

Generación de electricidad y calor

A través de un sistema sin conexión a red, la instalación consta de dos generadores, diésel y gasolina, 4200 W y 4500 W, respectivamente. El generador diésel produce 1684.2 kWh/año, mientras que el de gasolina apenas se usa. Por otra parte, los paneles fotovoltaicos consisten en paneles con instalación de pared de potencia 770 W y, los de instalación en el techo una potencia de 800 Ah. En relación con la generación de calor consta de una estufa y un horno de leña.

Transporte

El único modo de acceder al refugio es caminando. Por tanto, para transportar los bienes y el combustible se emplea un teleférico de carga. Aunque también se requiere del helicóptero para el caso de aquellas cargas más pesadas, como las provenientes de renovaciones o modificaciones del refugio.

Estado futuro

Una solución para mejorar la sostenibilidad de la cabaña de montaña es incrementar la capacidad de los módulos fotovoltaicos. Además de una turbina eólica de 500 W de potencia.

Refugio de Torino

Torino se encuentra abierto durante 11 meses al año (cerrado en noviembre). A diferencia del resto de refugios de montaña del proyecto, Torino está conectado a la red eléctrica con voltaje medio.

Generación de electricidad y calor

La instalación conectada a la red eléctrica con voltaje medio consta de un contador de 70 kW. Para la generación de calor, el calor se obtiene a partir de la electricidad, los dispositivos que se utilizan son 4 ventiladores eléctricos de 5 kW cada uno con una potencia instalada de 20 kW, y 6 calentadores eléctricos de 2 kW cada uno, además de 2 estufas de pellets.

Transporte

El refugio tiene un contrato para la gestión del teleférico de 21600 €/año para conectarse a ella, y otro para el transporte de agua. Además tiene otro contrato de 1800 €/mes para el transporte de bienes y de los empleados-

Estado futuro

Una de las propuestas para el Refugio de Torino es la instalación de paneles fotovoltaicos y una turbina hidraúlica.

Refugio de Bachimaña

Bachimaña se encuentra abierta durante todo el año. La cabaña consta de 2 generadores diésel y una micro hidráulica (una turbina), así como baterías y convertidores. Actualmente consta de un calentador diésel para la generación de calor.

Generación de electricidad y calor

La principal fuente de energía en Bachimaña es el agua (durante 10 meses al año) para la producción de electricidad, además se emplea el diésel (durante 2 o 3 meses) para la generación de calor. Por lo tanto, la instalación consta de 2 motores diésel de 8 kW y 25 kW, que en total suman una potencia total de 32 kW aunque se prescinde del generador diésel pequeño. La mini central hidráulica está formada por una turbina de 30 kW. Cabe destacar que el motor diésel pequeño solo se emplea en caso de que el mayor falle.

Cuando no se emplea la turbina se usa el generador diésel.

Transporte

Para proporcionar todos los bienes y combustibles necesarios, en este caso se requiere el uso de 2 métodos de transporte un camión y un helicóptero.

Estado futuro

A corto plazo, las tecnologías propuestas para hacer más sostenible el refugio son, en primer lugar una caldera eléctrica para sustituir la caldera diésel, se reemplazará el combustible fósil por la electricidad generada por una fuente renovable. Además, se propone la instalación de una micro turbina eólica y un colector de agua caliente.

Refugio de Lizara

El refugio se encuentra abierto durante los 12 meses del año. Está provisto de dos motores diésel, generación fotovoltaica y un sistema de almacenamiento de baterías, en donde se almacena la energía sobrante generada. En referencia al sistema de calefacción, el refugio consta de dos calderas de gas natural con un tanque de agua, además de una estufa de leña.

Generación de electricidad y calor

Los dos motores diésel tienen una potencia de 12 kW y 32 kW, respectivamente. Y en referencia a la potencia de la fotovoltaica se trata de 4 kW y 5 kW, cuya potencia útil instalada es de 0,5 kW, los paneles se encuentran divididos en 4 de 195 W, 17 de 123 W y 15 de 100 W. Por lo general, la cabaña opera con el generador pequeño, excepto si se requiere de más energía. El almacenamiento del sistema está compuesto por 24 baterías, de 2 V y 800 Ah cada una.

Para la generación de calor, la cabaña consta de dos calderas de gas natural con un tanque de una capacidad de 120 l de agua. Además de una estufa de leña.

Transporte

Para el acceso a la cabaña, en este caso se puede acceder a través de un vehículo (coche o camión), por lo que no se requiere el uso de helicóptero.

Estado futuro

Como propuestas para mejorar la sostenibilidad en el refugio de Lizara, se aumentará la potencia actual del sistema fotovoltaico en 3.5 kW adicionales. Además se reemplazaran las matrices más antiguas instaladas por otras nuevas. Con el objetivo de controlar automáticamente el sistema eléctrico, se considerará instalar un sistema de autómatas, AII (Advanced Automation of Installation)

Refugio Cap de Llauset

El refugio se encuentra abierto todo el año. Las tecnologías instaladas para la generación de electricidad son 2 motores diésel, un sistema fotovoltaico, además del sistema de almacenamiento formado por baterías.

Generación de electricidad y calor

El refugio Llauset consta de 2 motores diésel de 12 kW y 36 kW, respectivamente con generadores trifásicos en la cabaña y monofásicos para las baterías. Éstas pueden ser cargadas mediante los generadores trifásicos o bien por los paneles fotovoltaicos. Para la generación de calor la cabaña consta de 2 estufas pellet, mientras que el sistema de calentamiento de agua se emplean pequeños termos eléctricos.

Transporte

Para abastecer el refugio es necesario el uso del helicóptero.

Estado futuro

Está previsto instalar un micro-generador, pero será necesario analizar las condiciones del viento. Además, para el calentamiento de agua se reemplazará el sistema actual basado en pequeños termos eléctricos por dos calderas de gas natural.

Refugio Estós

El refugio se encuentra abierto durante todo el año. Para la generación eléctrica, la cabaña cuenta con un motor diésel, una turbina hidráulica, paneles fotovoltaicos y una serie de baterías para el almacenamiento de la energía sobrante.

Generación de electricidad y calor

Estós cuenta con un generador diésel de 35 kW de potencia nominal y una turbina hidráulica de 5 kW. Además, se encuentran instalados 20 paneles fotovoltaicos de 123 W (2,9 kW en total). En relación con las tecnologías empleadas para la generación de calor la única información disponible es que se realiza a través de una caldera diésel.

Transporte

El helicóptero es el transporte necesario para poder suministrar el refugio. No hay información específica relacionada con las horas de vuelo por año.

Estado futuro

La instalación adicional de paneles fotovoltaicos (2 kW adiciones), una estufa de pellets con una potencia total de 16 kW, así como una micro turbina son las posibles alternativas a considerar para instalar a futuro.

Refugio Montfalcó

El refugio de montaña se encuentra abierto todo el año.

Generación de electricidad y calor

Para la generación de electricidad, el refugio consta de un motor diésel de 50 kW (63 kVa) y un sistema fotovoltaico con una potencia total de 5,7 kW divididos en dos grupos, uno de 28 paneles con 150 W y otro de 8 paneles con 900 W. El sistema de almacenamiento de energía está formado por 24 baterías de 2 V y 2280 Ah cada una.

Para calentar el agua, el sistema de calefacción en la cabaña está formado por un sistema solar térmico. Un motor diésel de 12 kW, el cual solo se utiliza para el bombeo de agua y para una caldera diésel de entre 50 y 70 kW.

Transporte

En este caso es posible acceder al refugio mediante vehículo, por lo que para el transporte pesado de suministro y combustible se realizará mediante un camión, El diésel se suministra a la cabaña en 2 viajes al año.

Estado futuro

Se propone la instalación adicional de paneles fotovoltaicos en el refugio Montfalcó, así como una micro-turbina.

Refugio d’ Ayous

Ayous se encuentra abierto 4 meses al año, durante la temporada de verano.

Generación de electricidad y calor

El refugio cuenta con una instalación de 36 paneles solares que almacenan energía en 12 baterías eléctricas de 24 V cada una. Sin embargo, la cabaña también tiene un generador para una posible emergencia. Ambas tecnologías se emplean para la generación de electricidad.

Transporte

En este caso, el gas propano es transportado hasta el refugio por helicóptero y de acuerdo con el Parque Nacional de Pyrénees (PNP), es necesario tres viajes por año con una duración de 8 minutos cada uno (16 minutos de viaje de ida y vuelta).

Estado futuro

Se prevé aumentar el tiempo de apertura del refugio de 4 a 6 meses, lo que supondrá un incremento en el consumo de energía. Para contrarrestar con este aumento, se contempla instalar una pequeña central hidroeléctrica. Y en relación con la generación de calor, se reemplazará el calentador de agua a gas por uno eléctrico.

4 Metodología empleada para el Ciclo De Vida y Modelo Numérico

La evaluación del ciclo de vida (ACV, en inglés Life Cycle Assesment, LCA) aplicada en este estudio está definida por las normas ISO 14040 y 14044, y se define como la compilación y evaluación de las entradas y salidas y los posibles impactos ambientales de un sistema o de un producto durante la vida del mismo, en otras palabras, el ACV es una metodología que permite analizar un producto o servicio desde la cuna hasta la tumba.

La metodología LCA se desarrolla en cuatro pasos principales: objetivo y alcance, análisis de inventario, evaluación del impacto, y por último, interpretación.

De acuerdo con el objetivo de este proyecto, se analizaran todas las tecnologías utilizadas en cada una de las cabañas de montaña que se describieron en el capítulo 2 y capítulo 3. Con el fin de obtener una comparación entre estas tecnologías y obtener información no solo sobre los indicadores de CO2 y NOx, sino también sobre los criterios de impacto global, regional y local para todos ellos.

Para lograr el éxito en esta metodología, será necesario estudiar los siguientes problemas:

Generación de electricidad a partir de las tecnologías actuales instaladas

Generación de electricidad a partir de tecnologías alternativas

Producción de electricidad fotovoltaica en el caso del sistema actualmente instalado

Generación de calor a partir de tecnologías convencionales

Generación de calor a partir de tecnologías alternativas

Transporte mediante helicóptero, automóviles, furgonetas, camiones y otras tecnologías

Transporte con teleférico de carga

Con el objetivo de obtener mejores resultados se realizará el LCA, por un lado, para la producción de electricidad y por otro lado, para la generación de calor ya que cada refugio tiene una influencia diferente en términos de generación de electricidad y/o calor. Y por último, se realizará un modelo separado para el transporte.

Para poder comparar las diferentes tecnologías de generación tanto de electricidad como de calor, la unidad funcional utilizada será 1 kWh de energía generada para la electricidad y el calor y, en el caso del transporte, se establece 130 km y 5.5 t (1 hora de funcionamiento del helicóptero equivale a 130 km en camión).

5 Resultados

Para cada modelo obtenido con el software GaBi, los resultados se presentarán agrupados en una tabla en formato numérico de manera que para los 12 indicadores de impacto estudiados con la metodología CML 2001 se puede visualizar a simple vista el impacto que tiene cada valor respecto a la media ponderada de cada tecnología.

Las casillas en verde muestran las tecnologías que tienen un valor inferior al valor medio de todas las tecnologías o transporte para ese indicador estudiado, por el contrario el campo en rojo muestra aquellos valores que se encuentran con un valor superior del valor promedio.

Generación de electricidad

De los resultados mostrados en la Tabla 1 se concluye que el generador diésel es la tecnología que más emisiones de impacto emite. Las emisiones generadas en la combustión de su combustible así como la baja eficiencia que considerada debido al software GaBi dan lugar a valores más altos. En cuanto a las tecnologías alternativas, la turbina hidráulica muestra el menor impacto para los 12 indicadores. Seguida por la turbina eólica, aunque como se observa para el indicador TETP se tiene el valor más alto, esto es debido a las emisiones producidas durante la fase de fabricación de la turbina. En cuanto a la instalación fotovoltaica, a pesar de ser una de las tecnologías alternativas, la fabricación de esta instalación, así como el tamaño requerido para producir 1 kWh de electricidad en relación con otras tecnologías, no muestra una ventaja clara para instalarla.

CML2001 - Jan. 2016	diesel generator	hydro	photovoltaic slanted-roof	wind	photovoltaic facade
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.24E-06	2.73E-08	2.40E-06	1.96E-07	3.91E-06
Abiotic Depletion (ADP fossil) [MJ]	1.33E+01	4.99E-02	7.98E-01	1.44E-01	1.35E+00
Acidification Potential (AP) [kg SO2 eq.]	9.51E-03	2.52E-05	5.25E-04	7.87E-05	8.98E-04
Eutrophication Potential (EP) [kg Phosphate eq.]	2.38E-03	8.72E-06	2.53E-04	4.02E-05	4.32E-04
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	1.01E-01	3.02E-03	1.63E-01	5.21E-02	2.59E-01
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	9.43E-01	5.12E-02	7.61E-02	1.30E-02	1.29E-01
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	9.43E-01	1.16E-02	7.61E-02	1.31E-02	1.29E-01
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.86E-01	1.03E-02	1.49E-01	6.72E-02	2.53E-01
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	4.30E+02	6.05E+00	3.18E+02	4.03E+01	5.41E+02
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1.68E-07	4.05E-10	1.02E-08	7.07E-10	1.77E-08
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	9.19E-04	3.54E-06	4.10E-05	8.62E-06	6.91E-05
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	1.77E-03	2.96E-04	7.52E-04	1.76E-03	1.18E-03

Tabla 1: Resultados de cada indicador obtenidos para la generación de electricidad

Generación de calor

En resumen, para la generación de calor como se observa en la Tabla 2, la caldera de combustible ligero muestra mayores valores de impacto para todas las tecnologías. Estos valores están relacionados con las emisiones que se producen en la combustión del combustible. La estufa de pellets es la siguiente tecnología que presenta emisiones negativas en un 67 % de todos los indicadores estudiados, a pesar de que los pellets se clasifiquen como una energía renovable. El calentador eléctrico de agua muestra en la mayoría de los casos los impactos más altos, que están relacionados con la producción de electricidad requerida para su operación. Para calderas naturales y de propano, se han obtenido resultados equitativos (igual número de resultados negativos como de positivos). En general, la razón principal de las emisiones nocivas proviene de una menor eficiencia o incluso, de la combustión del combustible empleado en la tecnología empleada. Sin embargo, la caldera de gas a baja temperatura muestra los mejores resultados estudiados.

CML2001 - Jan. 2016	Wood pellet	propane	light fuel oil boiler	natural gas boiler	Electric water heater	Gas low temperature boiler
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.72E-07	5.81E-08	9.74E-08	1.01E-07	2.21E-07	1.70E-08
Abiotic Depletion (ADP fossil) [MJ]	6.95E-01	3.92E+00	4.86E+00	4.18E+00	4.42E+00	4.61E+00
Acidification Potential (AP) [kg SO2 eq.]	5.01E-04	6.01E-04	8.35E-04	4.53E-04	1.18E-03	1.54E-04
Eutrophication Potential (EP) [kg Phosphate eq.]	1.88E-04	1.52E-04	1.84E-04	8.29E-05	1.10E-04	2.23E-05
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	2.78E-02	1.01E-02	1.33E-02	1.71E-02	8.96E-04	9.30E-05
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	3.63E-01	3.11E-01	3.41E-01	2.87E-01	4.17E-01	2.78E-01
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	6.46E-02	3.10E-01	3.41E-01	2.87E-01	4.17E-01	2.78E-01
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	6.49E-02	3.72E-02	3.69E-02	3.47E-02	2.32E-02	1.54E-02
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	8.38E+01	3.39E+01	4.13E+01	4.89E+01	4.97E+01	1.31E+00
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4.07E-09	4.95E-08	6.19E-08	3.60E-08	1.84E-12	3.82E-14
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	7.39E-05	6.14E-05	6.76E-05	6.44E-05	7.38E-05	1.99E-05
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	1.40E-03	3.40E-04	5.18E-04	3.29E-04	3.01E-04	1.77E-05

Tabla 2: Resultados de cada indicador obtenidos para la generación de electricidad

Transporte

Con respecto al modelo de transporte, en la siguiente tabla se muestran los resultados obtenidos para los dos tipos de medios de transporte (helicóptero y camión, en inglés “truck”)

CML2001 - Jan. 2016	helicopter	Truck Euro 1	Truck Euro 2	Truck Euro 3	Truck Euro 4	Truck Euro 5	Truck Euro 6
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.21E-05	7.51E-06	7.39E-06	7.30E-06	7.26E-06	7.19E-06	7.02E-06
Abiotic Depletion (ADP fossil) [MJ]	1.42E+03	1.23E+03	1.21E+03	1.20E+03	1.19E+03	1.18E+03	1.15E+03
Acidification Potential (AP) [kg SO2 eq.]	4.13E-01	6.38E-01	6.53E-01	4.77E-01	3.32E-01	1.84E-01	6.77E-02
Eutrophication Potential (EP) [kg Phosphate eq.]	4.57E-02	1.65E-01	1.69E-01	1.22E-01	8.43E-02	4.64E-02	1.56E-02
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	2.80E+00	4.97E-01	4.89E-01	4.83E-01	4.79E-01	4.75E-01	4.63E-01
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	9.88E+01	8.73E+01	8.45E+01	8.84E+01	8.98E+01	8.70E+01	8.79E+01
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	9.88E+01	8.83E+01	8.55E+01	8.92E+01	9.05E+01	8.79E+01	8.86E+01
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	8.82E+00	3.09E+00	2.66E+00	2.55E+00	2.03E+00	1.86E+00	1.81E+00
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	1.62E+04	1.18E+03	1.17E+03	1.15E+03	1.15E+03	1.13E+03	1.11E+03
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1.82E-05	2.47E-12	2.44E-12	2.41E-12	2.39E-12	2.37E-12	2.31E-12
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2.58E-02	-2.94E-01	-3.05E-01	-2.12E-01	-1.21E-01	-5.89E-02	1.09E-03
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	9.47E-02	1.63E-01	1.60E-01	1.58E-01	1.57E-01	1.56E-01	1.52E-01

Tabla 3: Resultados de cada indicador obtenidos para ambos medios de transporte

De la Tabla 3 se puede concluir que el helicóptero es el medio de transporte que mayor impacto en el medio ambiente presenta, en relación con un camión que está categorizado con la normativa estándar actual, Euro 6. Cabe recordar que el estudio se realizó para 130 km con una carga de 5.500 kg (5,5 t). La causa principal del alto impacto del helicóptero es debido a la gran cantidad de queroseno requerida. Además, si se comparan el helicóptero consume mucho combustible (en este caso queroseno) que un camión (diésel), por lo tanto, el impacto es mayor.

En el siguiente escenario, se ha estudiado la posibilidad de sustituir la combinación de camión y helicóptero por el uso exclusivo del helicóptero. Los resultados que se pueden observar en la Tabla 4 muestran que la opción considerada de usar solo helicóptero no es la más apropiada, en términos de sostenibilidad para el medio ambiente en la cabaña de montaña.

CML2001 - Jan. 2016	Truck + helicopter	Only helicopter
Abiotic Depletion (ADP elements) [kg Sb eq.]	3.26E-05	8.46E-05
Abiotic Depletion (ADP fossil) [MJ]	4.39E+03	9.90E+03
Acidification Potential (AP) [kg SO2 eq.]	1.01E+00	2.89E+00
Eutrophication Potential (EP) [kg Phosphate eq.]	1.55E-01	3.20E-01
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	5.56E+00	1.96E+01
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	3.14E+02	6.92E+02
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	3.16E+02	6.91E+02
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.81E+01	6.18E+01
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	2.89E+04	1.13E+05
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	3.09E-05	1.27E-04
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	-5.46E-02	1.81E-01
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	4.23E-01	6.63E-01

Tabla 4: Resultados obtenidos para el suministro a un refugio a partir de diferentes combinaciones de transporte

6 Conclusiones

El objetivo principal era identificar y evaluar los impactos ambientales de todas las tecnologías utilizadas en los refugios para la generación de energía y del transporte a los mismos. En total, se han estudiado 9 cabañas o refugios de montaña involucrados en 4 países, todas en el ámbito del proyecto SUSTAINHUTS Life +. Una vez evaluado el estado inicial de los refugios de montaña también se evaluaron las futuras inversiones en términos de nuevas tecnologías y/o tecnologías alternativas. Todas las tecnologías se modelaron en el entorno del software Gabi Thinkstep. Los impactos ambientales se estudiaron usando LCA con la ayuda de la metodología de evaluación de impacto CML 2001 que evalúa 12 indicadores de impacto ambiental para estudiar el impacto que tiene cada tecnología.

De los resultados del análisis, se ha llegado a las conclusiones resumidas a continuación:

- Los resultados obtenidos para las actuales tecnologías utilizadas en la generación de electricidad muestran que el generador diésel es el mayor contribuyente a los impactos ambientales en las cabañas de montaña. A pesar de ser la opción más económica de generar electricidad, este dispositivo convencional debería ser reemplazado por una tecnología alternativa y con ello disminuir las emisiones globales en cada refugio. La razón principal de estos valores altos se debe a las emisiones generadas por la combustión del combustible utilizado, y también debido a la baja eficiencia considerada en el estudio. Por otro lado, se llegó a la conclusión de que hay dos tecnologías alternativas con muy poco impacto ambiental nocivo: la micro turbina hidráulica, en la que muestra para todos los indicadores estudiados los valores más bajos, seguida por la turbina eólica.

- De los tipos de paneles fotovoltaicos estudiados por 1 kWh de electricidad generada según su instalación. Se concluye que los paneles fotovoltaicos con una instalación de techo inclinado tienen menor impacto ambiental que los que se encuentran instalados en la fachada. La razón es debido a que para producir la misma cantidad de electricidad, los paneles instalados en una fachada requiere de una infraestructura mayor (más m^2) que la requerida para producir la misma cantidad de energía que laa que se produce en una de techo inclinado. Además, la fabricación de paneles fotovoltaicos también está relacionada con las altas emisiones de esta energía renovable, lo que no conlleva una ventaja decisiva para su instalación.

- En referencia a la generación de calor, la caldera diésel es la que presenta mayor impacto ambiental: en 10 de los 12 indicadores analizados, estos valores elevados están relacionados con las emisiones producidas en la combustión del diésel. Por otro lado, la caldera de gas natural tiene mejores resultados respecto de las tecnologías instaladas actualmente; los elevados valores de las emisiones provienen de la bajas eficiencias o incluso, la combustión de gas.

- Los resultados obtenidos para las tecnologías alternativas estudiadas concluyen que la estufa de pellets no contribuye de manera sostenible al medio ambiente, a pesar de que los pellets de madera se clasifican como una energía renovable, los resultados muestran lo contrario. Esto es debido a que el origen de los pellet no proviene de los residuos de madera sino de plantaciones de árboles de madera virgen, de manera que esto provoca un aumento de las emisiones. Además, el calentador eléctrico de agua resulta ser una de las tecnologías con mayor número de emisiones negativas; esto se debe a que se considera que la electricidad utilizada por el calentador proviene de una tecnología convencional. Aunque, si se demuestra que la electricidad utilizada proviene de un exceso de energía generada a partir de una tecnología alternativa, como la de la turbina hidráulica, las emisiones consideradas por la producción de electricidad pueden despreciarse y, en consecuencia, los valores más altos van para ser reducidos. Sin embargo, la caldera de gas a baja temperatura muestra los mejores resultados estudiados, puesto que en solo 1 indicador de 12 se ha obtenido el menor impacto.

- De la comparativa de las emisiones de acuerdo a las distintas normativas europeas para los camiones, se ha demostrado que el estándar actual (Euro 6) es el más restrictivo, aunque la reducción de emisiones en relación con el Euro 5 es de un 2% . No obstante, se debe asegurar que el camión utilizado para el suministro de los refugios de montaña sea el Euro 6. Por otro lado, el estudio del helicóptero ha llevado a cabo algunas suposiciones que no nos permiten llegar a conclusiones claras, aunque si se tienen en cuenta los resultados obtenidos, se concluye que el helicóptero debe evitarse en la medida de lo posible, y en el caso de que sea la única forma de acceder a la cabaña de montaña, se recomienda reducir la distancia a recorrer por el helicóptero.

- En relación con el estudio del transporte por cable de mercancías, se debe considerar que no se ha encontrado ningún proceso para modelar con el software GaBi. Sin embargo, se sabe que en Pogačnikov el teleférico de carga funciona con un motor diésel, mientras que en Torino el teleférico funciona con electricidad. Por lo tanto, se puede concluir a partir del modelo numérico utilizado por la generación de electricidad que el uso de un teleférico que está conectado a la red es menos dañino para el medio ambiente que el teleférico que funciona con un motor diésel.

En resumen, la sostenibilidad en los refugios de montaña todavía necesita ser cuidadosamente estudiada para evaluar la mejora del mismo, este estudio puede llevarse a cabo no solo a través de la integración de energías renovables, sino también con la mejora en el aislamiento, de manera que se podría lograr una mejora en la eficiencia energética y una reducción de las emisiones de CO_2. Por otra parte, además de reducir las emisiones también se contribuirá a la mejora de la calidad de vida, así como de las instalaciones en el entorno de cualquier refugio de montaña.

Recomendaciones para futuras investigaciones

Teniendo en cuenta que el proyecto SUSTAINHUTS + sigue siendo vivo hasta 2020, durante este período se debe considerar incluir las tecnologías que se propusieron para obtener cabañas más sustentables. Desde el punto de vista del modelado, será interesante tener la posibilidad de obtener datos adicionales en las bases de datos LCA que darán resultados aún más precisos.

UNIVERSITY OF LJUBLJANA

Faculty of Mechanical Engineering

Environmental Impact of the mountain huts

Okoljski vpliv planinskih koč

A Master's thesis of the second-cycle master's study programme in MECHANICAL ENGINEERING

López Iglesias, Paula

Ljubljana, June 2018

UNIVERSITY OF LJUBLJANA

Faculty of Mechanical Engineering

Environmental Impact of the mountain huts

Okoljski vpliv planinskih koč

A Master's thesis of the second-cycle master's study programme in
MECHANICAL ENGINEERING

López Iglesias, Paula

Advisor: assist. prof. dr. Mitja Mori, univ. dipl. inž.

Ljubljana, June 2018

Candidate
Paula LOPEZ IGLESIAS

MAGISTRSKI ŠTUDIJSKI PROGRAM II. STOPNJE: **MAG II/523 E**

NASLOV TEME: **Okoljski vpliv planinskih koč**

Planinska koča se nahaja v občutljivih delih narave in skozi delovanje vpliva okolje z emisijami v zrak, vodo in tla. Oskrba z energijo (električna energija in toplota) v skoraj vseh planinskih kočah v Evropi je delno odvisna od fosilnih goriv, ki pa povzročajo pomembne vplive na okolje. Planinske koče v Evropi se nahajajo v različnih regijah (Pireneji, Alpe, Karpati, itd.), so na različnih višinah, imajo različne tehnologije za oskrbo z energijo, različne čase odprtja, so različne po velikosti in imajo drugačen dostop. Vsi ti parametri so pomembni pri določitvi vpliva posamezne planinske koče na okolje. V magistrskem delu:

- opišite planinske koče, vključene v študijo, ki se nahajajo v različnih regijah v Evropi,
- identificirajte vse tehnologije, ki se uporabljajo v planinskih kočah za proizvodnjo električne energije in toplote,
- pridobite vse podatke, povezane z energijsko in masno bilanco vseh planinskih koč, vključno s prevozom energentov in drugega blaga do koče,
- preučite metodologijo ocenjevanja življenjskega cikla tehnologij, izberite metodologijo ocenjevanja okoljskega vpliva, ustrezne okoljske kazalce in funkcionalno enoto,
- v računalniškem okolju Gabi Thinkstep postavite numerični model za proizvodnjo električne energije in toplote iz različnih tehnologij prisotnih v planinskih kočah,
- primerjajte okoljske vplive vseh tehnologij, ki se trenutno uporabljajo za pridobivanje energije, z novimi tehnologijami, ki jih bodo v prihodnosti namestili na koče.

Magistrsko delo je treba oddati v jezikovno in terminološko pravilnem angleškem jeziku. Rok za oddajo tega dela je šest mesecev od dneva prevzema.

MASTER THESIS – MASTER'S DEGREE STUDY No. **MAG II/523 E**

TITLE: **Environmental impact of mountain huts**

A mountain hut is located sensitive parts of the nature and through operation effects environment with pollutants in the air, water and soil. Mountain hut energy supply (electricity and heat) in almost all huts in Europe is partly from fossil fuels that have significant environmental impacts. Mountain huts in Europe are located in different regions (Pyrenes, Alps, Carpathians, etc.) at different altitude, have different technologies for energy supply, different opening regimes, are different in size and have different access. All these parameters effect environmental impact of single mountain hut that is usually opened for the limited time frame in single year. In the thesis the candidate tasks are:

- Describe mountain huts involved in the study that are located in different regions in Europe.
- Identify all technologies used in mountain huts for electricity and heat generation.
- Obtain all data linked with energy and mass balance of all mountain huts including transport of energy carriers and other goods to the hut.
- Study the Life Cycle Assessment methodology and define Life Cycle Impact Assessment criteria with all relevant impact indicators, functional unit and boundary conditions.
- Set up numerical model in Gabi Thinkstep environment to calculate environmental impacts of observed technologies.
- Compare environmental impacts of all technologies that are currently used for energy generation with environmental impacts of new technologies that could/will be installed in the future.

The submitted master thesis must be written in standard English. The master thesis must be submitted six months after it was accepted.

Mentor

Assist. prof. PhD. Mitja Mori

Predsednik diplomske komisije/
President of Committee
Prof. PhD. Sašo Medved

Podpisana sem delo prevzela v Ljubljani/
I hereby confirm the receipt of the master thesis

Dne/date......04/05/2018.....

Podpis/Signature ....

Prodekan za pedagoško dejavnost
II. in III. stopnje/Vice Dean

Prof. PhD. Andrej Kitanovski

Acknowledgements

First of all, I have to be grateful my mentor, assistant professor Mitja Mori, for giving me the possibility of working with him in this project and, for his support and be accessible at any time, both during the project development and in his classes during the first semester. Thank you also for your advice and said you that I have you as a reference not only for your work as professor but your involvement in the sport as you are doing, I am proud of you and your team, and I wish you to continue achieve your goals.

Also, thank you to all partners of the project SUSTAIN MOUNTAINHUTS to allow me the opportunity of meeting with you and know more about the project, also for your availability to me and my partner, as well as for carrying out this project in order to improve our sustainability. Then, thank the European instrument LIFE+ for support this project.

To my boyfriend for his unconditional support always and be a great pillar of support in my life. To another pillar, my family, thank you so much for supporting me and advising me always, and leave me the freedom to make my decisions. To my friends, despite the distance, they are always with me.

Finally, and no less important thank you to my new family created here in Ljubljana, for all the good moments and memories that I will never forget, and for helping me grow as person with your habits and traditions. And thank you Irene for being my new discovery and overall my unconditional friend during this months.

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

Declaration

I, the undersigned Paula Lopez Iglesias student from Erasmus Exchange on the Faculty Of Mechanical Engineering at the University of Ljubljana, with registration number 70080237, author of the written final work of studies, entitled: Environmental impact of mountain huts,

DECLARE that

1. The written final work of studies is a result of my independent work;
2. The printed form of the written final work of studies is identical to the electronic form of the written final work of studies;
3. I acquired all the necessary permissions for the use of data and copyrighted works in the written final work of studies and clearly marked them in the written final work of studies;
4. During the preparation of the written final work of studies I acted in accordance with ethical principles and obtained, where necessary, agreement of the ethics commission;
5. I give my consent to the use of the electronic form of the written final work of studies for the detection of content similarity with other works, using similarity detection software that is connected with the study information system of the university member;
6. I transfer to the UL – free of charge, non-exclusively, geographically and time-wise unlimited – the right of saving the work in the electronic form, the right of reproduction, as well as the right of making the written final work of studies available to the public on the World Wide Web via the Repository of the UL;
7. I give my consent to the publication of my personal data included in the written final work of studies and in this declaration, together with the publication of the written final work of studies;
8. I give my consent to the use of my birth date in COBISS record.

In Ljubljana, 21 June 2018 Student's signature: ___________________

Abstract

UDC 004.942:519.876.5:620.9:728.5(043.2)

Serial No.: MAG II/523 E

Environmental Impact of the mountain huts

Paula López Iglesias

Keywords: Mountain huts
Environmental impact
Life Cycle Assessment
Energy and mass balance
Electricity
Heat
Transport

Nowadays the global climate change is the main concern. The environmental impacts of technologies used is the area in which we have to work to try to achieving near zero emissions for buildings and transport. In the present master thesis environmental impacts of nine mountain huts located in four different countries were analysed. In order to achieve the nearly-zero emissions from these mountain huts, the major activities which affect directly or indirectly the environment will be analysed. The electricity generation and heat generation are two main activities, which generate impacts to the environment, so the technologies used in both cases will be observed and studied with LCA methodology. The Life Cycle Assessment is the tool that has been chosen. The scope of the study is operational phase of the mountain hut with functional unit 1kWh of generated energy. The important part of the study was life cycle inventory analysis that has to be done in detail to gather all data relevant for all technologies in all observed huts. The LCI was translated into environmental impacts with the life cycle impact assessment methodology CML 2001, with 12 environmental impact indicators classified in global, regional and local. Gabi Thinkstep software was used as numerical tool in the study. The first part of the study was the use of current and future technologies for electricity generation, the second part was devoted to heat generation and the last one transport technologies to the hut. Results showed that there are several technologies, which can be installed in order to reduce environmental impacts. The technologies, which have highest environmental impact, are the diesel generator for electricity and, light fuel oil boiler as well as a wood pellet stove in case of heat generation. In relation with the alternative technologies, the best option to consider is the micro-hydro and micro-wind for electricity generation, while for heat generation it has concluded that is gas low temperature boiler. Despite electric boiler shows harmful results, if the use of excess electricity from a renewable source is considered to work, this technology will be acceptable.

Povzetek

UDK 004.942:519.876.5:620.9:728.5(043.2)

Ser. št..: MAG II/523 E

Okoljski vpliv planinskih koč

Paula López Iglesias

Ključne besede Planinske koče
Okoljski vpliv
Študija življenjskih ciklov
Energijska in masna bilanca
Električna energija
Toplota
Transport

Danes so podnebne spremembe eno izmed pomembnejših področij povezanih z uporabljeno tehnologijo na vseh področjih. Okoljski vplivi so pomemben faktor na katerem moramo delati, da bi lahko zmanjšali vpliv na okolje in dosegli nizke emisije v primeru stavb in transporta. V tem magistrskem delu smo analizirali vpliv delovanja devetih planinskih koč na okolje, ki se nahajajo v štirih različnih državah. Da bi dosegli skoraj ničelne emisije zaradi delovanja teh planinskih koč, bodo analizirane glavne dejavnosti, ki neposredno ali posredno vplivajo na okolje. Proizvodnja električne energije in proizvodnja toplote sta dve glavni dejavnosti, ki povzročata vplive na okolje, zato bodo tehnologije, uporabljene v obeh primerih, opazovale in obravnavane z metodologijo LCA. Ocena življenjskega cikla je orodje, ki je bilo izbrano za to študijo. Obseg študije je faza delovanja planinske koče s funkcionalno enoto 1 kWh proizvedene energije. Pomemben del študije je bila analiza inventarja življenjskega cikla, ki jo je treba podrobno opraviti, da bi zbrali vse podatke, ki so pomembni za vse tehnologije v vseh opazovanih kočah. LCI je bil preveden v okoljske vplive z metodologijo ocenjevanja vplivov na življenjski cikel, CML 2001, z 12 okoljskimi kazalniki, ki so razvrščeni na globalni, regionalni in lokalni ravni. Programska oprema Gabi Thinkstep je bila uporabljena kot numerično orodje v študiji. Prvi del študije je bila uporaba sedanjih in prihodnjih tehnologij za proizvodnjo električne energije, drugi del je bil namenjen proizvodnji toplote in zadnji tehnologiji transporta do koče. Rezultati so pokazali, da obstaja več tehnologij, ki jih je mogoče namestiti, da bi zmanjšali vpliv na okolje. Tehnologije, ki imajo največji vpliv na okolje so dizelski generator za električno energijo in peč na lahko kurilno olje ter peči za lesne pelete v primeru proizvodnje toplote. Medtem ko se je izkazala kot najboljša možnost električna energija iz mikro-hidro elektrarn in vetrne turbine ter plin v kondenzacijskem kotlu za proizvodnjo toplote.

Table of contents

List of figures

List of tables

List of acronyms used

Acronym	Meaning
AAI	Advanced Automation of Installation
AC	Alternating Current
ADP	Abiotic Depletion
AEMET	Agencia Estatal de Meteorología
AGG	Part of complete life cycle of a product
AP	Acidification Potential
CD	Direct Current
$C_6H_4Cl_2$	Dichlorbenzol
CH_4	Methane
CO_2	Carbon Oxide
CML	Centre for Environmental Studies
CFSc	Fluorine-Chlorine-Hydrocarbons
DG	Diesel Generator
EP	Eutrophication Potential
Eq	Equivalent
EU-28	European Union which consists a group of 28 countries
FAETP	Freshwater Aquatic Ecotoxicity Potential
FAM	Federation Aragonesa de Montañismo
FHA	Federal Housing Administration
GaBi	Ganzheitlichen Bilanzierung (German for holistic balancing)
GR11	Trans-Pyrenean Trail
GWP	Global Warming Potential
H_2	Hydrogen technologies
HTP	Human Toxicity Potential
ISO	International Organization for Standardization
kWh	Kilowatt hour
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LFO	Light Fuel Oil
MAETP	Marine Aquatic Ecotoxicity Potential
MHP	Micro hydro power plant
MW	Megawatt
NIM	New Isolated Materials
ODP	Ozone Depletion Potential
P-AGG	Partly terminated system
PNP	Parc Natural des Pyrénees
POCP	Photochemical Ozone Creation Potential
PO_4	Phosphate
PV	Photovoltaic
RES	Renewable Energy Sources
SDP	Alpine Association of Slovenia
TETP	Terrestric Ecotoxicity Potential
U-SO	Unit process Single Operation

1. Introduction

1.1 Background and motivation

In the mountain of difficult or limited access there are isolated constructions called mountain huts. The operation of mountain huts impacts the environment because of energy generation as electricity and heat needed in the hut and because of transportation of all goods to the hut. In order to make mountain huts more sustainable with less emissions to the environment, renewable energy sources have to be implemented in mountain huts and current technologies used have to be optimized in the way to reach maximum possible energy efficiency. With these actions all emissions to air, water and soil could be reduced to minimal possible values. Life SustainHuts project has the goal of implementing sustainable solutions in the mountain huts and decrease emissions of CO_2 and NO_X as defined in the project goals.

To supply the electricity and heat besides all general goods in the mountain hut nowadays processes are used that are mainly linked to fossil fuels consumption. As previously mentioned, the main transport technology in mountain huts is the helicopter that means an increase of all pollutants due to transportation. In addition to fossil fuels (diesel and gasoline) in the case of heat generation also firewood or pellets are used. In the current status some of the electricity and the heat is generated also with renewable energy systems. On the other hand, the constructions of the huts are well-prepared for the extremely condition, even though they are not well-prepared for energy-efficient, so it is important selecting additional and new isolating material which helps to reduction overall consumption energy.

In order to reduce the dependence from fossil fuels and promoting renewable energy generation as a way of achieving the goal of this project, all technologies currently used, will be identified to compare with the new alternative technologies in order to determine environmental impacts and potential of new installed technologies. The different technologies that will be included in this study are photovoltaics, big share of fossil fuels, micro hydro power generation, batteries and solar thermal collectors. On the other hand, new integrated technologies are planned to be photovoltaic panels (PV), micro wind turbine (wind), micro-hydro power plant (Hydro), batteries, biomass boilers, new isolated materials (NIM) and hydrogen technologies (H2) with included fuel cell and electrolyser.

Therefore, the Life Cycle Assessment (LCA) is the tool chosen for the study of environmental impact. Although, in many different ways to study it, for the present project it has been decided on the methodology of impact assessment method CML 2001, in where 12 environmental impact indicators will be studied. The indicators are classified in global, regional and local. With Gabi Thinkstep software three numerical model can be carried out, it will be done a numerical model for electricity generation and for heat generation, as well as for transport technologies. For make an easier comparation between electricity technologies and also for heat technologies, the functional unit will be 1 kWh per energy generated. While for transport, the functional unit will 130 km (1 hour) and 5.5 t.

For further analyses with the technologies used in the huts, it will be considered additional process in electricity, such as the electricity generation from fossil fuels, or even from grid mix not only from the EU-28 but all the countries in where are the mountain huts in the project (Spain, Slovenia, Italy and France). Likewise, additional heat process will be added in order to compare with the different heat technologies, in this case this process also come from fossil fuels.

With the aim of concluding with successful results, it will try to follow as much as possible all these proposals, such as replacement the conventional technologies which are producing a considering amount of negative emissions by the alternative technologies which can help to decrease the harmful effect into the environment and also can affect the inhabitants life.

1.2 Goals of the study

The main goal of this study is identify all technologies currently used in energy consumption and energy generation in all observed mountain huts (electricity and heat), as well as the new innovate technologies. Starting from the data at the initial status of the huts LCA analysis will be done. Main goals are:

- Study relevant literature and standards
- Collect all the data from each of the mountain huts and make inventory analysis of the current status of huts
- Study LCA methodology and software environment Gabi Thinkstep
- Define Impact Assessment methodology
- Make numerical models of energy generation technologies
- Determine the future status of mountain huts regarding technologies used
- Present results in the form of diagrams and make useful conclusions

1.3 Methodology

To begin with the current project, it will be necessary to collect all relevant data for each of the hut. In case any data is missing or not available in the previous studies, complete all the data with the inquiries to hut owners or partners. After the basic methodology used to collect the data, specific questionnaires and interviews of huts owners will be done. In addition to current data also data regarding future investments and modifications in the specific hut will be obtained. Since data differs from hut to hut, it will be necessary to bring them to the same denominator, in order to use them in numerical model. The functional unit will be 1 kWh of energy for electricity and heat, for every technology analysed.

In order to demonstrate the reduction of environmental impact of mountain hut, Life Cycle Assessment methodology will be used. For this project, the life cycle numerical model will be created with GaBi Thinkstep software. The Life Cycle Impact Assessment (LCIA) will be CML2001.

To ensure the credibility and comparability of such analyses the results will be interpreted in order to be able to estimate the result of new technologies implementation than it permit us make final conclusions.

1.4 Limitations of the study

Several limitations must be kept in this studies, among them are the physical boundaries set to mountain hut and their infrastructure. However, in all cases the transport of fuels (natural gas, biomass, fuel oil, etc.) and energy sources of mountain huts (electricity grid, etc.) are included. Technologies reviewed in the study are just currently used technologies and energy carrier in the mountain huts.

From operational point of view, for further LCA study only the integral data (average working hours, yearly fuel consumption, electricity consumption if connected to power grid, nr. of transportations of the fuel to the huts, etc.) will be included. No manufacturing stage of technologies and/or the hut is included in the study.

From methodological point of view, both positive and negative environmental impacts through different environmental indicators according to CML 2001 standard will be listed for each type of implemented technology. There are 12 indicators given by the method which are divided into global, regional and local indicators, with last two categories very important for the mountain huts.

2. Mountain huts involved in the study

In this chapter the nine mountain huts attached to the project will be described broadly. The mountain huts are located in 4 different European countries. Particularly, there are 2, which are located in Slovenia (Kocbekov dom and Pogačnikov dom); 5 mountain huts located in Spain, four involved in the project (Bachimaña, Llauset, Lizara and Estós) and another one will be included proximately (Montfalcó); 1 in Italy (Refugio de Torino) and the most recent one in France (Refuge D'Ayous.

In Slovenia, there are 2 demo huts placed on Slovenian Alps:

- Kocbekov dom (1808 m)
- Pogačnikov dom (2050 m)

In Spain, there are 5 demo huts placed on Spanish Pyrenees:

- Montfalcó (790 m)
- Lizara (1540 m)
- Estós (1890 m)
- Bachimaña (2200 m)
- Cap de Llauset (2450 m)

In Italy, a demo huts placed on Italian Alps:

- Refugio Torino (3375 m)

In France, a recent demo hut placed on Pyrénées-Atlantiques

- Refuge D'Ayous (1980 m)

Below it detailed data regarding the specifications of each hut of this project together with some tables where are identify the technologies that there are in each hut, these are distinguee between electricity sources and heat sources with the target to be able to describe in the next chapter (Chapter 3: Inventory: mass and energy balance). The principal aim is showing detailed all of the huts involved in the project as the current state of hut as the future activities or state expected, such as dimensions, average of visits per day, capacity of accommodation, as well as the surroundings in where hut is located in order to analyse the possibility of install new technologies or improve current ones. Moreover, insulation is inspected to get better analysis of hut basic condition.

Based on important parameters such as tourism demand, location and the weather on the mountain hut, as well as economic aspect, each hut has different technologies although the majority of them are similar, because of the target is compare all of them.

2.1. Kocbekov dom

Kocbekov Dom is located at the altitude of 1808 m in Slovenia; more concretely, on the western under the mountains Ojstrica, Lučki Dedec and Koroški vrh at the edge of a huge meadow, which is called Korošica, as seen in Figure 2.1. Latitude of the hut is 46,355651 and longitude is 14,639763.

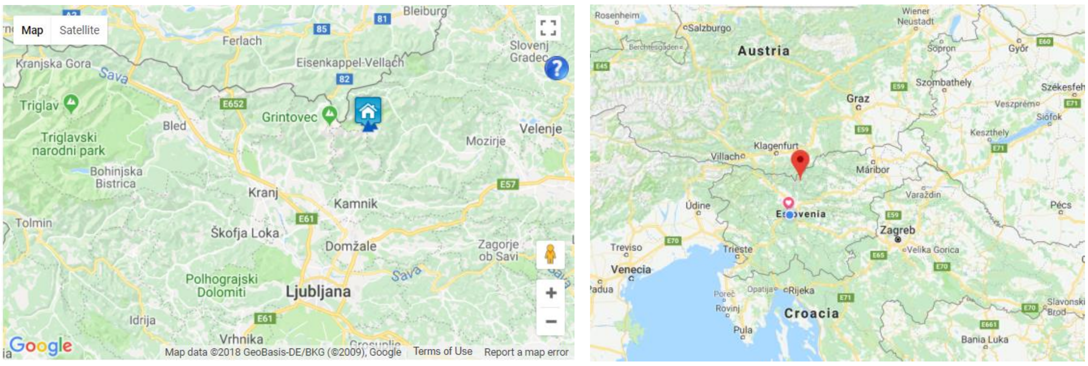

Figure 2.1: Location of Kocbekov Dom, Slovenia [1]

After wold war II, Kocbekov Dom was opened in 1945. It was restored in August of 1894 after being burned in 1882 [13]. Later, there was last renovation in 2007 where they completely isolate walls with new panels' on the whole building envelope [5], likewise the roof was renovated with the same panels, as well as it can be observed in the Figure 2.2. In this figure is shown a view of Kocbekov hut whose dimensions are 23.5 x 8.5 x 8.1 (L x H x W) [14].

It is opened from June to October (summer season). In spite of providing shelter for 5 person during winter, in general is uninhabited this is the main reason because of closing. Although it mostly hosts one day visitors, the hut is a home for climbers has capacity for approximately 100 persons and 80 seats in the dining room. The average of accommodation per day is 45, while the visits per day are 150. Hence, the number of employees is 2 [14]. It should be noted that number of visits increases during weekends, consequently the specific power demand of the hut also increase.

According to Official Website of Alpine Association of Slovenia (SPD), washing and drinking of fresh water is not possible due to dry winter and smaller amount of rain [2]. Mainly because the weather in the mountain is usually very cold in winter and the summer is warm and rainy (alpine climate) [3]. In general, the rainfall reach their peak in October, are rare in March and relatively important in April.

Figure 2.2: Kocbekov Dom before (left) and after (right) last renovation [5]

On the other hand, the technologies with which are provided the hut both electricity generation and heat generation are summarized in the following table (Table 2.1), besides also is attached the insulation of the hut:

Table 2.1: Current Status of technologies in Kocbekov hut

Hut	Electricity sources	Heat sources	Insulation
Kocbekov Dom	Diesel generator	Firewood stove	Outer walls
	Batteries storage		Roof
	PV panels		

2.2. Pogačnikov dom

The Pogačnikov hut (Figure 2.3) is located in Triglav National Park to 4 km from Slovenia's highest mountain Triglav, it is perched on a small hilltop at the altitude of 2050 m on the peak of Kriški podi Kriški podi and also is surrounded by other six peaks: Bovški Gamsovec, Križ, Stenar, Razor, Planja and Pihavec. There are marked routes in order to can access to all of them. In the Figure 2.4 is shown the location of the hut. Latitude of the hut is 46,401965 and longitude is 13,800577 [6], [13].

Figure 2.3. Pogačnikov dom, Slovenia hut [13]

The hut was built during 1948 and 1951, though it was renovated and extended in 1973. After that, a freight cableway was constructed (nowadays is upgraded since 2003), while in 2004 the roof of the hut was renovated [6].

As mentioned above, due to the weather on this mountain (Slovenia Alps) the hut is opened during summer season from June to September and seldom during winter [4], [13]. On the other hand, Pogačnikov hut is smaller than Kocbekov Dom (other Slovene hut), due to the dimensions of the hut are 15.5 x 11.5x 7.5 m [14], where this one has capacity for nearly 80 people, but the average accommodation per day is 28, besides 3 people work there [13].

Unlike the hut mentioned before, Pogačnikov dom has not only diesel generator but also gasoline generator.

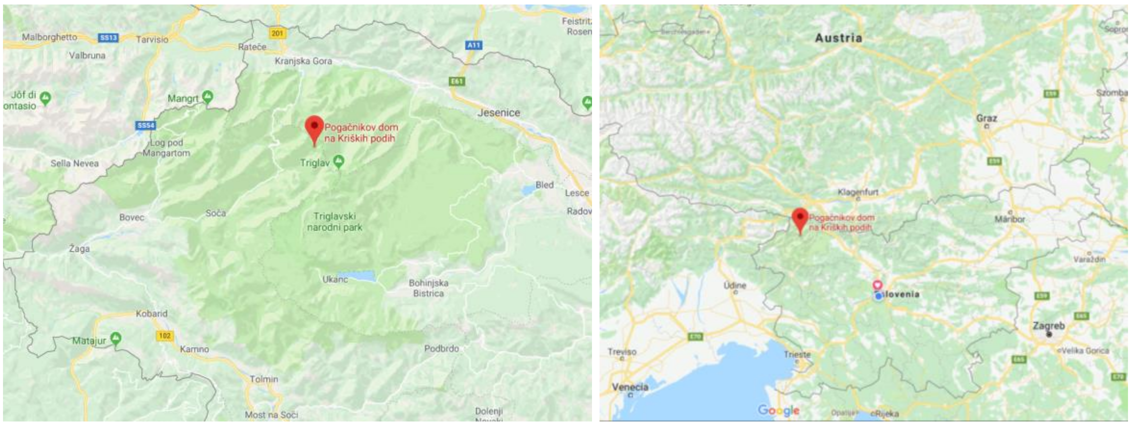

Figure 2.4. Location of Pogačnikov dom in Slovenia Alps [15]

In relation with the technologies which are available in Pogačnikov dom, in the table below it can be observed all of them.

Table 2.2: Current status of technologies in Pogačnikov dom

<table>
<tr><th></th><th>Electricity sources</th><th>Heat sources</th><th>Insulation</th></tr>
<tr><td rowspan="4">Pogačnikov dom</td><td>Diesel generator</td><td rowspan="2">Wood stove</td><td rowspan="2">Outer walls</td></tr>
<tr><td>Petrol generator</td></tr>
<tr><td>Batteries storage</td><td rowspan="2">Wood-burning oven</td><td rowspan="2">Roof</td></tr>
<tr><td>PV panels</td></tr>
</table>

Finally, the members who integrate the Life SustainHuts are the following: Slovenia Mountain Partnership, Slovenia's Hydrogen Technology Center and Ljubljana University.

2.3. Refugio de Torino

Italian Alpine Club Turin6 section is the Italian member who integrate this project. In this country the mountain hut which has been selected for the study is Refugio de Torino (Figure 2.5). The Torino Refuge hut was built with financial contribution from the Aosta Region, due to Climbing Club of Italy and sections Turin and Aosta in the nineteen fifties [17].

Torino Refuge is remarkable due to the famous Skyway cable car, which was built in very hard conditions during the construction: cold, wind, snow, thin air and long work shifts. Finally, the Skyway was officially opened in summer of 2015. Currently, the refuge was renovated in June 2016. From February 2017, the hut remain open the hole year [17]. This is located at 3,375 m (55 m higher than the original refuge [7]. About the weather, in Torino is classified as temperate sub-continent climate, where the summer are hot summers and cold winters, however stays between warm and humid all year [18].

Nowadays, Torino hut has capacity for 160 people, accommodated in bedrooms from 4 to 16 bedded rooms [17]. Otherwise, the dimensions of the hut are 25.5x12x15 m, while the number of employees required to offer service are 10 [14].

Figure 2.5. Refugio de Torino, Italy [13]

The Refugio de Torino is a mountain hut which is located in the Alpes in north western Italy. In the Figure 2.6 it can see the location of the hut. As the figure shows, the Refugio de Torino is closed the border with France, exactly 5 km southwest of Mont Dolent, bordering with Switzerland [13]. However, from Italian side can be most easily accessed by the Skyway Monte Bianco cable car from La Palud in Courmayeur, with a change at the Pavilion du Mont Fréty. The entrance for Alpinists is situated on the old terrace on the ground floor [17].

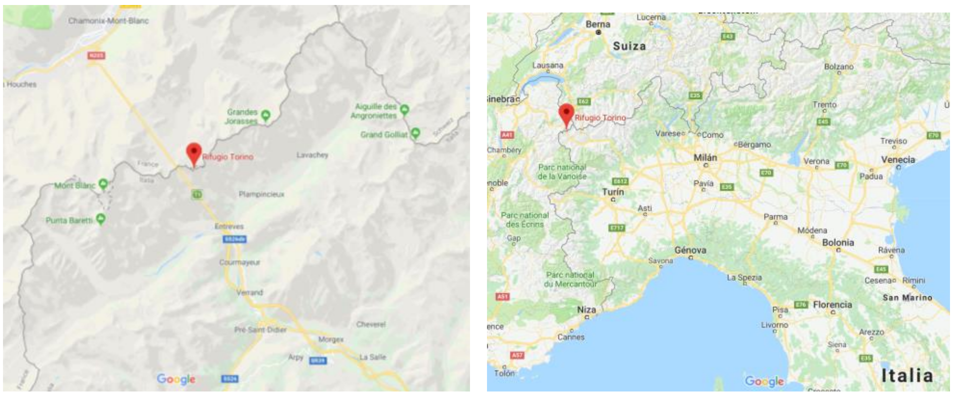

Figure 2.6. Location of Refugio Torino, Italy [16]

In this case, due to the special service which the hut offers it is important to mention some actions that are carried out in high season in order to reduce the consumption of water, such as use recyclable plates to serve food on because of water shortage, not enough guarantees of availability of water in showers, as well as the use of toilets [17].

In referring to technologies of Refugio Torino, it is noteworthy that Refugio Torino is connected to electrical grid, despite being the unique which do not other electricity sources, although it has heat sources as shown in the following table.

Table 2.3: Current status of technologies in Refugio Torino

	Electricity sources	Heat sources	Insulation
Refugio Torino	Connected to electrical grid	Electric fans (4)	Bar room
		Electrical heaters (6)	
		Diesel fans (2)	Lunch room
		Pellet stove (2)	

2.4. Bachimaña hut

The Bachimaña Hut is a new and modern mountain hut, which is located in the Alto Gallego region (Panticosa, Spanish Pyrenees), at 2200 m altitude, in the same vestibule of a whole set of glacial cirques [21]. Nowadays, it is occupied in its base by a great number of mountain lakes, called tarns, which are Gramatuero, Pezico and Blue tarns [13]. To access it can be from the Spanish side through the picturesque village of Panticosa or from the French side through the Port of Portalet [21]. In the following pictures, first it can be observed the Bachimaña hut (Figure 2.7) and also as previous it has been mentioned the ubication of the hut (Figure 2.8).

Figure 2.7. Bachimaña hut [13]

Impressive range of peaks and crests of great beat beauty surround Bachimaña hut, where some of them haunt the three thousand meters of altitude, like Los Infiernos, La Gran Facha or Garmo Negro and Argualas [13], [21].

It should be also emphasized that it is situated in within the Trans-Pyrenean Trail (GR11), this is a famous route which goes through many huts across the Pyrenees, the Figure 2.9 shows the route.

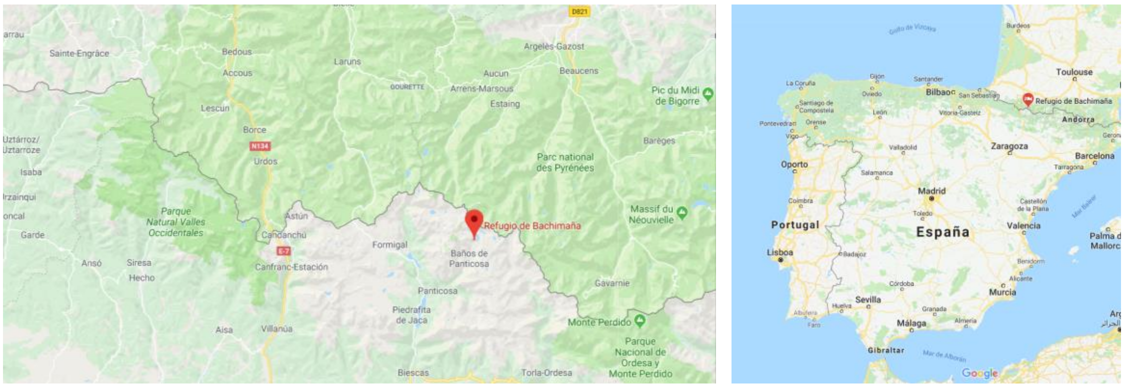

Figure 2.8. Ubication of Bachimaña hut in Spanish Pyrenees [19]

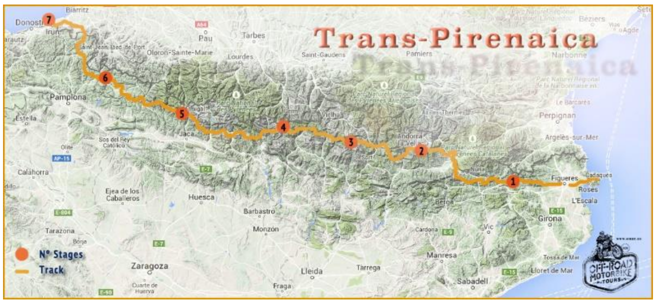

Figure 2.9. Route GR11 [21]

According to the data of a Spanish meteorology agency, AEMET, the weather in the region of Pyrenees can be classified as warm and template, although in the specific ubication of the hut the summers are very sunny and the winters are cold and mostly it snows daily so it can be concluded that it is a rainy place in the hole year [20],[22].

Bachimaña hut has a capacity of 80 people, in rooms from 4 to 12 persons which dispose of showers, hot water, bar service, nursing, heating, lockers, radio, telephone, internet, webcams, weather data collection as well as heliport [21]. Together with Torino Refuge, Bachimaña is open the entire year.

All of these services allow to offer a huge range of options in the sportive function, such as hiking, climbing, mountaineering and other difficulty activities, in addition to public service installation, due to his privileged location [21].

On the other hand, regarding to the technologies which Bachimaña hut has, it should be noticed the micro-hydro power plant that it is operating when the reservoir is full, besides other sources which are collected in the Table 2.4., while the diesel heater is the only heat source available in the hut.

Table 2.4: Current status of technologies in Bachimaña hut

	Electricity sources	Heat sources	Insulation
Bachimaña hut	Large diesel generator	Diesel heater	Walls
	Smaller diesel generator		
	Batteries storage		Roof
	Hydro-turbine		

2.5. Lizara hut

Aragüés-Jasa valley is one of the four valleys of the Natural Park of the Western Valleys as it can see in the Figure 2.11, very close to the French borderline, in where the Lizara hut is located (show in the Figure 2.10), more concretely in Lizara plain and under impressive Bisaurín (at the end of the Aragüés-Jasa valley) [13], [21]. The altitude of the hut is at 1540 m which is possible to reach by car, by bicycle and on foot [21].

Figure 2.10. Lizara hut [13]

Figure 2.11. Location of Lizara hut [23]

Due to its ubication and surroundings, it is a marvellous point for development of initiation activities in all type of mountain sports because of middle mountain tours [21], even for being outside of citizens and also the connections with other huts that make possible the crossing of several days. In winter, not only all of these activities are available, but also it is important to remark the possibility of practise cross country ski, so it is available a track background since Lizara hut contribute to carry it out [21]. The weather is warmer in the summers and colder in the winters, also it is characterized because it is a very rainy place.

Since October 2004, Lizara hut is certified with ISO 14001, with the purpose of achieving environmental management model with the facilities of Renewable Energy Sources. Due to the fact consist in a pioneering experience in Spain and Pyrenees in the field of mountain refuges [21].

Otherwise, Lizara hut has the capacity for 78 guests, where it is provided by room with bathroom with the services of showers, hot water, heating, bar, meal service [21]. The hut counts with an annex building, here are allocated the PV panels, as well as the generators and the batteries [8].

According to these needs, the mean number of employees may range from 1-2, in winter, to 2-5 in summer season, while the dimensions of the hut are 29 x 9 x 11.5 m [14].

In relation with the technologies both electricity sources and heat sources. All of them are summarized in Table 2.5:

Table 2.5: Current status of technologies in Lizara hut

	Electricity sources	Heat sources	Insulation
Lizara hut	Diesel generator	Firewood stove	na
	Diesel generator		na
	Batteries storage	Natural gas heater	na
	PV panels		na

2.6. Cap de Llauset hut

The Cap de Llauset hut is located in the highest level of mountain huts in the Aragonese Pyrenees, at 2450 m of altitude, in the Ribagorza region, in the Maladeta massif, within the Posets-Maladeta Natural Park. Just like Bachimaña hut or Lizara hut, Llauset hut is located within the GR11 (the Trans-Pyrenean Trail), so as to make this route of international interest on account of giving also coverage, service and security to many mountaineers. In the next picture it is noted the ubication of the hut in the map [13],[21].

The hut is protected from avalanches and sunny most of the day [9]. The Llauset hut has been built with the funds of the Provincial Council of Huesca, the town hall of Montanuy and the FAM itself. In 2010, the hut had built which dimensions are 35.25x6.83x10.74 m, and since summer 2016 the hut opens with a capacity for accommodation of 30 guests. However, the main idea of the hut is achieve the capacity for 80 people with then second building [21]. Because work is planned to ensure this accommodation reaching low levels of impact in the environmental.

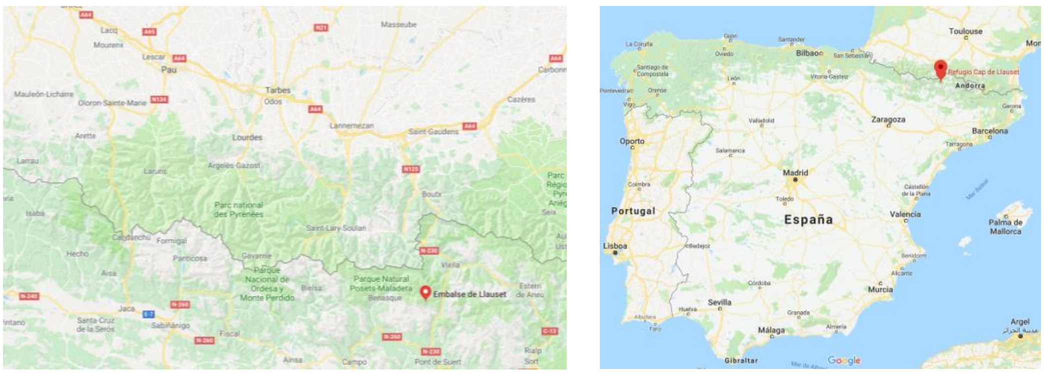

Figure 2.12. Ubication of Cap de Llauset hut, in Aragonese Pyrenees [24]

The average accommodation per day of the hut is of 60 people during summer, while the rest of the year are 27, besides there are 4 employees of average who works in the entire year for keeping the property function of the hut. Providing accommodation during hole year [14].

Figure 2.13. Cap de Llauset hut, in Spanish Pyrenees [21]

In the hut, the weather ranges between sunny summers and cold winters (with snows daily), because of the weather on the region is classified as warm and template [9].

Furthermore, in Table 2.6 are all the technologies present in the hut which are:

Table 2.6: Current status of technologies in Cap de Llauset hut

	Electricity sources	Heat sources	Insulation
Cap de Llauset hut	Diesel generator	Pellet stove (Ecoforest)	Roof
	Diesel generator		
	Batteries storage		Walls
	PV panels		

2.7. Estós hut

The Estós hut is located in the heart of the Posets-Maladeta Natural Park, at 1890 m of altitude, in particular in the Estós valley, which is consider as one of the most charismatic places in the Pyrenees for mountaineers due to counted first with a guarded mountain hut. Also it is consider as one of the eldest of the Pyrenees [10], [21].

Figure 2.14. Estós hut, in Aragonese Pyrenees [13]

Estós valley is a glacial valley in where extensive meadows coexist that allows its cattle exploitation, leafy forests, tarns and high mountains with more than 3000 m such as Posets-Llardana and el Perdiguero [13], [21].

The Estós hut which is located in the middle of the valley, it is a starting point for mid and high mountain activities as a final point for a beautiful and easy hiking trail, which combines the climb up the valley floor and the return to the Batisielles lakes. The hut is a strategic point for crossing of several days due to be within the GR11, and also between Spanish and French huts [21]. During winters, it is recommended it for the most experiment mountaineers due to the dangerous access to the hut, reason why is necessary access by helicopter in case of need of necessities.

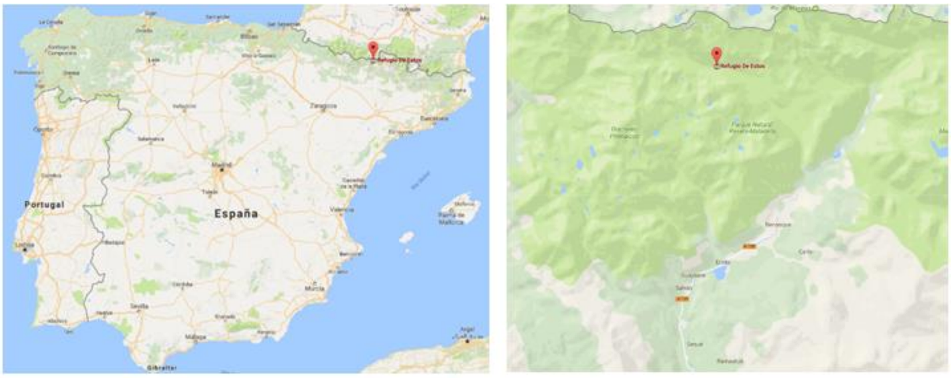

Figure 2.15: Location of Estós hut [25]

The hut was completely destroyed by a fire in 1984 and reconstructed in 1984, nowadays it is opened all year and has a capacity for 115 people, as long as the average accommodation per day is 12, achieving 43 during summer season. Moreover, the average number of employees is of 3,5 person (guards) [15].

The weather on the region is classified as warm and template. Thus, the summers are very sunny while the winters, which has snows daily, are cold.

On the other hand, Estós is one of the two huts in the project which have hydro turbine power, besides of the traditional electricity sources as diesel generation, PV panels or batteries storage. However, in this case like heat sources has a boiler.

Table 2.7: Current status of technologies in Estós hut

	Electricity sources	Heat sources	Insulation
Estós hut	Diesel generator	Boiler	Roof
	Batteries storage		
	PV panels		Walls
	Hydro turbine		

2.8. Montfalcó hut

Montfalcó hut is the last spanish hut included in the present study which replaces the initial hut called La Renclusa, this one has been dropped out. Consist on an experimented and well ready for public service installation as well as a sportive [11]. The hut is open the hole year.

The building comes from an old familiar house. In 2004, the house turned into a mountain hut after was reformed. Nowadays, the hut has the capacity for 45 guests, meanwhile according with the FAM statistics, the average affluence of guests per month is 4923.

Figure 2.16: Montfalcó hut [11]

The location of the hut is been at 790 m of altitude. Located in the Huesca Province, in the Montsec Range. To access the hut is possible do it by vehicle, so it is an excellent point of meeting for the nature lovers. The hut is in an environment that combines medium and high mountains, even so, a wide range of activities, such as kayaking and other water sport in a close reservoir, is possible do there.

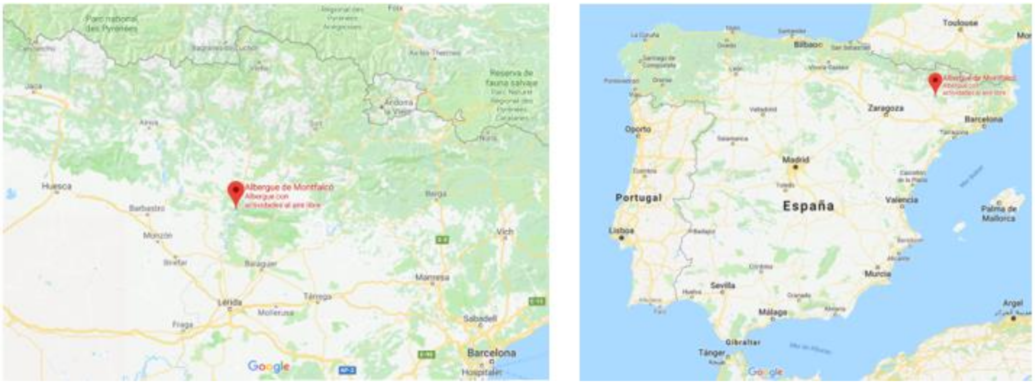

Figure 2.17: Location of Montfalcó hut [26]

According with the Spanish meteorology agency, AEMET the weather on the region is classified as warm summers and cold winters. Therefore, there are sunny summers and cold winters. The hut has tools which allow it for have information about the weather, even though, the measurements are compared with the database of AEMET [11].

The Montfalcó hut is committed to an environmental management model with the currently installation of renewable energy sources.

Table 2.8: Current status of technologies in Montfalcó hut

	Electricity sources	Heat sources	Insulation
Montfalcó hut	Diesel generator	Thermal Solar system	Roof
	Diesel generator		
	PV panels	Diesel boiler	Walls
	Batteries storage		

2.9. Refuge d'Ayous hut

Refuge d'Ayours (Figure 2.18) is the unique French mountain hut which is in Sustainhuts project and is located in the most protected area of Zone Coeur (Park National des Pyrénées, PNP). The hut is at 1980 meters of altitude, in particular is located in Nouvelle-Aquitaine region and Pyrénées-Atlantiques department, this location can be seen in Figure 2.19. To access at the hut, the unique way is a foot (a path of 2 hours, approximately) [12].

Figure 2.18: Refuge D'Ayous, in Pyrénées [12]

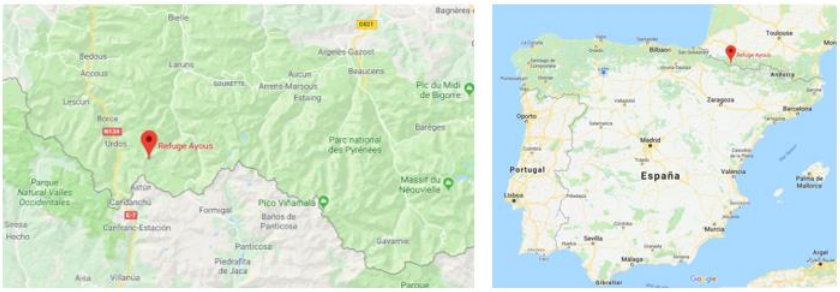

Figure 2.19: Location of Refuge D’Ayous [27]

The hut is open from June to the end of September, that means 4 months per year. The accomodation of the hut is for 47 guests, besides the average of employees are 5 workers.

Table 2.9: Current status of technologies in Refuge D'Ayous

	Electricity sources	Heat sources	Insulation
Refuge D’Ayous	Diesel generator	Gas via propane bottles	Roof
	PV panels		Walls
	Batteries storage		

3. Inventory: mass and energy balance

Below it is detailed specification of each hut of this project together with some tables, where operational characteristics are summarized. The principal aim is to reach the maximum information about the technologies installed on the hut, and the current state of hut, such as dimensions, average of visits per day, capacity of accommodation, as well as the surroundings, where the hut is located in order to analyse the possibility of install new technologies or improve current ones.

3.1. Kocbekov dom

Kocbekov dom hut is open from June to October (4 months/year). The hut has installed 1 diesel generator, photovoltaic panels for electricity generation with supported equipment such as batteries and converters. The hut has a wood stove that is powered by biomass (firewood) and also a wood burning oven for heat generation.

Based on the information gathered during the first 6 months of the project, in the following tables are collected all data that describe the current state of the hut in term of electricity and heat consumption, in order to have all data that it will be needed for LCA of each technology. In these tables are listed all the technical specifications for each technology used and the consumption of the fuel for one [4], [5], [14].

3.1.1. Electricity and heat generation

Electricity is provided using a diesel generator with 5 kW nominal power and produces 1500 kWh of electricity per year, PV Panels consist of wall panels (12x Siemens SM50) of 600 W power and roof panels (10x Siemens SM70) of 700 W, batteries (12 x 2V) of 1200 Ah capacity and three charge controllers, thus the hut is not connected to grid system (off-grid). In the system of the hut is 1500 W DC/AC inverter [14].

Table 3.1: Technologies used for electricity generation in Kocbekov dom

Type of Technology	Brand / type	m^2	Installed power	Max efficiency	Electricity generation
Diesel generator	Rade Končar AD-4-3x400/230	/	5000 W	26.0 %	1500 kWh/year
PV panels	Siemens SM50 (12x) in SM70 (10x)	10	1300 W	12.5 %	1539 kWh/year
Batteries storage	TAB 12 OPzS 1200 Ah (2V*12)	/	172,8 kWh ~28800	/	/
Electricity consumption					**3039 kWh**

So, the total amount of electricity consumption that Kocbekov dom is **3039 kWh** a year.

Heat generation is based only on biomass, particularly firewood in a wood burning oven/stove, the data are listed in the Table 3.2 which is shown under [4].

Table 3.2: Technologies used for heat generation in Kocbekov dom

Heat sources	Installed power	m^2	Efficiency	Energy generation
Firewood stove	5 kW	/	70 %	10850 kWh/y
Energy consumption				**10850 kWh/y**

In terms of heat, the total amount of energy consumption that Kocbekov dom has for year is **10850 kWh** [4]. The total amount of fuels consumption per year for the electricity and heatis listed in Table 3.3:

Table 3.3: Consumption required for technologies in Kocbekov dom

Fuels – consumption per year	Type of fuel	Used for	m^3	Mass kg
Liquid fuel	diesel	**Electricity**	0.12	/
biomass	firewood	**Heat**	6	/

3.1.2. Insulation

The insulation for the hut is made of insulated Alu panels, air gap and stone wall, even the roof is made of Alu panels and also wood. In the following table the specific data for insulation of Kocbekov dom are presented [5].

Table 3.4: Current status of insulation in Kocbekov dom

Insulation	Type/brand of insulation	Surface m^2	Thickness cm	Thermal conductivity W/(mK)
Outer walls	Insulated Alu panels	535	8	0.276
	Air		15	0.025
	Stone wall		70	2
Roof	Alu panels	214	0.5	250
	Wood		42	0.1

3.1.3. Transportation

The only way to access the hut is by foot. However, the goods and fuel is transported by helicopter. Although it was used for transportation of tools, equipment, diesel fuel and wastes during the analysis done in 2016.

3.1.4. Kocbekov dom after modification

One solution to improve the sustainability of Kocbekov dom is increased the capacity of PV modules, due to the current storage capacity is oversized for the existing systems and also it is still adequate for the modified systems. The target is increase the total capacity by 110%.

Table 3.5: Technologies proposed after modification in Kocbekov dom

Technology Proposed	Replaced	Power [kW]	Type/brand	Used for
New PV modules	(Increase capacity)	na	na	Electricity

Finally, in the Table 3.46 is attached all the technologies for electricity generation that each hut has, as well as the technologies proposed after modifications (Table 3.47). Regarding to heat generation, the technologies can be observed in Table 3.48 and Table 3.49

3.2. Pogačnikov dom

Pogačnikov dom is a hut in Slovenia open 3 month/year. The technologies in the hut are a gasoline generator and a diesel generator installed for electricity generation. The hut has installed a photovoltaic panels, batteries and converters. For the heat generation, the hut uses both a wood stove and wood burning oven, biomass.

3.2.1. Electricity and heat management

Through a system without grid connection which is formed by a diesel and petrol generators, PV panels and batteries, it is possible to provide the electricity to the hut. The nominal power for diesel and petrol generator is 4200 W and 4500 W, respectively. The diesel generator produces 1684.2 kWh per year, whereas the petrol generator produces 202.5 kWh per year.

Table 3.6: Technologies used for electricity generation in Pogačnikov dom

Electricity sources	Brand / type	Time	m^2	Installed power	Max efficiency	Electricity generation
Diesel generator	Nutool NDGS5000T	401 h	/	4.2 kW	19 %	1684.2 kWh/year
Petrol generator	Honda EC60002k	45 h	/	4.5 kW	22 %	202.5 kWh/year
PV panels	BP 255	/	4.32	1.37 kW	15 %	1347 kWh/year
Batteries storage	TAB 8 OPzS 800 Ah (2V*8)	/	/	115.2 kWh ~19200	/	/
Electricity consumption						**3233.7 kWh/y**

On the other hand, photovoltaic panels consist of wall panels of power 770 W and roof panels of 600 W. Pogačnikov dom hut has DC/AC inverter of power 1300 W and stack of 12 batteries of capacity 800 Ah. In relation with the heat sources in Pogačnikov dom, the generation is based on biomass in a wood stove and wood burning oven.

Table 3.7: Technologies used for heat generation in Pogačnikov dom

Heat sources	Installed power	m^3	Efficiency	Energy generation in 1 year/kWh
Wood stove	8	8	/	36167 kWh
Wood-burning oven	5	/	70 %	
Energy consumption				**36167 kWh**

Besides, the consumption per year of different type of fuel are attached in Table 3.8.

Table 3.8: Consumption required for technologies in Pogačnikov dom

Fuels – consumption per year	Type of fuel	Used for	m^3	Mass kg
Liquid fuel	diesel	Electricity	0.882	733.82
Liquid fuel	Petrol 95	Electricity	0.09	74.88
biomass	firewood	Heat	20	/

3.2.2. Insulation

The insulation of the hut is formed by wool and ceramic/cement façade, while roof is made of wood and roof tiles, the specific data are collected in the Table 3.9. The surface area without windows both outer walls and roof are 261 m^2 and 194 m^2, respectively.

Table 3.9: Current status of insulation in Pogačnikov dom

Insulation	Type/brand of insulation	Surface m^2	Thickness cm
Outer walls	Concrete	261	30
	Insulation + facade		15
Roof	Wood	194	20
	Decking		1

3.2.3. Transport

For accessing to the hut the only way for the visitors and employees is by foot. While for transporting the goods and fuel is necessary do it by their own cargo ropeway. Helicopter transport is hired only for heavier cargo, such as renovations or modification of the hut.

3.2.4. Pogačnikov dom after modification

Based on three types of systems which were simulated, the proposal that will be installed is listed in Table 3.10. One modification is to increase the capacity of PV, the target is increased by 160 %. Also, a wind turbine of 500 W will be installed

Table 3.10: Technologies proposed after modification in Pogačnikov

Technology Proposed	Replaced	Power [kW]	Type/brand	Used for
New PV modules	(Increase capacity)	na	na	Electricity
Wind turbine	-	0.5	na	Electricity

Finally, in the Table 3.46 is attached all the technologies for electricity generation that each hut has, as well as the technologies which are proposed after modifications (Table 3.47) Regarding to heat generation, the technologies can be observed in Table 3.48 and Table 3.49

3.3. Refugio de Torino

Torino hut is open during 11 months per year (closed in November). Unlike other huts, the hut is connected to electrical grid with medium voltage. The electricity need are 96155 kWh/year, while for heat generation biomass, diesel and electricity are required.

3.3.1. Electricity and heat management

Refugio de Torino is the only hut that it is connected to the medium voltage grid for electricity. It has a counter of 70 kW.

Table 3.11: Technologies used for electricity generation in Refugio Torino

Type of technology	Brand / type	Time of operation	Installed power	Connected to the electrical grid
Electrical grid	Medium voltage	/	70 kW	96155 kWh
Total Electricity consumption				**96155kWh**

For heat generation, the heat gets from electricity, the devices which are used are 4 electric fans (4x5 kW) with a total installed power of 20 kW, and 6 electric heaters (6x2 kW). Besides, there are 2 diesel fans with a modulated output from 20-60 kW (located in the drying room and the self-service room) and 2 pellet stoves (located in the room bar and in the lunchroom).

Table 3.12: Technologies used for heat generation in Refugio de Torino

Heat sources	Installed power	m^3	Efficiency	Energy (heat) consumption
Electric fans (4x 5 kW)	20	/	/	
Electrical heaters (6x 2 kW)	12	/	/	
Diesel fans (2)	20-60 kW	/	/	
Pellet stoves (2)		/	/	
Energy consumption				**Electricity for heating is not measured separate**

Based on this requirement the yearly consumption is listed in the Table 3.13.

Table 3.13: Consumption required for technologies in Refugio Torino

Fuels – consumption per year	Type of fuel	Used for	m^3	Mass kg/year
Liquid fuel	diesel	Heat	4	3280
biomass	pellet	Heat	3	2700

3.3.2. Insulation

The insulation in Torino hut is only in the bar room and lunchroom with a surface area of 76 m^2 without windows. Rock wool is the type of insulation has been chosen for it.

Table 3.14: Current status of insulation in Refugio Torino

Insulation	Type/brand of insulation	Surface m^2	Thickness cm
Wall	Rock wool	76	63.6
Wall	Sand & cement	na	na
Wall	Rock	na	na
Window	PVC	na	na

3.3.3. Transport

Refugio de Torino hut has a contract with the management of the cableway of 21600 €/y for being connect to it, and for water transport pays 0,085 €/kg. Besides for the transport of employers and materials (fuel is included), food and water, the hut have another contract of 1800 €/ month.

Despite having a contract for the water, the service is not always guaranteed. However, the ropeway transports 2000 l/day of water. The number of times that the hut needed the helicopter during 2016 was 7 times. By helicopter can be transported only 600 l of water and each trip cost 250 €. Whereas, the cableway can transport 2000 l/day of water.

3.3.4. Refugio Torino after modification

The technologies proposed in a future in the mountain hut of Torino is the increased of new photovoltaic panels, and the installation of an hydro-turbine. Data regarding to specification are no available.

Table 3.15: Technologies proposed after modification in Refugio Torino

Technology Proposed	Replaced	Power [kW]	Type/brand	Used for
New PV panels	-	na	na	Electricity
Hydro-turbine	-	na	na	Electricity

Finally, in the Table 3.46 is attached all the technologies for electricity generation that each hut has, as well as the technologies which are proposed after modifications (Table 3.47) Regarding to heat generation, the technologies can be observed in Table 3.48 and Table 3.49

3.4. Bachimaña hut

Bachimaña hut is open all year. The hut has installed 2 diesel engines and a mini-hydro power plant with supported equipment such as batteries and converters. Nowadays, the hut has a diesel heater for heat generation.

3.4.1. Electricity and heat management

The main energy sources of Bachimaña are water (almost 10 months per year) and diesel (2 or 3 months) for electricity production and only diesel in generation of heat. Therefore, the hut is formed by 2 diesel engines of 8 kW and 25 kW respectively in which total amount is 32 kW, although the small diesel generator do not use it. The mini-hydro power plant with a turbine of 30 kW (since 7 years ago) has manual regulation [14], [21]. It is highlight that the small diesel engine is only used in case that the biggest one breaks down.

Table 3.16: Technologies used for electricity generation in Bachimaña

Electricity sources	Brand / type	Time of operating (m/year)	m^2	Installed power	Max efficiency	Electricity generation
Diesel generator (Large)	SORILUX / HYW-35 T5	9-10	/	25 kW	/	2106 kWh/year
Diesel generator (smaller)	SORILUX / HLA1-10T STD	9-10	/	8 kW	/	0 kWh/year
Hydro-Turbine	SALTOS DEL PIRINEO / ECOWATT	/	/	30 kW	/	107603 kWh/year
Batteries storage	Hoppecke	/	/	73.1 kWh	/	/
Electricity generation						**109709 kWh/year**

Despite using diesel heater during all the year, the diesel generator are used to produce electricity when the turbine is not used (when there is not water availability). However, in short-time, instead of using diesel heaters it is expected to change it by electric heaters in order to reduce the power of micro-hydro [21].

Table 3.17: Technologies used for heat generation in Bachimaña

Heat sources	Installed power	m^3	Efficiency	Energy (heat) consumption
Diesel boiler	73-178 kW	5586 liters	/	55480 kWh
Energy consumption				**55480 kWh**

The hut is provided by a data logger since June 2017, in order to take measurements of the electric consumption in the hut. This allow us the amount of energy consumed monthly and the electric daily profile, even though it is not possible to know the specific consumption of every part of the hut. Despite of having different consumption per year due to the water availability, it is included electricity and heat together, the average diesel which is consumed ranges from 4000-5000 litters per year [21]. While the energy provided by the hydro turbine is collected manual, so its value is illustrative. The total amount of water in the reservoir during March, April and May is considered zero.

Table 3.18: Consumption required for technologies in Bachimaña

Fuels – consumption per year	Type of fuel	Used for	l/year	Mass kg
Liquid fuel	diesel	Electricity	1197 l	
Liquid fuel	diesel	Heat	6633 l	70 % of all mass
Natural water of reservoir	Water	Heat		variable

3.4.2. Insulation

The most relevant insulation in Bachimaña hut is the roof, which is made by wood and extruded polystyrene, and walls which are formed by a surface of 328.4 m^2.

Table 3.19: Current status of insulation in Bachimaña

Insulation	Type/brand of insulation	Surface m^2	Thickness cm	Thermal conductivity W/ (mK)
Walls	Stone	328.4	45	1.5
Roof	Wood	342.72	35	0.12
	Extruded Polystyrene			0.03808

3.4.3. Transport

To provide the hut with all the diesel, which Bachimaña requires, is necessary 2 methods of transportation, a truck that carries the diesel from Sabiñanigo to Baños de Panticosa (37,9 km), and then an helicopter, which continues with the travel from Baños de Panticosa to the hut (500 m). The amount of trips as well the length of them are:

By truck:

- trips per year: one during spring and another one during autumn

By helicopter:

- 9 trips per year (limitations due to weight)
- 7 minutes of length from Baños de Panticosa and the hut (14 mins considering return)
- 20 minutes between Viella (the headquarter helicopter) and Baños de Panticosa

The helicopter trips have a length of 7 minutes (14 considering the round trip) between Baños de Panticosa and the hut and 20 minutes (40 considering the round trip) between the headquarter helicopter (located in Viella) and Baños de Panticosa. It is usually done twice per year, one during spring and another one during autumn

3.4.4. Bachimaña after modification

In the short-term, there are some technologies proposed for installing in Bachimaña hut in order to improve the sustainability of the hut. First, the diesel boiler will be replaced by an electric boiler, in this way it is possible to replace the fossil fuel by electricity generated by renewable sources (hydro turbine excess electricity); also they are proposed a hot water collector and a micro wind turbine.

Therefore, the hydro turbine might supplied all the energy that is needed and currently generated with the diesel boiler. Besides, the wind turbine will supply renewable energy when the hydro turbine cannot work.

So far, due to the amount of renewable power installed, is not expected to install a PV system. Furthermore, hydrogen storage system is proposed in order to stock up the surplus of electricity from turbine. In the Table 3.20 are shown the proposal for installing.

Table 3.20: Technologies proposed after modification in Bachimaña

Technology Proposed	Replaced	Power [kW]	Type/brand	Used for
Electric Boiler	Diesel boiler	10		Heat
Micro Wind Turbine	Diesel boiler	2.5(x)0.3	LE-300/Leading Edge	Heat
HSS	Batteries storage			Energy
H2	-			

Finally, in the Table 3.46 is attached all the technologies for electricity generation that each hut has, as well as the technologies which are proposed after modifications (Table 3.47) Regarding to heat generation, the technologies can be observed in Table 3.48 and Table 3.49

3.5. Lizara hut

Lizara hut is open 12 months of the year. The hut has 2 diesel engines, with a photovoltaic generation and a battery storage system, where the energy is accumulated. Regarding the heating system, the hut has 2 natural gas boilers with a tank of water, as well as a wood burning stove. For electricity generation, the main primary energy carriers are diesel and sun, whereas for heat generation are gas and wood [14].

3.5.1. Electricity and heat management

Regarding the electricity generation, Lizara has 2 diesel engines, one of 12 kW is currently damaged, although it is expected to be repaired in short-time, and other of 32 kW power.

In addition to a photovoltaic generation which supply with a power of 4 kW and 5 kW (the useful power installed is 0.5 kW), where are divided in 4 panels of 195 W, 17 of 123 W and 15 of 100 W. In general, the hut operates with the small generator, except when the hut requires more energy, for instance when the big dishwasher is working.

The single-phase consumption is supplied by a rack of batteries, which are charged by the three-phase generators, or by the PV panels. The system storage is composed by 24 batteries, of 2 V and 800 Ah each one, each battery is from different age (this could be a problem).

Otherwise, the commutation between the generators and the PV panels is manual. Besides, it should be noted that the energy produced in 1 year by diesel generator is based on the volume of diesel consumed per year and its calorific power, while the energy produced by PV panels is based on 6 h of daylight per day.

Table 3.21: Technologies used for electricity generation in Lizara

Electricity sources	Brand / type	m^2	Installed power	Electricity generation
Diesel generator	Sorilux	/	12.8 kW	11655 kWh/year
Diesel generator	Marelli Generators	/	25.6 kW	1090 kWh/year
PV panels	Alex Solar		4.3 kW	631 kWh/year
Batteries storage	Hoppecke		8.4 kWh	/
Electricity consumption				**13376 kWh/year**

For heating generation the hut has two natural gas boilers with a tank of 120 l of water. In addition Lizara has a wood burning stove (firewood stove or chimney).

Table 3.22: Technologies used for heat generation in Lizara

Heat sources	Installed power	m^3	Efficiency	Energy Production in year
Natural gas boiler	na	-	-	83950 kWh
Firewood stove	na	20	10 %	350 kWh
Energy consumption				**84300 kWh**

The annual consumption is 6000 kg of natural gas, while for firewood there is no information of the amount of consumption. These data are gathered in the Table 3.23:

Table 3.23: Consumption required for technologies in Lizara

Fuels – consumption per year	Type of fuel	Used for	m^3/year	kg/year
liquid fuel	diesel	Electricity	6	5290 l/year
gas fuel	Natural gas	Heat	10001	-
other	wood	Heat	-	700 kg/year
Total consumption per year				/

3.5.2. Insulation

The hut is insulated on the roof and the walls with a thickness of 40 cm. The insulation is made with a mix of stone and wood. It could be said that the hut has a good isolation level due to have isolated the most relevant surfaces of the hut. In the Table 3.24 is shown in detail the current status of insulation.

Table 3.24: Current status of the insulation in Lizara hut

Insulation	Type/brand of insulation	Surface m^2	Thickness cm
Front	Stone/ Wood	146	40
Right	Stone/ Wood	72.9	40
Left	Stone/Wood	72.8	40
Back	Stone/Wood	166	40
Roofs	Stone/Wood	390	40

3.5.3. Transport

It is possible to arrive by car, therefore for the transport of fuel, food and basic things, in this case, it is not necessary use a helicopter.

3.5.4. Lizara after modification

The current power of PV will be increased installed by 3.5 kW more. It is also considered to replace the oldest PV arrays installed in order to increase the annual production. Besides, it is considered to install an automaton system, such as AAI (Advanced Automation of Installation) in order to control automatically the electric system, this means that it will not be necessary to control the batteries, DGs and PV system manually like it is doing. Therefore operating hours of the largest generator will be reduced, while those of the smallest generator will be increased. In this way the amount of diesel consumed could be decreased.

In order to reduce the amount of natural gas consumed, it is proposed the substitution of open chimney by thermo-chimney. With this implementation it will be possible to increase the heat produced and the efficiency of the chimney, as well as the use of a local resource, such as firewood.

Table 3.25: Technologies proposed after modification in Lizara

Technology Proposed	Replaced	Power [kW]	Used for
PV added Installation	-	3.5	Electricity
New PV arrays	Eldest PV arrays	-	Electricity
AAI	Manual system	-	Heat
Thermo-Chimney	Open chimney	-	Heat

3.6. Cap de Llauset hut

Llauset hut is open all year round. The technologies available are 2 diesel engines for electricity generation, photovoltaic system and a lack of batteries storage. The primary energy carrier is diesel and the sunlight for electricity production, while for heat generation pellets. The hut is opened since 2016, so there is still not enough data available for the consumption of diesel generation.

3.6.1. Electricity and heat management

Llauset hut has 2 diesel engines of 12 kW and 36 kW, respectively with an three-phase generators in the hut and a single-phase for the rack of batteries, which can be charged by either the three-phase generators or by PV panels [9]. In order to control the source of the power, there is a system of control switches, which assure that there is only one supplier.

Table 3.26: Technologies used for electricity generation in Llauset

Electricity sources	Brand / type	m^2	Installed power	Electricity generation
Diesel generator	Grupos Electrógenos y Generadores SC/STAMFORD	/	12 kW	7866 kWh/year
Diesel generator	Grupos Electrógenos y Generadores SC/STAMFORD	/	36 kW	-
PV panels		33	4 kW	-
Batteries storage	Hoppecke	/	73.1 kWh	-
Electricity consumption				**7866 kWh**

The installation for the heat generation is done with 2 Pellet stoves. For the water heating system small electrical thermoses are used.

Table 3.27: Technologies used for heat generation in Cap de Llauset

Heat sources	Installed power	Energy (heat) consumption
Pellet stove (Ecofores)	16 kW	-
Small electrical thermoses	na	-
Energy consumption		**10694 kWh**

Regarding the consumption an estimation about the consumption of pellet per day is done, because of not enough information [9]. Otherwise, the water is obtained from the tarn Cap de Llauset.

Table 3.28: Consumption required for technologies in Cap de Llauset

Fuels – consumption per year	Type of fuel	Used for	m^3	Mass kg
Liquid fuel	diesel	**Electricity**	4.5	/
biomass	pellets	**Heat**	/	14 kg/day

3.6.2. Insulation

In order to achieve better insulation in the hut, Llauset hut was been insulated both on roof and walls with several layers of wood and insulating materials - Table 3.29. In particular, the enclosure is formed by: the walls of the facade are made with wood because it is a structural material of easy prefabrication. The external surface is galvanized mini-wave plate, while the outdoor walls have: 0.6 mm of galvanized mini-wave + 10 cm of waterproof sheet + 5 cm of thermal acoustic insulation of natural cork + 10cm of plywood board BBS [9]. The cover has the same structure that enclosure, although instead of 10 cm one of 9.5 cm.

Table 3.29:Current status of insulation in Cap de Llauset

Insulation	Type/brand of insulation	Surface m^2	Thickness cm
Front	Several layers of wood and insulating materials	52.73	38
Lateral right		30.85	38
Lateral left		32.91	38
Back		62.57	38
Both roofs		103.09	38

3.6.3. Transport

To supply the hut with all the materials both fuel and food and basic things, it is necessary to do it by helicopter.

3.6.4. Cap de Llauset after modification

It is planned to install a micro wind generator, but it will be necessary to analyse the conditions of the wind through a wind logger, which was installed [9].

Moreover, for the water heating, two natural gas boilers are going to replace the current system based on small electrical thermoses. The target is to install one boiler in each building.

Table 3.30: Technologies proposed after modification in Llauset

Technology Proposed	Replaced	Type/brand	Used for
Micro wind generator	-	na	Electricity
Natural gas boiler (2)	Small electrical thermoses	na	Heat

Finally, in the Table 3.46 is attached all the technologies for electricity generation that each hut has, as well as the technologies which are proposed after modifications (Table 3.47) Regarding to heat generation, the technologies can be observed in Table 3.48 and Table 3.49

3.7. Estós hut

Estós hut is open the entire year. For electric generation has a diesel engine, an hydro turbine, photovoltaic panels and a rack of batteries for the storage.

3.7.1. Electricity and heat management

The hut has a diesel generator with 35 kW of nominal power which produces 8844 kWh electricity per year and a hydro turbine of 5 kW which generates is 2580 kWh electricity per year.

In addition 20 photovoltaic panels of 123 W (2.9 kW in total) are installed. An electric generation per year is 1712 kWh and a rack of batteries of 48 V with 1200A C100 that means about 58 kWh.

Table 3.31: Technologies used for electricity generation in Estós

Electricity sources	Brand / type	m^2	Installed power	Energy production
Diesel generator	Grupos Electrógenos y Generadores SC / STAMFORD	/	35 kW	8844 kWh/year
PV panels	-	3	2.9 kW	3933 kWh/y
Hydro turbine	-	/	5 kW	5004 kWh/year
Batteries storage	Hoppecke		38.4 kWh	-
Electricity production				**11279 kWh**

The heat generation is done with a diesel boiler, but regarding the heating system there is no information.

Table 3.32: Technologies used for heat generation in Estós

Heat sources	Installed power	m^3	Energy (heat) production
Diesel Boiler	-	-	32121 kWh/year
Energy production			**32121 kWh**

Regarding to the consumption of each technology the fuel is the need required which amount of each used is attached below.

Table 3.33: Consumption of fuel required for technologies in Estós

Fuels – consumption per year	Type of fuel	Used for	m^3	Mass kg
Liquid fuel	diesel	**Electricity**	4498 l	/
Liquid fuel	diesel	**Heat**	3840 l	/

3.7.2. Insulation

No specific information regarding insulation has being gathered since the hut is very old. It can be considered the same kind of insulation as in Bachimaña hut.

Table 3.34: Current status of insulation in Estós (considered as Bachimaña hut)

Insulation	Type/brand of insulation	Surface m^2	Thickness cm	Thermal conductivity W/ (mK)
Walls	Stone	328.4	45	1.5
Roof	Wood	342.72	35	0.12
	Extruded Polystyrene			0.03808

3.7.3. Transport

The helicopter is the transport which is necessary to transport the material required in the hut, such as fuels, food and basic things [10]. Not specific information regarding flying hours per year is available.

3.7.4. Estós after modification

The technologies proposed to consider install in a future are listed in the Table 3.35. As it can be observed it is considering to install an additional installation of PV panels (2 kW more), a pellet stove with a total power of 16 kW and also a micro-hydro turbine.

Table 3.35: Technologies proposed after modification in Estós

Technology Proposed	Replaced	Power [kW]	Type/brand	Used for
Hydro turbine	-	na	na	Electricity
New PV	-	2	na	Electricity
Pellets Stove	-	16	na	Heat

Finally, in the Table 3.46 is attached all the technologies for electricity generation that each hut has, as well as the technologies which are proposed after modifications (Table 3.47) Regarding to heat generation , the technologies can be observed in Table 3.48 and Table 3.49.

3.8. Montfalcó hut

Montfalcó hut is open all year. The hut has 2 diesel engines, of which one is only used for water pumping and another for the electricity generation in the mountain hut. It has a PV system and energy storage in a form of 24 batteries.

The hut has a diesel generator in order to pump the water to the building, which is supplied from a water natural spring located hundreds of meters from the mountain hut.

3.8.1. Electricity and heat management

For electricity generation the diesel engine of 50 kW (63 kVa) and a PV system of total power of 5.7 kW divided in a group of 28 panels with 150W and 8 panels with 900W are installed.

The electricity generated is three-phase in case of generators, and a single-phase in the case of PV panels. Therefore, the single-phase is supplied by a rack of batteries or the PV panels. Otherwise, the energy storage system has 24 batteries of 2V and 2280 Ah (C100) each one. In order to not discharge the batteries below optimal conditions, there is an automatic commutation between the generator and the PV panels.

An estimation of the energy consumption was made based on the data gathered in Lizara hut and using the amount of guests in both huts - Figure 3.1.

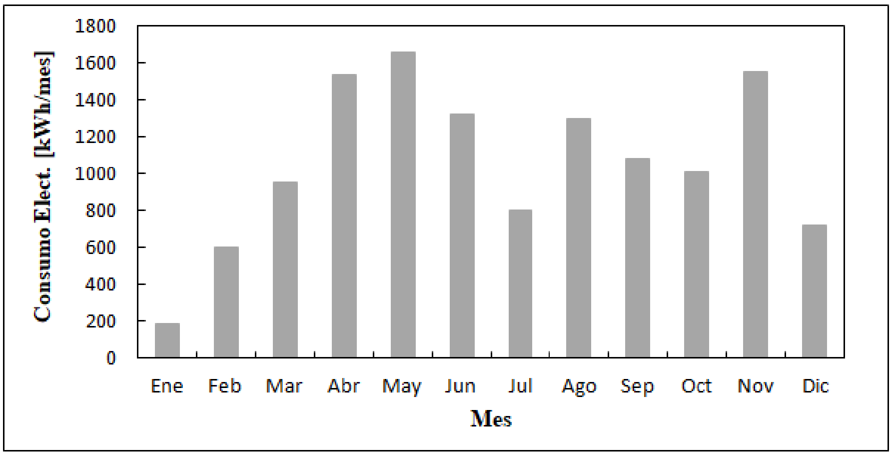

Figure 3.1: Monthly estimated electric consumption in Montfalcó hut [11]

Therefore, the average of total electricity consumption for 1 year is 1033.33 kWh/year.

Table 3.36: Technologies used for electricity generation in Montfalcó hut

Electricity sources	Brand / type	m^2	Installed power	Max efficiency	Electricity generation in 1 year/ kWh
Diesel generator	NEWAGE STAMFORD	0.97x0.57x0.96	50 kW	%	-
PV panels	PHOTWATT	35.8	4.2 kW		-
PV panels	SACLIMA	10.2	1.5 kW		-
Batteries storage	PowerSafe and BAE	0.28x0.21x0.83	109.5 kWh		-
Electricity consumption					**1033.3 kWh**

To heat the water, the heating system in the hut is formed by a thermal solar system. A diesel engine of 12 kW is only used for water pumping and for a diesel boiler around 50 - 70 kW. In this case, it is not possible distinguish between the consumption of the fuel used in generator and boiler because to the tank is the same. Estimated to 10000 l/year.

Table 3.37: Technologies used for heat generation in Montfalcó hut

Heat sources	Installed power	m^3	Energy (heat) consumption
Thermal solar system	5 panels	1.5	
Diesel boiler	50-70 kW	10	
Energy consumption			**kWh**

Table 3.38: : Consumption of fuel required for technologies in Montfalcó hut

Fuels – consumption per year	Type of fuel	Used for	m^3	Mass kg
Liquid fuel	diesel	**Electricity Heat**	5000 approx.	10000 l/year
Water from solar thermal	Hot water	**Heat**	N/A	N/A

3.8.2. Insulation

The insulation installed in Montfalcó hut is a mix of stone and wood on the roof and the walls, with thickness of 60 cm.

Table 3.39: Current status of insulation in Montfalcó hut

Insulation	Type/brand of insulation	Surface m^2	Thickness cm
Front	Wood/Stone	160	60
Lateral right		100	60
Lateral left		100	60
Back		160	60
Both roofs		160	60

3.8.3. Transportation

To access the hut is possible by vehicle, so for the transport of material (fuels, food and basic things) the truck is the vehicle.

The diesel used in the generators is carried from Benabarre (Huesca), with 2 trips. The truck consumption is estimated as 0.3 l/km obtained as the Figure 3.2 shows. Therefore, it is necessary 30.48 litters of diesel consumption for supplying the hut [11].

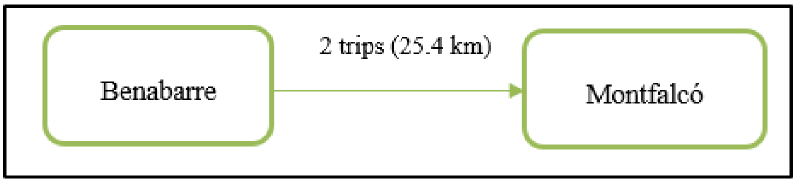

Figure 3.2: Trip with the truck to Montfalcó

3.8.4. Montfalcó after modification

A new additional installation of PV panels is proposed to install in Montfalcó hut, as well as an hydro-turbine. Regarding to the technical specifications do not available yet (Table 3.40).

Table 3.40: Technologies proposed after modification in Montfalcó

Technology Proposed	Replaced	Type/brand	Used for
PV added Installation	-	na	Electricity
Hydro-turbine	-	na	Heat

Finally, in the Table 3.46 is attached all the technologies for electricity generation that each hut has, as well as the technologies which are proposed after modifications (Table 3.47) Regarding to heat generation, the technologies can be observed in Table 3.48 and Table 3.49.

3.9. Refuge D'Ayous

Ayous hut is opened 4 months a year (summer season). The electricity is generated by solar panels connected with a rack of batteries. The system has a fossil fuel (diesel) generator in case of emergency.

In short-term a Refuge d'Ayous manages will be opened two additional months (March and April) that means a rise of the energy consumption

3.9.1. Electricity and heat management

The system of the hut have 36 solar panels of 18 m^2 that storage the energy in 12 electric batteries of 24 V each one. Nevertheless, the hut has also a generator that is just in the case of emergency [12].

Table 3.41: Technologies used for electricity generation in Ayous hut

Electricity sources	Brand / type	Time of operating (m/year)	m^2	Installed power	Max efficiency	Electricity generation
Diesel generator	na		/	-	/	0
PV panels	na	/	18	1.8 kW	/	489 kWh/y
Batteries storage		/	/	24V (12 batteries)	/	/
Electricity consumption						**489 kWh/y**

Regarding to thermal energy consumptions, it has an average of 5900 kWh divided between domestic hot water, kitchen and washing machine, the heat is generated from propane with an installation of 35 or 36 bottles of 13 kg each one.

Table 3.42: Technologies used for heat generation in Ayous hut

Heat sources	Installed power	m^3	Energy (heat) consumption
bottles of propane	35-36 bottles		5900 kWh
Energy consumption			**5900 kWh**

Overall propane consumption is about 455 to 468 kg per season that means for four months.

Table 3.43: Consumption of fuel required for technologies in Ayous hut

Fuels – consumption per year	Type of fuel	Used for	m^3	Mass kg
Liquid fuel	Diesel	**Electricity**	0	0
Gas	Propane	**Heat**		455 kg/season

3.9.2. Insulation

The roof with a delta structure and the front and back facades are insulated both with rockwool. There are two windows with double glazing. There are some parts of the hut which are not insulated, such as the stone basement and the floor, neither the guardian space of 10 m^2 nor 10 m^2 of roof have insulation [12].

Table 3.44: Current status of insulation in D'Ayous

Insulation	Type/brand of insulation	Surface m^2	Thickness cm
Front	Rockwool	35	20
Lateral right	Rockwool	70*	20
Lateral left	Rockwool	70*	20
Back	Rockwool	40	20

* The floor interior do not have insulation

3.9.3. Transport

The transport of the propane gas is with helicopter, and according to Parc National of Pyrénees (PNP), it is necessary three trips per year with a length of 8 minutes each one (16 mins return trip). Therefore, total amount of time operation by helicopter are 48 minutes in a year.

3.9.4. Refuge D'Ayous after modification

In short-term the hut will be open 6 months instead of 4. This action will be supposed an overconsumption which carried out to be offset by generator or wood additional transportation by helicopter. To avoid this increase, it will be considered, first a small hydro power plant is planned to install in order to save 4000 kWh of gas consumption. In relation with the heat generation, instead of gas water heater, an electric water heater will be installed, the electricity for its used will be supply from the hydro-plant. Finally, it will be interested to experiment domestic anaerobic digestion to produce kitchen gas, with this modification it would be possible to replace the gas bottles used to supply the kitchen. In this way, an overall save of 8892 kWh/season, as well as CO_2 and NO_x generation will be equal to zero.

Table 3.45: Technologies proposed after modification in Ayous

Technology Proposed	Replaced	Power [kW]	Type/brand	Used for
Micro- Hydroelectric plant	-	na	na	Electricity
Electric water heater	Gas water heater	na	na	Heat
Domestic anaerobic digestion	-	-	-	Heat

The trips by helicopter will decrease for 15 % because of the reduction of gas consumption and firewood that means the trips in a future will be about 2 to 3 minutes rotations.

Finally, in the Table 3.46 is attached all the technologies for electricity generation that each hut has, as well as the technologies which are proposed after modifications (Table 3.47) Regarding to heat generation, the technologies can be observed in Table 3.48 and Table 3.49.

Table 3.46: Current status of technologies for electricity generation

	Kocbekov	Pogačnikov	Torino	Bachimaña	Lizara	Llauset	Estós	Montfalcó	D'Ayous
Larger diesel generator	-	-	-	25 kW	25.6 kW	36 kW	35 kW	50 kW	na
Smaller diesel generator	5 kW	4.2 kW	-	8 kW (no)	12.8 kW	12 kW	-	4.2 kW	-
Petrol generator	-	4.5 kW	-	-	-	-	-	-	-
PV panels	1.3 kW	1.37 kW	-	-	4.3 kW	4 kW	2.9 kW	1.5 kW	1.8 kW
Electrical grid	-	-	70 kW	-	-	-	-	-	-
Hydro-turbine	-	-	-	30 kW	-	-	5 kW	-	-
Batteries storage	172.9 kWh	115.2 kWh	-	73.1 kWh	38.4 kWh	73.1 kWh	38.4 kWh	109.5 kWh	(12 x 24V)

Table 3.47: Current Status of technologies for heat generation

	Kocbekov	Pogačnikov	Torino	Bachimaña	Lizara	Llauset	Estós	Montfalcó	D'Ayous
Firewood stove	5 kW	8 kW			na				
Wood burning oven		5 kW							
Electric boiler			(6x 2kW)						
Pellet stove			(2)			16 kW			
Electric fan			(4x5kW)						
Electric boiler									
Electric water heater									na
Diesel boiler				73-178 kW			na	50-70 kW	
Gas Natural boiler					na				
Diesel fan			20-60 kW						

Table 3.48: Future Status of technologies for electricity generation

Current technologies	Technologies proposed								
	Kocbekov	**Pogačnikov**	**Torino**	**Bachimaña**	**Lizara**	**Llauset**	**Estós**	**Montfalcó**	**D'Ayous**
Larger diesel generator	-	-	-	25 kW	25.6 kW	36 kW	35 kW	50 kW	na
Smaller diesel generator	Fuel cell system	Fuel cell system	-	~~8 kW~~	12.8 kW	12 kW	-	4.2 kW	-
Petrol generator	-	~~4.5 kW~~	-	-	-	-	-	-	-
PV panels	Increase capacity	Increase capacity	-	-	Increase capacity	4 kW	Increase capacity	1.5 kW	1.8 kW
Electrical grid	-	-	70 kW	-	-	-	-	-	-
Hydro-turbine	-	-	-	30 kW	-	-	5 kW	-	proposed
Batteries storage	Hydrogen energy storage	Hydrogen energy storage	-	HSS	38.4 kWh	73.1 kWh	38.4 kWh	109.5 kWh	(12 x 24V)
Micro Wind turbine				300 W		proposed	proposed		

Table 3.49:Future Status of technologies for heat generation

Current Technologies	Kocbekov	Pogačnikov	Torino	Bachimaña	Lizara	Llauset	Estós	Montfalcó	D'Ayous
Firewood stove	5 kW	8 kW			na				
Wood burning oven		5 kW							
Electric boiler			(6x 2kW)						
Pellet stove			(2)			16 kW	16 kW		
Electric fan			(4x5kW)						
Electric boiler				10 kW					
Electric water heater									Gas water heater
Diesel boiler				~~73-178 kW~~			na	50-70 kW	
Natural Gas boiler					Thermo-chimney	Small electrical thermoses			
Diesel fan			20-60 kW						
-									Domestic anaerobic digestion

4. Life Cycle Assessment methodology and numerical modelling

The Life Cycle Assessment (LCA) applied in this study is defined by the ISO 14040 and 14044 standards created, and is defined as the compiling and evaluation of the inputs and outputs and the potential environmental impacts of a product system during a product's lifetime, in other words, the LCA is a methodology that allows to analyse a product or service from cradle to grave [31], [32].

The LCA methodology is developed by four main steps: goal and scope, inventory analysis, impact assessment and interpretation, in where all of which will be described in-depth analysis in the following sub-chapter.

According to the target of this project, we will analyse all different technologies used in all mountain huts that have been described in the chapter 2 "*Mountain huts involved in the project*" and also, considering the chapter 3 "*Inventory: mass and energy balance*" of the present study. In order to make comparison between these technologies and get some information not only about the CO_2 and NO_x indicators but also global, regional and local impact criteria to all of them.

4.1. Goal and Scope

The goal of the present study is to make detailed LCIA (Life Cycle Impact Assessment) for each different technology of each mountain hut and carry out the LCA model of each one, including all possible inputs and outputs.

In order to achieve success in this methodology, it will be necessary to study the following issues:

- Electricity generation from current technologies installed
- Electricity generation from alternative technologies
- PV electricity production in the case of currently installed system
- Heat generation from conventional technologies
- Heat generation from alternative technologies

- Transport done with helicopter, cars, vans, trucks and other technologies due to mountain hut care, fuel supply, waste among other things
- Transport with freight cableway

With the aim of doing easier comparison of environmental impacts before and after the current study, each LCA model will be divided by one side for **electricity production**; on the other hand, for **heat production** since each hut have different influence on heat/electricity generation needs according to the changes in each specific technologies. Separate will be a **transport model**.

4.1.1. Functional unit

In order to be able relative comparison of different technologies for electricity and heat production the functional unit used will be **1 kWh of energy generated for electricity and heat** and per 1 hour or 130 km in the case of transport.

4.1.2. System boundaries

The target of this sub-chapter is make the system boundaries easier to understand, for that it is necessary to defined the process that will be included in or excluded in the LCA. According to these boundaries, it is possible to define the inputs of each technology, among which are: energy, necessary material or transportation, this last means that is necessary to take in account the fuel and the energy. The outputs are emissions in electricity and heat generation case as well by transport. Even though, it is an output the electricity, heat and distance covered by transport means. The input is also materials for maintenance but since there is very small amount of those materials are let of the scope of the study.

Starting for electricity sources, the first device which will be analysed is the **diesel generator** that are 12 (Figure 4.1). In the Figure 4.2 the system boundaries for petrol generator (only one in one hut) are presented. Both of them have as inputs liquid fuel, converting into electricity, in this process emissions are produced as a consequence of fuel combustion.

Electricity generation

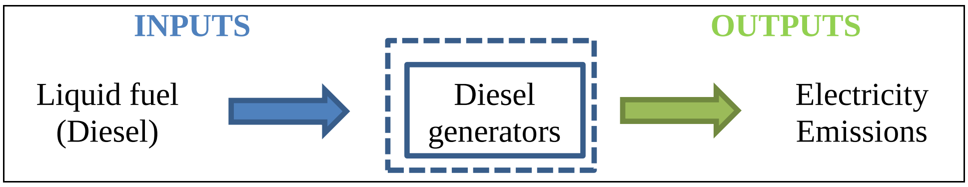

Figure 4.1: System boundaries for diesel generators

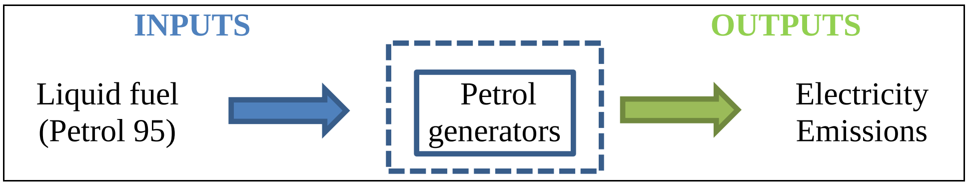

Figure 4.2: System boundaries for petrol generator

In relation with the micro-hydro power plant there are 2 small hydro power plant, which converts the natural flow of water (input) into electricity (output). It is characterized because have lower emissions resulting from the conversion process, that means which the effects on the environment is hardly harmful. (Figure 4.3).

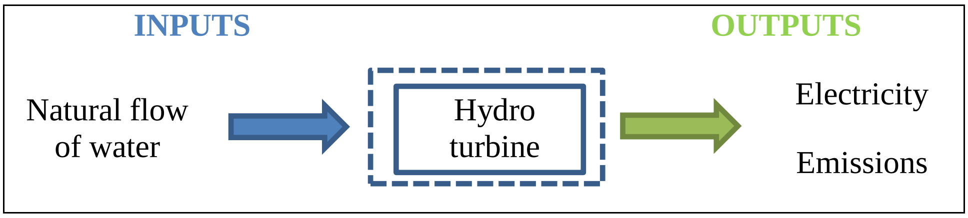

Figure 4.3: System boundaries for hydro turbine

The photovoltaic panels which will be studied in this present project are installed in 7 out of 9 huts contemplated, as with any renewable technology, the PV panels has not harmful emissions either (Figure 4.4).

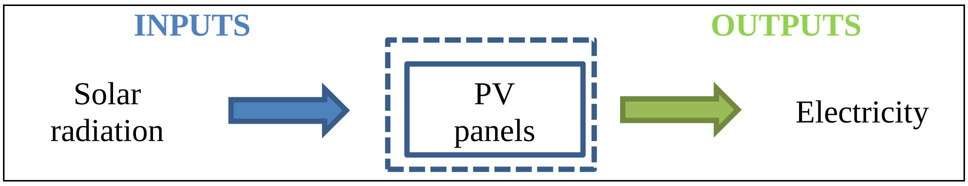

Figure 4.4: System boundaries for PV panels

Batteries storage consist of a rack of batteries where the energy from devices that convert the primary energy source into useful energy is stored. Therefore there will not be any emissions in the operating phase (Figure 4.5). In the project, there are 8 storage systems.

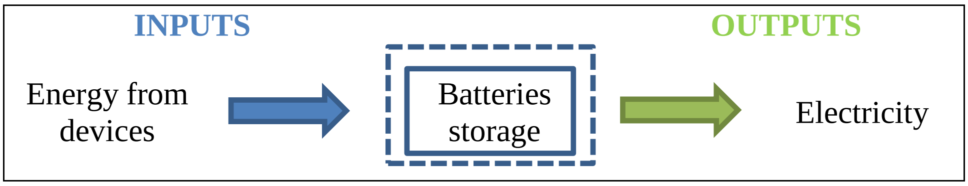

Figure 4.5: System boundaries for batteries storage

Heat generation

In the case of firewood stove or wood stove the raw material is a biomass, firewood or wood, while in the process of conversion is obtained heat and emissions (outputs). There are installed 3. Although wood-burning oven is used for other purposes, the aim of system boundaries are like firewood device (Figure 4.6).

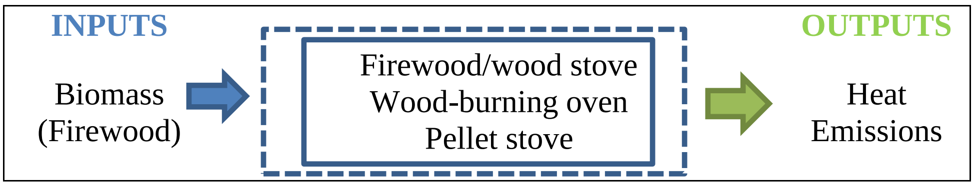

Figure 4.6: System boundaries for firewood stove or wood stove

Like firewood stove, a pellet stove is also a stove in where the wood or biomass pellets are burned, in where is created a source of heat. Unlike wood stoves, this devices must use a sealed exhaust pipe to prevent exhaust gases escaping into the space of mountain hut, so if we consider this statement the emissions into the environmental are almost 0, see Figure 4.7.

Respect to heaters, there are three different types. One of them is the natural gas heater, which works burning the gas (input) that obtain the heat for heating the room. In this process is generated low level of CO (carbon monoxide) emissions that are harmful for the human.

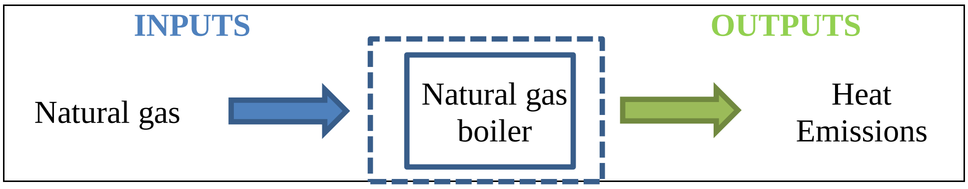

Figure 4.7: System boundaries for gas boiler

The electrical heater has the advantage that they produce 0 gas emissions, that means there are not gas emissions, but electricity has to be generated with RES to be acceptable. In this case the input in the system is the electricity, in the Figure 4.8.

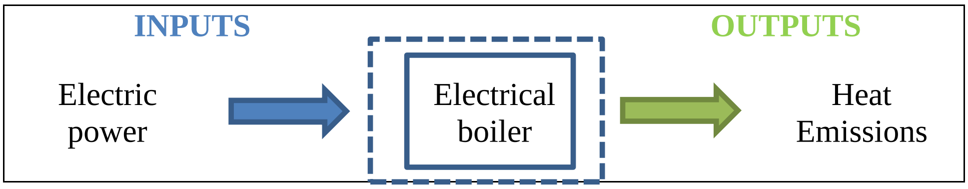

Figure 4.8: System boundaries for electrical heater

A diesel boiler works from diesel fuel (input), while the outputs for this devices are the heat and the emissions such as CO, HC or even smoke emissions [37]. Like a diesel fan has the same inputs and outputs in the Figure 4.9 are gather the scheme of system boundaries both diesel boiler and diesel fan.

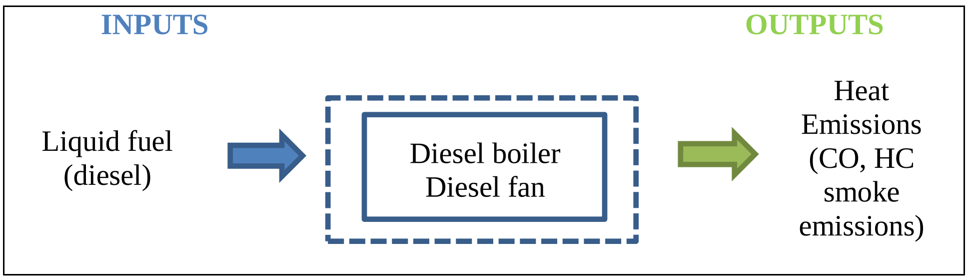

Figure 4.9: System boundaries for diesel heater

4.1.3. Assumptions

Assumptions are made according to available data obtained from the mountain huts and data that are available in LCA databases in order to get some relevant comparisons between technologies used in general in all mountain huts:

- The smaller diesel generators are not modelled separately (1) because they are not working and mainly installed in order to use for an emergency; (2) The size of the engine does not affect results in such a manner than the technology used;
- The fuel cell system it is not included in the model since it is still not defined and not available in LCA database. However, the study of fuel cell system will be interested because they do not have harmful emissions;
- In Ayous hut, it will be considered the possibility to include the domestic anaerobic digestion for the functioning of a kitchen gas, despite this, in the model is not considered due to the missing data in LCA database. This technology would be supplied by kitchen compost waste and dry toilets residue. Therefore, with this implementation could be saved 8892 kWh per season;
- The insulation will not be included because we are making comparison per 1 kWh of energy and insulation affects the overall energy balance in one year that it is not the goal of our study. But on the other hand, it is very important to insulate huts and in Bachimaña hut, for instance it was calculated that with insulation there is 5.4 % of energy savings for heating. That results in less primary energy carriers consumptions;
- Neither it is considered in the numerical model the AAI proposed in Lizara hut because affects the overall energy balance in one year and we are making comparison per 1 kWh of energy, and this is not the goal of our study. The aim is reduce the consumption of the devices which are controlling;
- Regarding the transport, the ropeway and cableway which is used to supply the mountain huts both Torino and Pogačnikov are neglected in the numerical model due to not be available in the database of the GaBi software;

4.2. Life Cycle Impact Assessment methodology – CML 2001 with 12 indicators

The impact methodology that will be used in this study is the CML 2001, one of the two main approaches that are used to classify and characterize environmental impacts [33]. The so-called CML method is the methodology of the Centre for Environmental studies (CML) of the University of Leiden, which focuses on a series of environmental impact categories expressed in terms of emissions to the environmental.

Gabi software defined CML 2001 as "*an impact assessment method which restricts quantitative modelling to early stages in the case-effect chain to limit uncertainties. Results are grouped in midpoint categories according to common mechanisms (e.g. climate change) or commonly accepted groupings (e.g. ecotoxicity)*" [34]. For this study, it has been considered three midpoint indicators: global, regional and local environmental. In total there are twelve environmental impact indicators, all of which will be explained, as set forth in more detail below.

4.2.1. Global Indicators

Global Warming Potential (GWP)

The mechanism of the greenhouse effect can be observed on a small scale, while also can occur on a global scale. The short wave radiation from the sun comes into contact with the earth's surface and is partly absorbed and partly reflected as infrared radiation. On the other hand, the reflected part is absorbed and is re-radiated in all directions (also back to earth), so as to increase the warming earth's surface, as it can observe in the Figure 4.10.

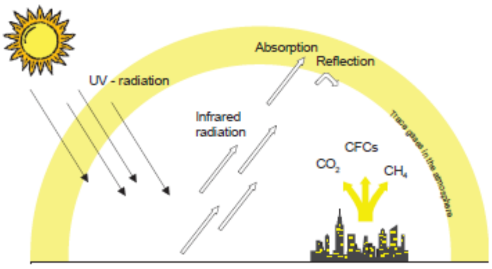

Figure 4.10: Greenhouse effect [32]

Moreover, the greenhouse effect is also increased due to human activities, where can be observed for instance, in the increasement of carbon oxide (CO_2), methane (CH_4) and CFCs. As a result, all those effects must be consider in an analysis of the global effects because of being impact in long-term.

The Global Warming Potential (GWP) is calculated in carbon dioxide mass equivalents (CO_2-Eq), in other words, the greenhouse potential of an emission is given in relation to CO_2.

Ozone Depletion Potential (ODP)

Ozone is developed in the stratosphere due to the disassociation of oxygen atoms that are exposed to short wave UV-light. This is essential for developing the ozone layer in the stratosphere, which has an important role for life on earth. As it can be observed in Figure 4.11, Ozone absorb the short wave UV-radiation and releases it in longer wavelengths, so only a small quantity achieve the earth.

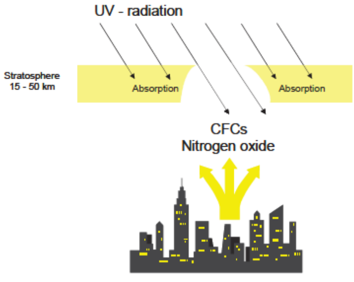

Figure 4.11: Ozone Depletion Potential [32]

It should be kept in mind that one effect of ozone depletion is the warming of the earth's surface. Although, there are more directly effects, such as harvest crops, tumors in living things or decrease of sea plankton.

Then, from different ozone relevant substances, the Ozone Depletion Potential could be calculated and is measured in CFC 11 equivalents.

Abiotic Depletion Potential

All natural resources and fossil energy carriers are covered by the abiotic depletion potential such as metal containing ores, crude oil and mineral raw materials.

Abiotic resources include both raw materials from non-living resources and non-renewable (at least 500 years), and describes the reduction of the global amount of non-renewable. So, this impact category analyze the availability not only of natural elements, but also of fossil energy carriers. Thus, the antimony is the references substance for this factor.

4.2.2. Local Indicators

Eutrophication Potential (EP)

Eutrophication is defined as the enrichment of an ecosystem with some nutrients in a certain place. This one can be a natural process in aquatic areas or terrestrial, occurring as they age through geological time. Human activities, such as air pollutants, wastewater and fertilization in agriculture, contribute to accelerate the eutrophication.

On the one hand, the effects in the water are both the decrease in photosynthesis and less oxygen production, because of accelerating algae growth which prevents sunlight from reaching the lower depths. In consequence of these effects, the dead fish and anaerobic decomposition will be develop. So that, it will contribute with destruction of the eco-system.

On the other hand, on very eutrophicated soils, it can arise to enrichment of nitrate which can increase nitrate content in groundwater and also drinking water, which can be toxic to humans. All these causes are shown in the Figure 4.12.

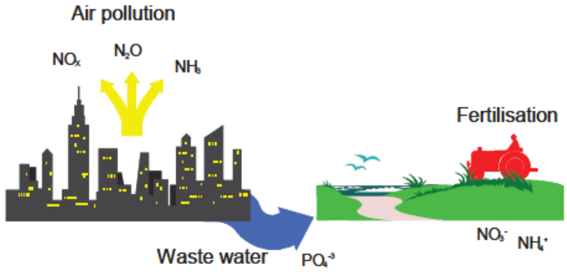

Figure 4.12: Eutrophication Potential [32]

Finally, the units of calculating the eutrophication potential is phosphate equivalents (PO_4-Eq).

Photochemical Ozone Creation Potential (POCP)

Photochemical Ozone production in the troposphere is known as summer smog, and could be damage vegetation and material.

Although POCP contribute to protect the stratosphere, radiation from the sun, as nitrogen oxides and hydrocarbons produce complex chemical reactions, such as ozone which in high concentrations are toxic to humans. These high concentrations of ozone arise when the temperature is high; the humidity is low, when air is relatively static and when there are high concentrations of hydrocarbons, as it can be observed in Figure 4.13. Nowadays, it is assumed that NO and CO contribute to reduce the accumulated ozone to NO_2, CO_2 and O_2. Otherwise, in areas of clean air there is less NO and CO.

For analyzing the POCP is necessary take the weather and the local conditions into consideration because all of them influence it. Besides, it is referred in ethylene-equivalents (C_2H_4-Äq).

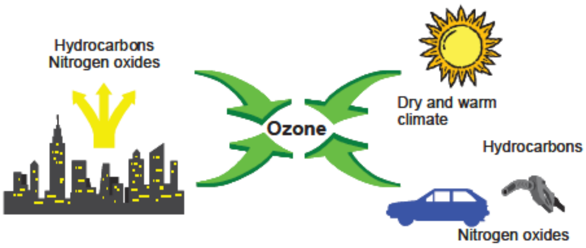

Figure 4.13: Photochemical Ozone Creation Potential [32]

Human and Eco-toxicity

Nowadays, there is not a method for analyzing the impact assessment of toxicity potential yet. Therefore, with the Human Toxicity Potential (HTP) is possible to estimate the negative impact of a process on human, as the example which is shown in the following scheme (Figure 4.14).

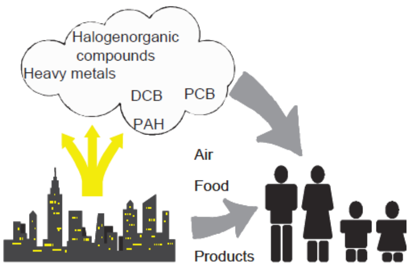

Figure 4.14: Human Toxicity Potential [35]

Whereas the Eco-Toxicity Potential follows to outline the damaging effects on an ecosystem, in where there are two types, one Terrestrial Eco-Toxicity Potential (TETP) and another Aquatic Eco-Toxicity Potential (AETP), in the Figure 4.15 is shown both cases.

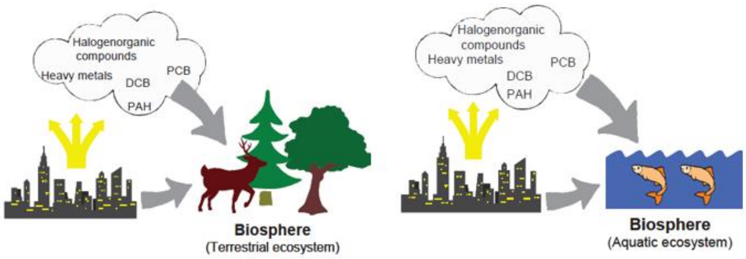

Figure 4.15: Eco-Toxicity Potential [35]

The potential toxicities (human, aquatic and terrestrial ecosystems) are generated from a proportion based on the reference substance 1,4 Dichlorbenzol ($C_6H_4Cl_2$) in the air reference section. In this case, the unit is 1,4 Dichlorbenzol-Equiv. (kg DCB- Äq.).

The model is based on a comparison of effect and exposure assessment, from the amount of emission, a distribution model and the risk characterization via an input sensitive module, it is calculated the concentration in the environment.

From toxicological threshold values, it can be calculated the toxicity potential. Thus, based on the location of the emission source: air, water or soil, three values are calculated, considering the groups HTP, AETP, TETP.

4.2.3. Regional Indicators

Acidification Potential (AP)

The acidification potential (AP) is described as the ability of certain substances to build and release H^+ - ions. Through the transformation of air pollutants into acids leads the acidification of soils and waters, decreasing the pH-value of rainwater and fog. So, sulphur dioxide and nitrogen oxide and their respective acids (H_2SO_4 und HNO_3) produce relevant contributions. In the Figure 4.16, it can be observed the impact pathways of acidification.

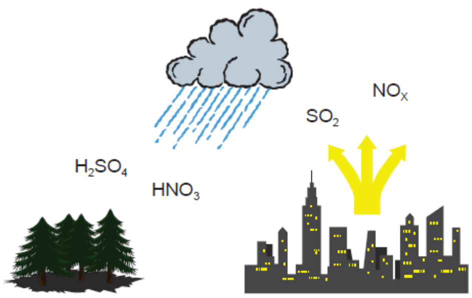

Figure 4.16: Acidification Potential [32]

For analyzing acidification the units are given in Sulphur dioxide equivalents (SO_2-Eq.). It is remarkable to mention that has both direct and indirect damaging effects.

4.3. Software

GaBi Thinkstep is the software that it will be used for this study. The target of this chapter is to explain how to work with GaBi as well as the object of using this program in this project.

GaBi is the software that enables us to carry out the Life Cycle Assessments (LCA) using databases available in the software. It will be used in order to show which technology is better to use in the mountain hut for electricity and heat generation and why. Technologies will be compared with other technologies that are not used in the mountain huts just to get the better understanding and evaluation of results. Transport will be evaluated and compared with different types of transport to get the best possible solution.

Databases used were Ecoinvent 3.3 database and Gabi Professional database. Although this software offers a wide variety of internal datasets, in particular, over 12,000 Life Cycle Inventory datasets for this study it is also necessary to create an additional customized database in order to suit the needs of the project, and get an unique data to the project [36].

First of we have to connect a database to the software. GaBi software has three main objects: plans, processes and flows. In the Figure 4.17 it can be seen an example of a plan of the project that is built from several processes and connected with flows

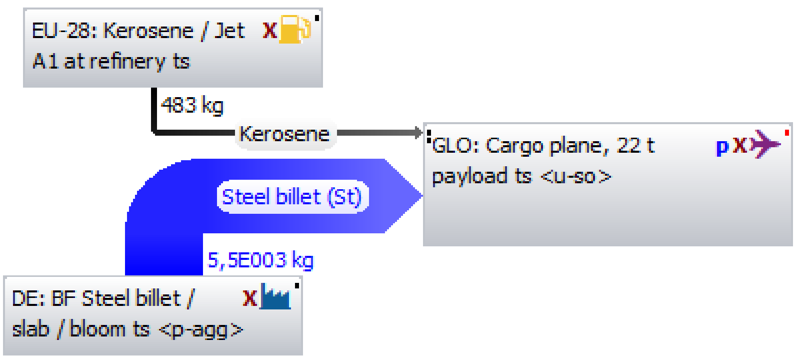

Figure 4.17: Example of transportation to mountain hut with GaBi software

According with the GaBi Paper Clip Tutorial a plan represents the system with its boundaries as well as the flows between the processes.

4.4. Numerical model

In this chapter the numerical model for electricity, heat generation and transport will be presented. It should be taken into account that in each model all the technologies will be modelled in a unique plan, due to the main target is can discuss in a properly path the results obtained by each indicator.

4.4.1. Electricity generation model

For the electricity generation model a plan called electricity generation mountain huts will be created, where all the technologies identified in the mountain huts could be found, as well as those which are considered to include or are already installed in order to run in a short-term or even a long-term vision (summer 2020). It should be noted that the process can be founded in the Ecoinvent 3.3 and Professional + Extension Database. To evaluate the technologies even more in details, some additional technologies are linked with the plan.

For **larger diesel generator**, it has been chosen the global (GLO) process: diesel burned in diesel-electric generating set with a power of 18.5 kW. Taking from ecoinvent 3.3 database.

The **photovoltaic panels** will be calculated through the process: electricity production of photovoltaic with 3 kWp slanted-roof installation in a single panel mounted. Taking from ecoinvent 3.3 database. Although, the photovoltaic panels are present in all the mountain huts, except for Bachimaña and Torino, the nation chosen is been Spain.

For the **micro-hydro turbine**, it was selected the electricity production from a hydro reservoir in a non-alpine region. Taking from ecoinvent 3.3 database. The nation chosen is Spain (ES) due to be where the mountain huts with hydro power plants are located.

For the **micro-wind turbine** in GaBi software is available the process of electricity production from wind with less than 1MW turbine in a location onshore. Taking from ecoinvent 3.3 database. Also, it is chosen ES process because the current wind turbine is in Bachimaña and the proposed are in Llauset and Estós in Spain and Pogačnikov dom in Slovenia.

In the Table 3.46, it was observed that besides the technologies mentioned above there are the petrol generator and batteries storage that are not available in database. However the petrol generator is not working in the hut on the other hand batteries storage has zero impact in the operation stage and would contribute just in the manufacturing stage, so it can be neglected in the operational stage.

In order to compare results for all this technologies it has been decided to add processes in the numerical model to generate the electricity from fossil fuels. The electricity generation comes from the grid mix of the EU-28 (it is a data collection from 28 member states of the European Union), as well as from four countries in where the mountain huts of this present project are located (Spain, Slovenia, Italy and France). All those process can be obtained from the Professional + Extension database.

It is remarkable to comment that all the process have been scaled for 1 kWh, which is the functional unit.

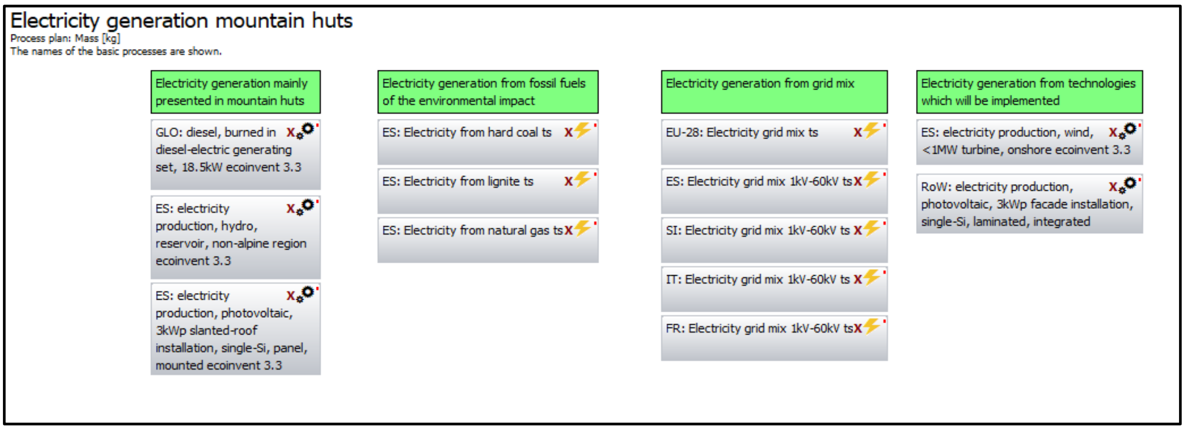

Figure 4.18: Technologies evaluated in GaBi according to electricity generation in mountain huts

4.4.2. Heat generation model

For the technologies listed in the Table 3.47 and Table 3.49 regarding the heat generation the processes picked in Gabi databases are explained below.

For **pellet stove**, in the ecoinvent 3.3 database, available process for heat production is by wood pellet stove of 9 kW or 25 kW. Despite the technology has an installed power of 16 kW in Llauset, considering this power and the possible options, it was decided to choose the 25 kW in order to study the worst case, because the smallest one always is going to be less harmful than this one.

For the **diesel boiler**, the process assumed is a light fuel oil. The total power of this technology is 100 kW.

For **natural gas boiler**, it was selected the process of heat production in natural gas boiler. Power is 100 kW and it is also modulating. RoW (Rest of the World) is the “nation” which has taken into account.

The **bottles of propane** will be modelling as a process of heat production propane at industrial furnace with 100 kW. This process is available in the ecoinvent 3.3 database. The nation chosen for this device has been RoW (Rest of the World).

In relation with the heat generation from future technologies, the technologies which were included in the heat generation model for the mountain huts are:

For **electric water heater**, there is a process in the Professional + Extension database as electric instantaneous water heater, which inputs are based on the EU-28 (Nation chosen).

Unlike, the natural gas boiler, it has also decided included the gas low temperature boiler with a power of 20 kW to considerer the effects of this device and see the difference or similarity with the natural gas boiler. This process can be obtained from Professional+ Extension database in GaBi for the EU-28.

Regarding the technologies which are showed in the Table 3.47 and Table 3.49 and they were not mentioned previously, it is because either their process is not in the database or it is assumed that the emissions are zero in the operational phase.

In case of thermal solar system the process the process is not available in databases.

The firewood stove and wood burning oven are not available but pellet stove is good approximation, so conclusions will be based on that.

The electric boiler did not be able to database of GaBi software. Therefore, its study with the numerical model for electricity generation from the technologies is not possible. Likewise electric boiler, with electric and diesel fan happen the same

The domestic anaerobic digestion system is an option to be included in the short-term in French hut but still unavailable in the database.

To make some additional evaluation of environmental impacts the heat generation from conventional technologies, such as thermal energy from natural gas, from lignite, from light fuel oil (LFO), from hard coal and also from biomass are included. All of them are in the Professional + Extension database.

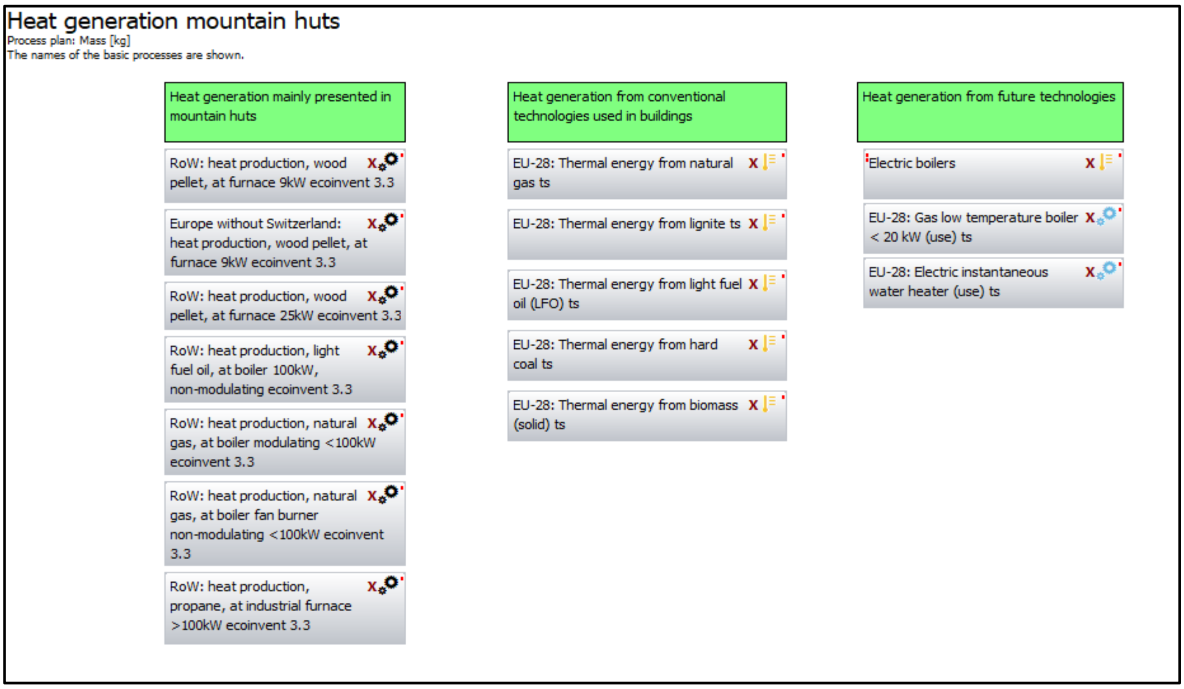

Figure 4.19: Technologies evaluated in GaBi according to heat generation in mountain huts

Like in the electricity generation, for this model the functional unit selected is 1 kWh of heat generated.

4.4.3. Transport model

For the transport model two plans will be created. First it will be analysed the different options in the air transport:

An **helicopter**, is the option that at first sight, seems like easily due to the only data needed was the number of hours which fly, although the unit for the rest of the transport is the km, so as the functional unit is 130 km the equivalence in hours by an helicopter is 56 mins which will be approximately an hour.

The **truck** is the other type of the transport used in the transportation of goods to the mountain huts. So, the cargo truck selected is 7.5 t, due to the average cargo transported 5,500 kg (5.5 t). Besides that, there is a current normative in the Terrestric transport in where there are controlled emissions into the atmosphere. This normative is the Euro emissions standard, also known as Euro number (the number shows how restrictive is the normative). Euro 6 is the current Euro standard. Despite this statement, it is decided to include all six standards in order to see the range of environmental impacts. As in the case of cargo plane, the functional unit used was fixed to 130 km (as an average between the Bachimaña and Montfalcó hut and a cargo of 5.5 t.

Figure 4.20: Air transport model in GaBi

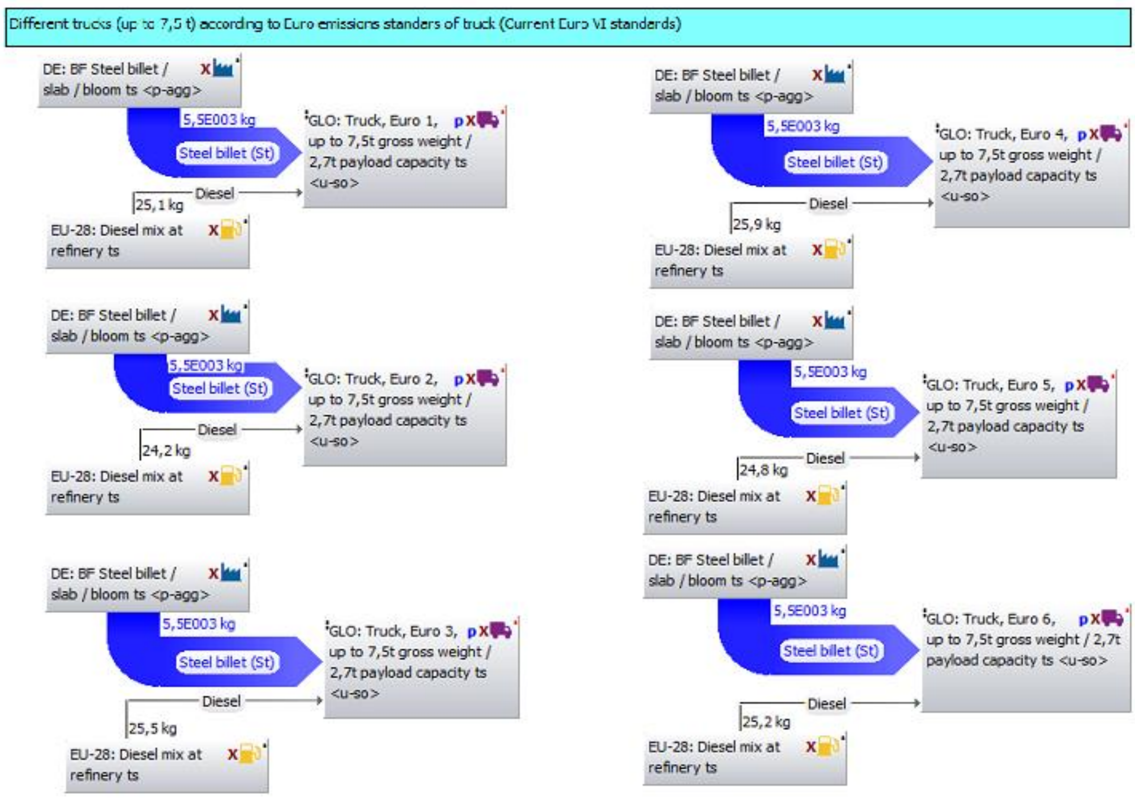

Figure 4.21: Terrestric transport model in GaBi software

5. Results

To continue with the aim of the present study for each numerical model (electricity generation, heat generation and transport) the 12 environmental impacts indicators according to the methodology CML 2001 will be assessed. Results will be presented with diagrams. The 12 indicators will be grouped according to the global, local and regional environmental indicators.

5.1. Electricity generation

The technologies chosen in GaBi according to the current and proposed device which were gathered in the Figure 4.18 are listed below. Besides, this technologies will be compared with other the electricity generated from fossil fuels, even from grid mix, as well as, other devices that are not used in the mountain huts just to get the better understanding and evaluation of results.

- **Current technologies presented in the huts:** diesel-electric generator of 18.5 kW, hydro reservoir in non-alpine region and photovoltaic slanted-roof of 3 kWp.
- **Electricity generation from fossil fuels**: hard coal, lignite and natural gas.
- **Future technologies which could be installed**: wind turbine up to 1 MW and photovoltaic facade installation of 3 kWp.

Global Warming Potential (GWP 100 years)

The Global Warming Potential (GWP) results can be seen in the Figure 5.1.

It can be observed that the diesel generator is the technology that shows the highest impact even if it is compared with the electricity which comes from the grid mix for the four countries analysed. The reason of this is because the diesel is the only source considering the generator while the grid mix includes several sources for producing electricity, not only fossil fuels. In fact, the diesel generator emits 0.943 kg CO_2 eq per 1 kWh.

In relation with results obtained for the electricity from the fossil fuels, it is remarkable to comment that the electricity from hard coal and lignite is 16.5% and 7 % higher respectively than from the diesel generator. However and as expected, the amount of CO_2 emitted by renewable sources is much lower since they are totally clean. For instance, there is around 92 % less emissions for the hydro turbine comparing it with the coal source. There is an interesting comment regarding the photovoltaic that should be highlighted. The GWP impact is higher for the facade installation since the sunlight does not reach it as well as it does on the roof. Because of this, the same environmental impact over less production of energy will be translated into higher net impact.

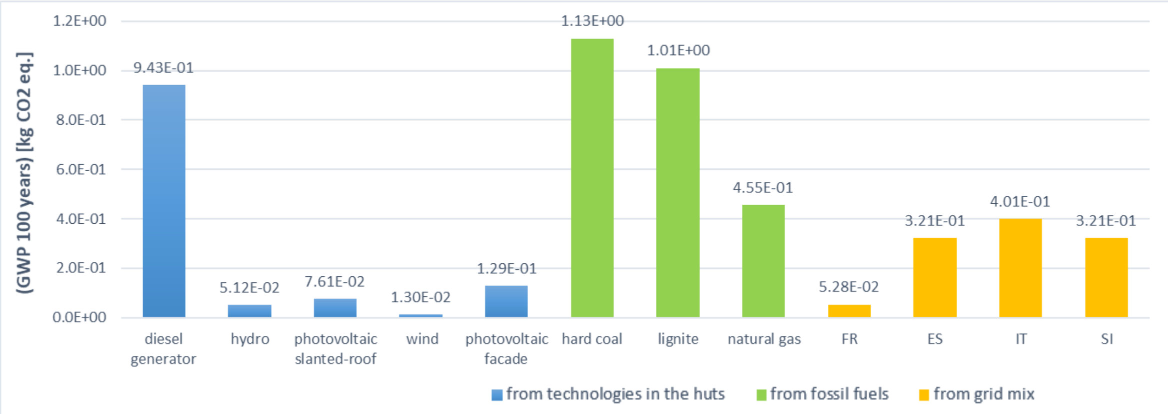

Figure 5.1: Global Warming Potential (GWP 100 years) according to electricity generation technologies per 1kWh

Global Warming Potential excl. Biogenic carbon (GWP 100 years)

This indicator excludes the biogenic carbon from the global warming potential. Any biogenic element is a chemical element that is part of the living organisms and it is indispensable for its development.

Figure 5.2. shows there is not a big difference between the GWP including or excluding the biogenic carbon and that is why this indicator is not being really presented.

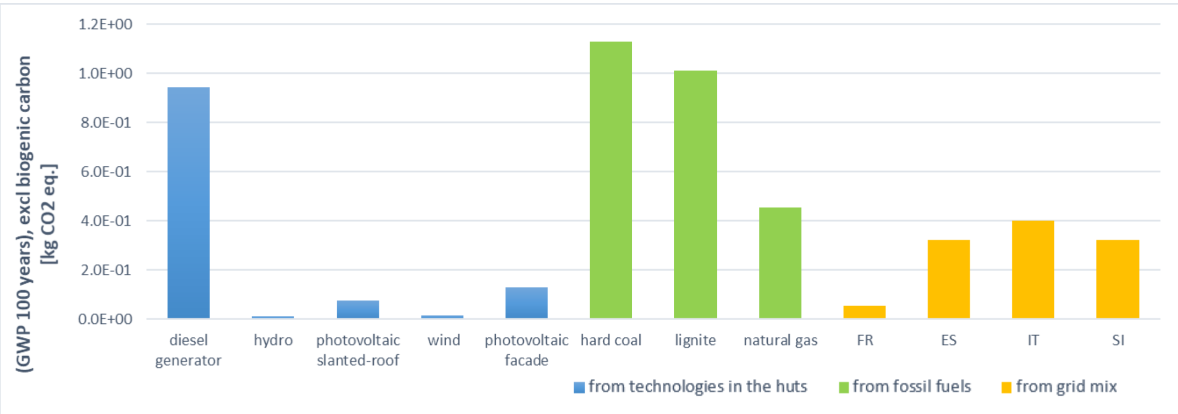

Figure 5.2: Global Warming Potential excl. biogenic carbon according to electricity generation technologies per 1kWh

Ozone Layer Depletion Potential

The evaluation of Ozone Layer Depletion Potential (ODP) should be take into consideration the long-term effects because one effect of ozone depletion is the warming of the earth's surface, in where the nitrogen oxides (NOx) and fluorine-chlorine-hydrocarbons (CFSc) are the blameworthy.

Figure 5.3 shows the results related with the ozone layer depletion. The production of electricity with the diesel generator implies the highest impact, followed by the photovoltaic technology. This last situation is related with the materials used for the manufacturing phase of the panels, which contribute to the generation of CFC's.

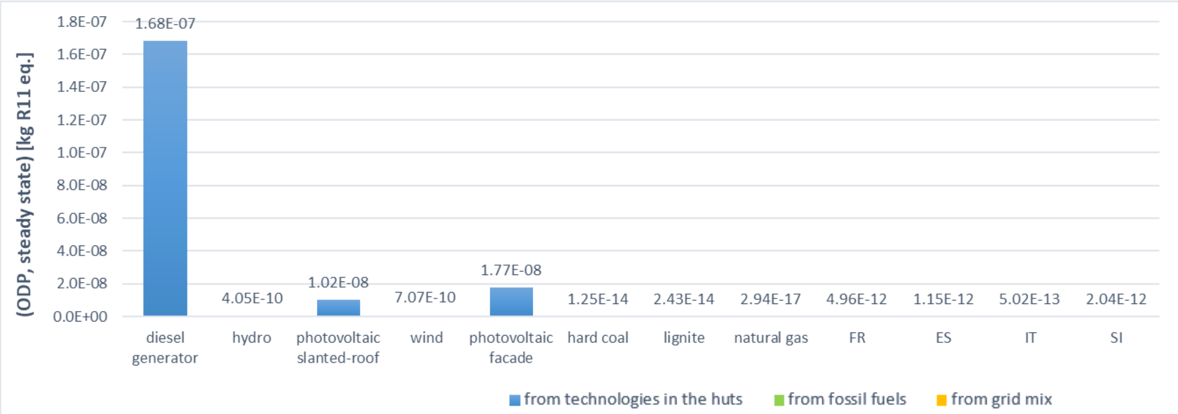

Figure 5.3: Ozone Layer Depletion Potential (ODP) according to electricity generation technologies per 1 kWh

Abiotic Depletion Potential elements

The Abiotic Depletion Potential (ADP) covers all-natural resources also included the fossil energy carriers and minerals. Therefore, on one side there is the loss of natural elements which are available in the environment, while on the other side there is the loss of fossil energy availability. In this section, the elements loss will be analysed.

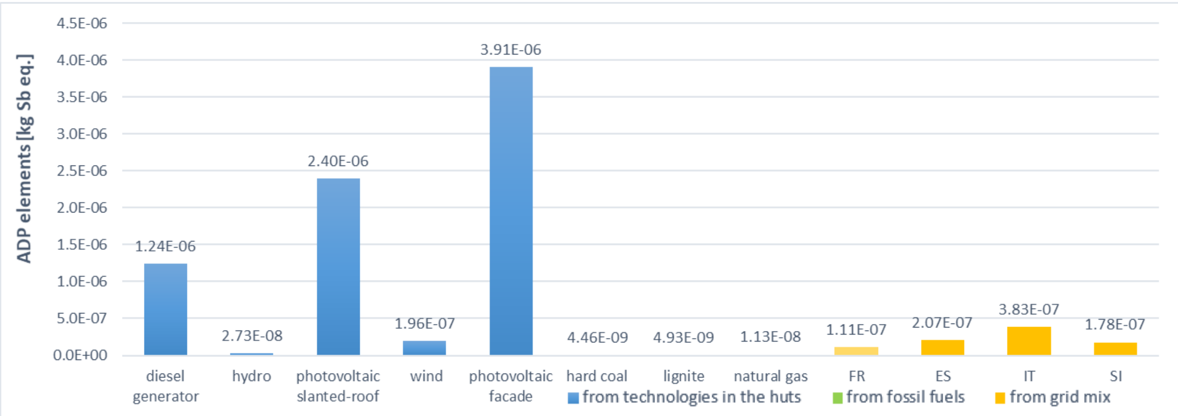

Figure 5.4: Abiotic Depletion (ADP) according to electricity generation technologies per 1 kWh

The results from GaBi software are shown in the Figure 5.4. It can be observed that both photovoltaic installations and diesel generator have the highest values, following by the wind. As expected, abiotic depletion is strongly dependent on used forms of electricity generation and because of ecosystems are being used for this technologies, it makes sense that those technologies have a response with higher abiotic depletion potential.

Abiotic Depletion Potential fossil

The diagram presented in Figure 5.5 shows that the diesel generator is the technology which has the highest impact per 1 kWh for electricity generated, followed by other technologies using fossil fuels. The reason of this is related to the definition of this indicator itself, since it explains the loss of fossil energy availability. Therefore, technologies which use fossil fuels as raw materials will have higher impact.

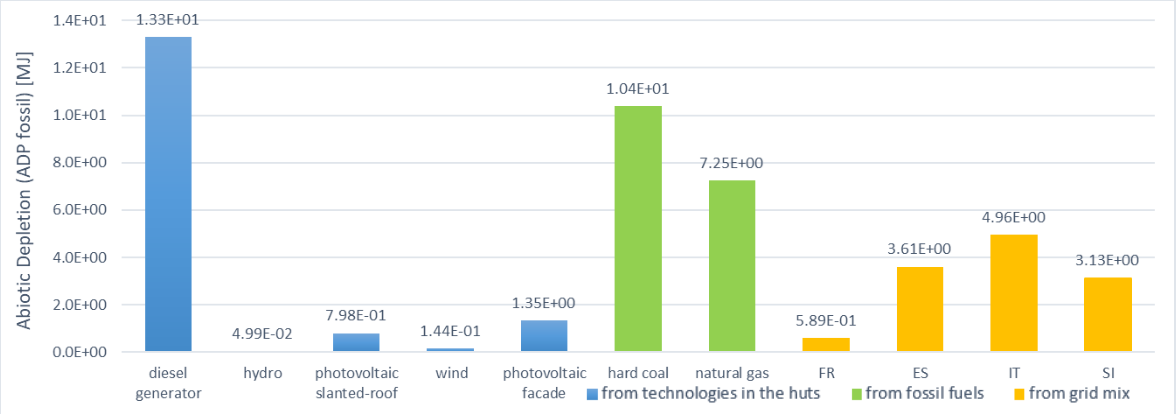

Figure 5.5: Abiotic Depletion (ADP fossil) according to electricity generation technologies per 1 kWh

Eutrophication Potential

The Eutrophication Potential, EP, is the environmental indicator that informs us how the technologies contribute in the destruction of the eco-system. Moreover, this category is within the local indicator.

Results, presented in the Figure 5.6**,** show the diesel generator is the technology whose EP impact is the highest. Then, the photovoltaic and technologies using fossil fuels appear. For the generator, the combustion of the fuel at high temperatures generates NO_x which help to this phenomena of eutrophication to develop. Moreover and as it has been mentioned before, there are some materials during the manufacturing of photovoltaic which contributes to these numbers, for instance phosphate and sulphur oxides.

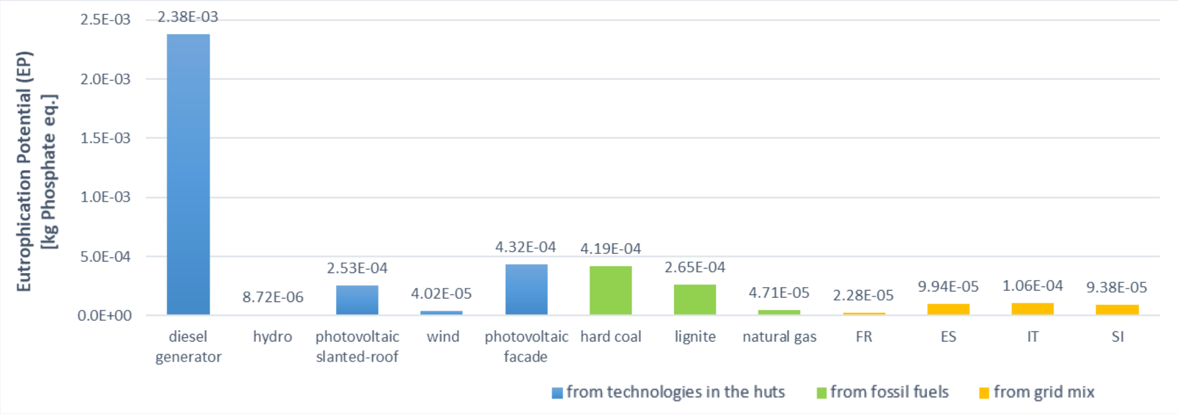

Figure 5.6: Eutrophication Potential (EP) according to electricity generation technologies per 1 kWh

Photochemical Ozone Creation Potential

The Photochemical Ozone Creation Potential (POCP) allows us to analyse the summer smog, which is related to damage the vegetation, material and even human health.

POCP results for all technologies are available in the Figure 5.7. The presence of NO_X and hydrocarbons produce some aggressive reaction products, contributing to this photochemical ozone creation potential. As it can be deducted, any process which uses combustion of the fossil fuel will contribute to POCP increase. That is the reason the diesel generator and the technologies using coal and lignite have a highest impact on this environmental indicator. However, there is a difference of 77 % between the diesel generator and the electricity coming from the coal source which has to be commented. This is related to the higher efficiency the industrial process have when producing electricity, comparing with the low performance of the generators in mountain huts. Results obtained in the POCP for hydro turbine and wind turbine are the lowest, whereas the facade installation of photovoltaic system is higher than the obtained for the slanted-roof, even though both continues to be low.

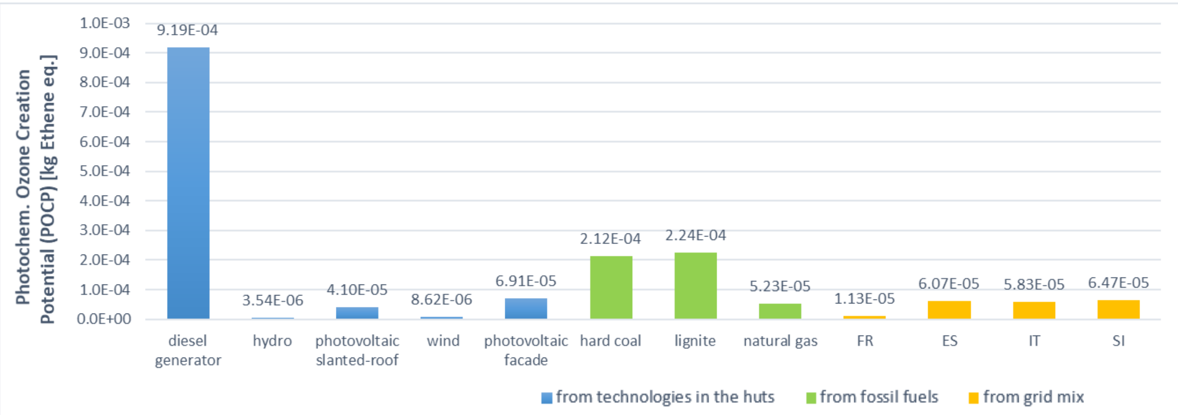

Figure 5.7: Photochemical Ozone Creation Potential (POCP) according to electricity generation technologies per 1 kWh

Human Toxicity Potential

The Human Toxicity potential (HTP) has the target to estimate the negative impact on human's health. The results obtained from GaBi software are shown in the Figure 5.8. The highest impact comes from photovoltaic with a facade installation and it is followed by the impact generated by diesel. For producing the same amount of energy, the needs are higher for the PV than for the generator, needing a really big surface which implies several toxic materials while manufacturing.

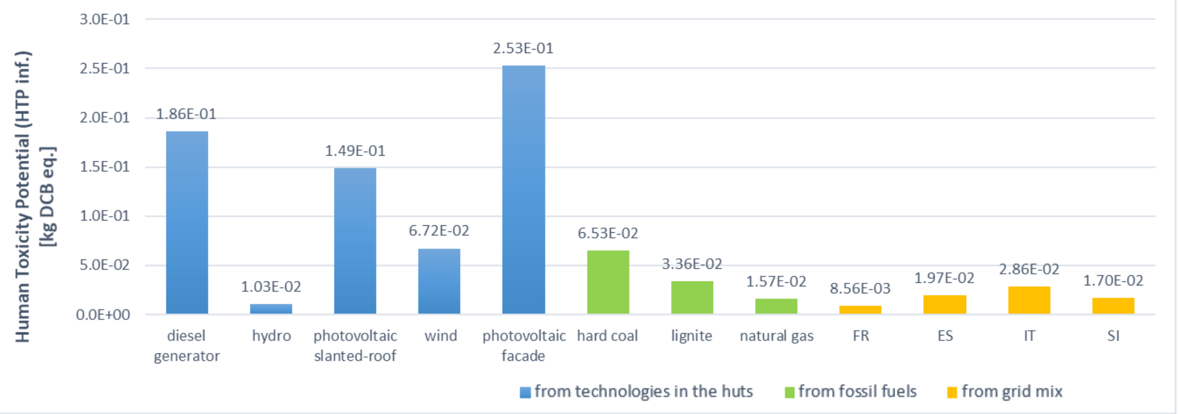

Figure 5.8: Human Toxicity Potential (HTP) according to electricity generation technologies per 1 kWh

Marine Aquatic Ecotoxicity Potential (MAETP)

Marine Aquatic Ecotoxicity Potential (MAETP) is one of the indicators which allow to analyse the impact assessment of Eco-Toxicity potential of the damaging effects on an ecosystem (Figure 5.9).

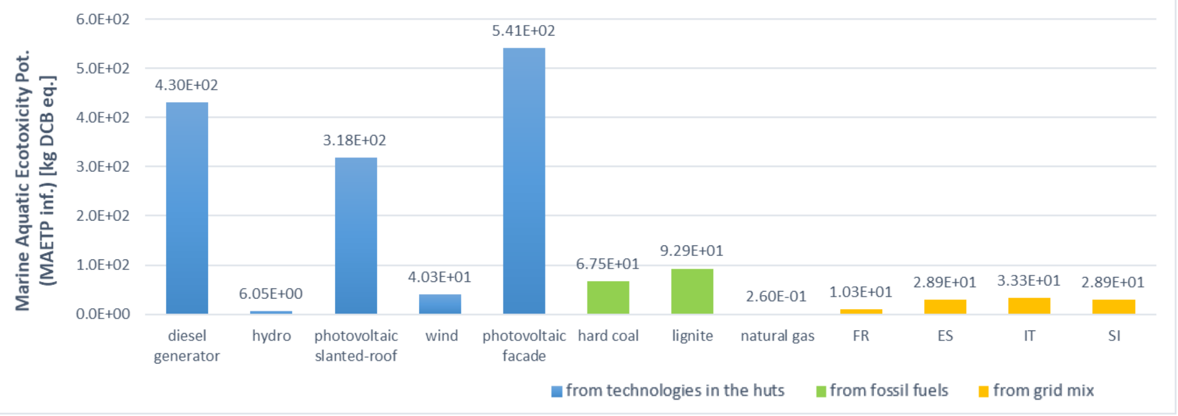

Figure 5.9: Marine Aquatic Ecotoxicity Potential (MAETP) according to electricity generation technologies per 1 kWh

In this case, the technologies which highest values show are photovoltaic with facade installation followed by diesel generator and photovoltaic slanted-roof. The reason of the higher impact of the photovoltaic are largely related with emissions of metals, and their emissions could be related with significant effects of changes in metal concentrations on marine aquatic ecosystems. Related to diesel generator the fossil-fuel combustion is the reason of the higher value.

Freshwater Aquatic Ecotoxicity

Freshwater Aquatic Eco-Toxicity (DCB) is the other indicator which allow the evaluation of Eco-toxicity (Figure 5.10**).** The highest values are in the case of photovoltaic facade, followed by the photovoltaic slanted-roof and then by the diesel generator and wind.

The reduction of amount of stainless steel in this technologies will be obtained a reduction of these toxicity values, because once more the effects are related with the emissions of metals.

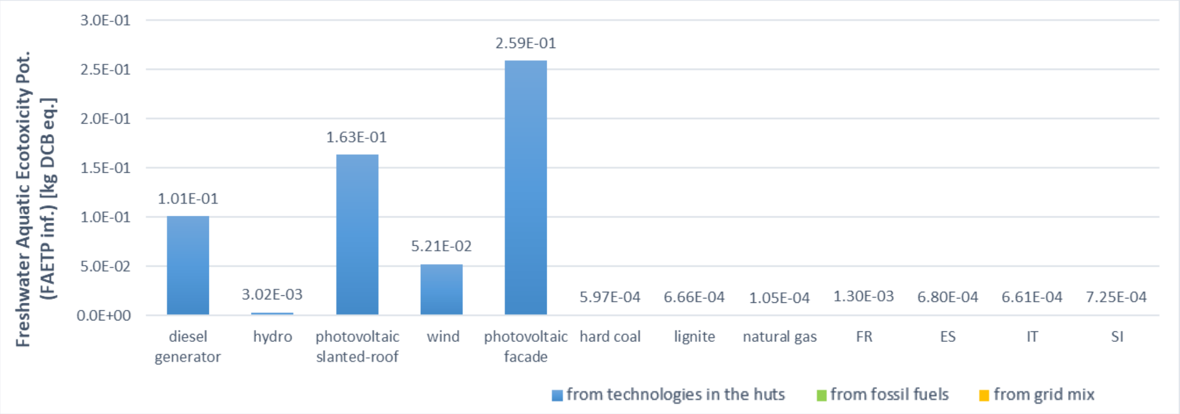

Figure 5.10: Freshwater Aquatic Ecotoxicity (DCB) according to electricity generation technologies per 1 kWh

Terrestric Ecotoxicity Potential

Besides the human and aquatic potential toxicities, there is a terrestrial ecotoxicity indicator named Terrestric Ecotoxicity Potential (TETP) presented in Figure 5.11. In where emissions of toxic substances to air, water and soil is the main cause of this impact.

For this indicator the highest impact comes from diesel generator and wind turbine. As expected for the diesel generator, the higher values comes due to the combustion of fossil fuels, in where the emissions of nitrogen oxides are relevant. However, the manufacturing of the wind turbine is the reason of its higher values, because of producing emissions result from the production of metals, such as steel and stainless steels. They are followed by the photovoltaic installation, as it was mentioned for other indicators, their manufacturing contributes to these values.

In comparation with the results obtained for the in the fossil fuels electricity generation, the emissions generated by the photovoltaic slanted-roof installation are roughly those issued by electricity generation with hard coal, although lower than introducing from lignite.

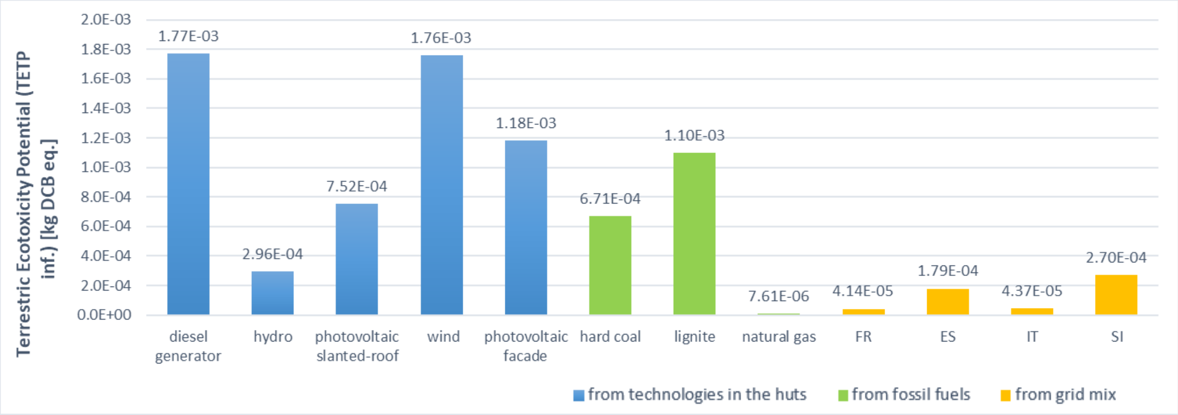

Figure 5.11: Terrestric Ecotoxicity Potential (TETP) according to electricity generation technologies per 1 kWh

Acidification Potential

This indicator lets to know which is the impact of every technology over the ecosystems, being the indicator which measures the forest dieback, for instance. Figure 5.12 presents the results obtained.

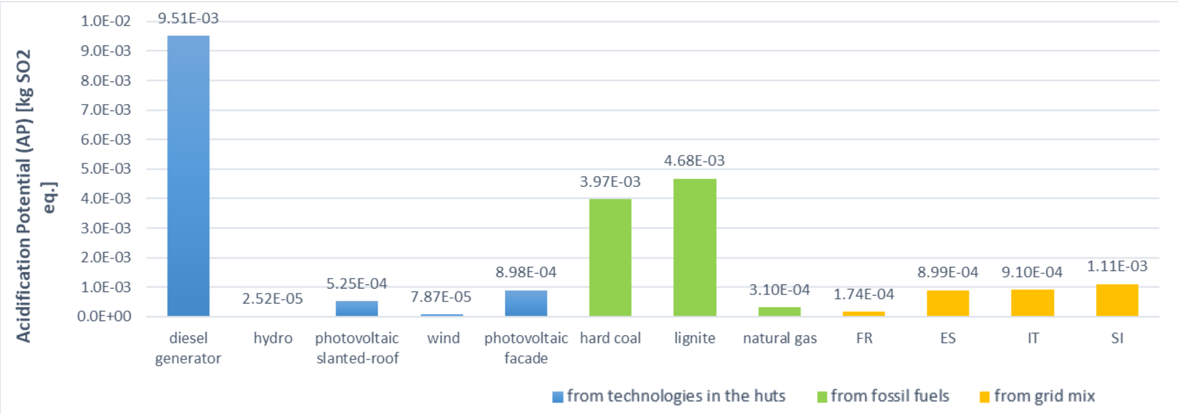

Figure 5.12: Acidification Potential (AP) according to electricity generation technologies per 1 kWh

As it can be observed the diesel generator is the technology which has the highest impact with a value of 0.00951 kg SO_2 eq per each 1 kWh of electricity generated, an around 85% higher than the impacts from the production of electricity with the European grid mix. This could be explaining with the sources used in both cases: the diesel fuel for the generator against several sources (including nuclear or renewable) for the grid mix. Regarding the comparison between diesel and the rest of fossil fuel technologies, it must be mention again the efficiency related to industrial process for the hard coal and lignite against the lower performance of the generator for mountain huts. In general, fossil fuels have much higher AP than others due to SO_x emissions that are responsible for AP impact criteria to be higher.

Results for electricity generation

The results obtained with GaBi software according with CML 2001 methodology by each technology are attached in Table 5.1. It can be seen the value of each impact category, in where the results are shown according two colour legend. The field in green shows the technologies which has a higher value than the mean value of all technologies for this indicator, while the red one means the opposite, the value is lower than the average value.

Table 5.1: Results of environmental impact indicators for electricity technologies studied

CML2001 - Jan. 2016	diesel generator	hydro	photovoltaic slanted-roof	wind	photovoltaic facade
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.24E-06	2.73E-08	2.40E-06	1.96E-07	3.91E-06
Abiotic Depletion (ADP fossil) [MJ]	1.33E+01	4.99E-02	7.98E-01	1.44E-01	1.35E+00
Acidification Potential (AP) [kg SO2 eq.]	9.51E-03	2.52E-05	5.25E-04	7.87E-05	8.98E-04
Eutrophication Potential (EP) [kg Phosphate eq.]	2.38E-03	8.72E-06	2.53E-04	4.02E-05	4.32E-04
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	1.01E-01	3.02E-03	1.63E-01	5.21E-02	2.59E-01
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	9.43E-01	5.12E-02	7.61E-02	1.30E-02	1.29E-01
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	9.43E-01	1.16E-02	7.61E-02	1.31E-02	1.29E-01
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.86E-01	1.03E-02	1.49E-01	6.72E-02	2.53E-01
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	4.30E+02	6.05E+00	3.18E+02	4.03E+01	5.41E+02
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1.68E-07	4.05E-10	1.02E-08	7.07E-10	1.77E-08
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	9.19E-04	3.54E-06	4.10E-05	8.62E-06	6.91E-05
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	1.77E-03	2.96E-04	7.52E-04	1.76E-03	1.18E-03

Based on the previously analysis, and with the help of the table above, it is concluded that the diesel generator shows the highest impact emissions. The emissions generated in the combustion of its fuel and the lower efficiency, which is considered for this devices, give rise the highest values for this device. Regarding to alternative technologies, the hydro shows the lowest impact for all of its indicators. Followed by the wind, even though for TETP has the highest value due to the emissions produced for manufacturing its turbine. Regarding to photovoltaic installation, despite being an alternative technology, the manufacturing of this installation, as well as the size required to produce a 1 kWh of electricity in relation with other technologies that this does not lead to a decisive advantage for install it.

5.2. Heat generation

Technologies selected for heat generation are discussed in the chapter 4, and are:

- **Current technologies presented in the huts:** Wood pellet at furnace 25 kW, propane at industrial furnace (>100 kW), light fuel oil at boiler 100 kW, natural gas boiler (<100 kW).
- **Heat generation from fossil fuels**: hard coal, lignite and natural gas.
- **Future technologies which could be installed**: electric water heater, gas low temperature boiler (< 20 kW).

Global Warming Potential (GWP 100 years)

Global Warming Potential for a time range of 100 years is presented in the Figure 5.13.

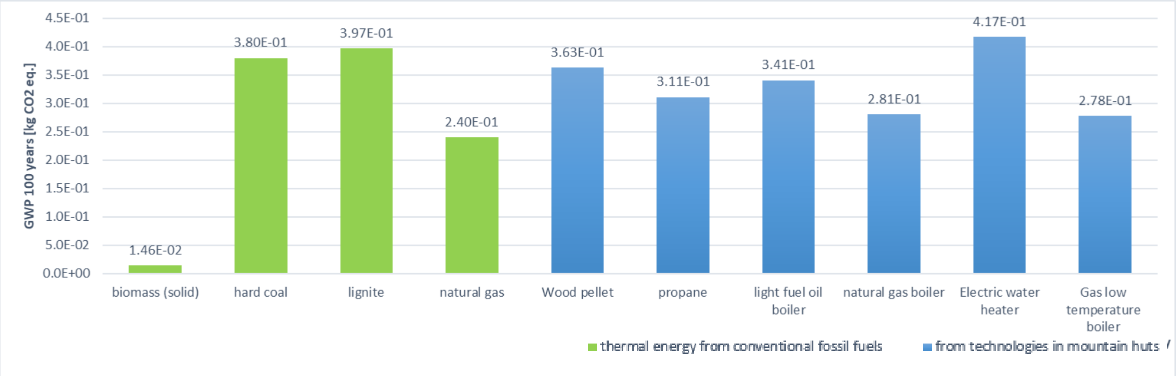

Figure 5.13: Global Warming Potential (GWP 100 years) according to heat generation technologies per 1kWh

It can be observed that the values are quite similar for all type of technologies. As it is expected, the biomass has the lowest values it is considered as a neutral fuel in terms of CO_2 emissions because its emissions from its burning are reabsorbed again through photosynthesis of plants.

Regarding to the highest values, electric water heater stands out, followed by pellet stove and diesel boiler. The reason for the pellet stove is because when the wood pellets are burned this release even more carbon dioxide per unit of energy.

Ozone Layer Depletion Potential

The warming of the earth's surface is one of the long-term effects produces by Ozone Layer Depletion Potential, ODP. In the Figure 5.14 results are shown.

It can observed that the biggest impact is due to light fuel oil boiler followed by propane and natural gas boiler. In case of boiler, these results are expected because the main pollutant generated are nitrogen oxides which reacts with other pollutants to form ozone. Also contribute to the generation of CFC's.

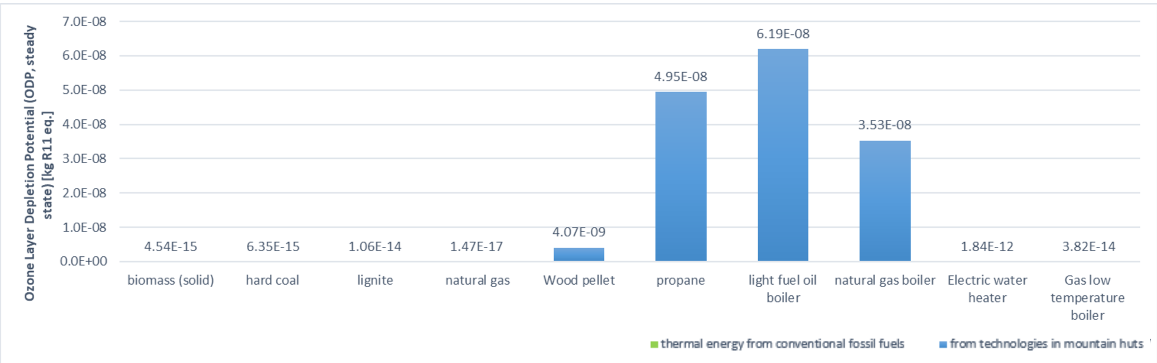

Figure 5.14: Ozone Layer Depletion Potential (ODP) according to heat generation technologies per 1 kWh

Abiotic Depletion Potential elements

The results for ADP elements are presented in Figure 5.15. As it can be observed the technologies which more impact has in this category are the electric heater and the pellet stove.

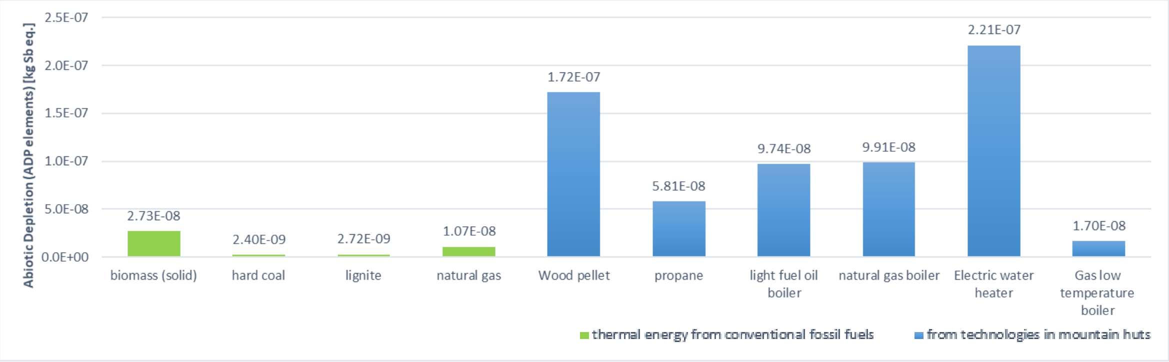

Figure 5.15: Abiotic Depletion (ADP) according to heat generation technologies per 1 kWh

As previously commented, abiotic depletion is strongly dependent on used forms of electricity generation. So, the higher results shows for electric water heater mainly comes from the electricity which required to work. Therefore, if this electricity is provided from the excess of electricity generated from a renewable energy source, the consequence of this impact will be decrease, and the emissions for the electric water heater will be lower. Otherwise, the production of additional electricity for providing the heater is not the best option. Likewise, the problem of higher emissions in the pellet stove comes from the pellets which are made from virgin growth and second-growth hardwoods, in other words when the pellets do not come from wood waste.

Abiotic Depletion Potential fossil

From the point of view of availability of fossil energy carries, the ADP will be analysed below. The graph in where results obtained from GaBi software is the Figure 5.5 .

If it is compared the graph above with this one, the major difference it is found between pellet stove and natural boiler. As expected, the wood pellet in ADP-fossil requires lower quantity of resources compared to the largest amount of quantities to produce the fossil fuels.

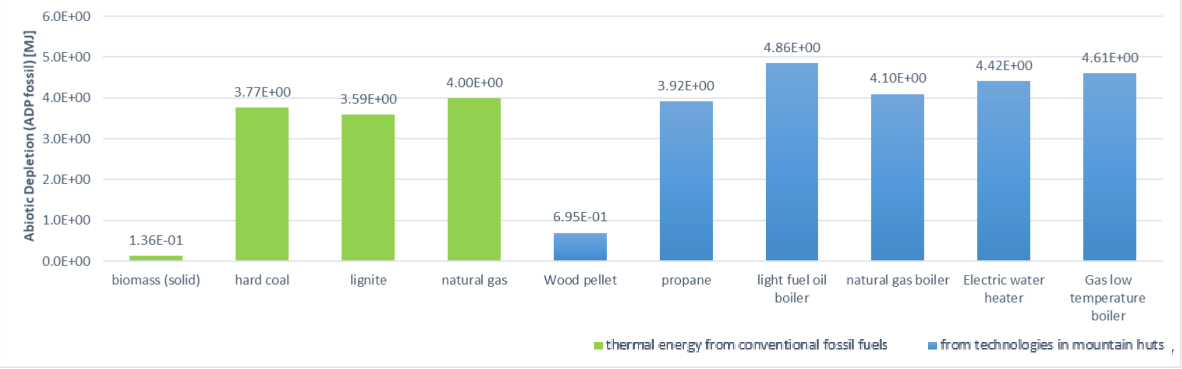

Figure 5.16: Abiotic Depletion (ADP fossil) according to heat generation technologies per 1 kWh

On the other hand, the remaining technologies have the same impact that the heat generated from the fossil fuels, such as hard coal, lignite.

Eutrophication Potential

Based on the results presented in the Figure 5.17, the lowest impact come from natural gas low temperature boiler, in where its value is almost the same that the emissions produced by the heat generation from natural gas. While, natural gas boiler has higher emissions than the heat generated from natural gas. The reason is because in the natural gas the process are more controlled than in a simple natural gas boiler that it is working with lower efficiency.

The higher results from light fuel oil boiler and propane were expected because the combustion of the fuel at high temperatures generates NO_x which help to this phenomena of eutrophication to develop.

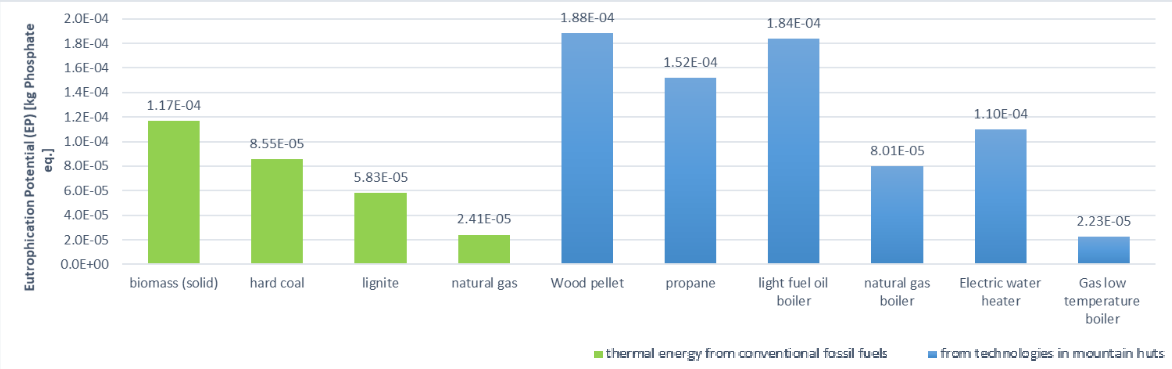

Figure 5.17: Eutrophication Potential (EP) according to heat generation technologies per 1 kWh

Photochemical Ozone Creation Potential

The summer smog is evaluated with the Photochemical Ozone Creation Potential (POCP) in the Figure 5.18.

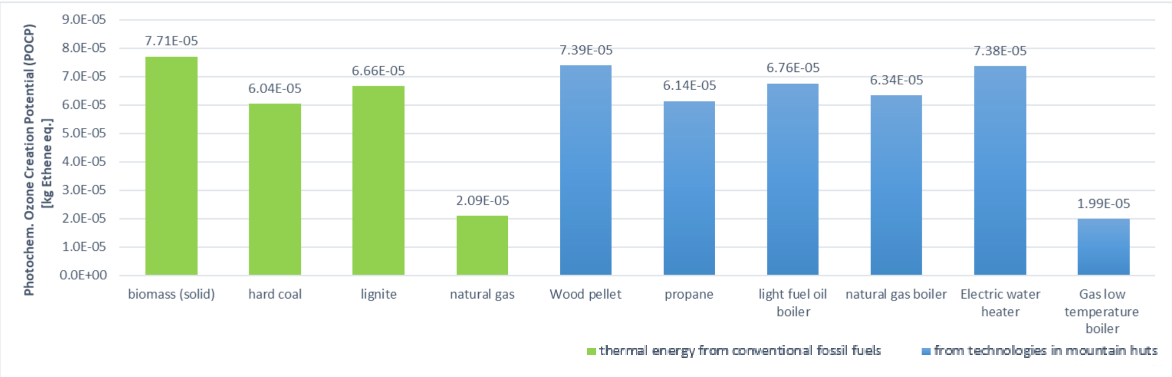

Figure 5.18:Photochemical Ozone Creation Potential (POCP) according to heat generation technologies per 1 kWh

It can be concluded that the lowest relevance in the summer smog will be due to the gas low boiler. As expected, the higher impact comes from the technologies which uses combustion of the fossil fuel , in where the NOx and hydrocarbons contribute to POCP. Despite pellet stove, it does not come from a fossil fuel, as it was mentioned before, the production of wood pellets for the installation is also contributing to increase of this impact.

Human Toxicity Potential

The Human Toxicity potential (HTP) has the target to estimate the negative impact on humans. The results obtained from GaBi software are shown in the Figure 5.19.

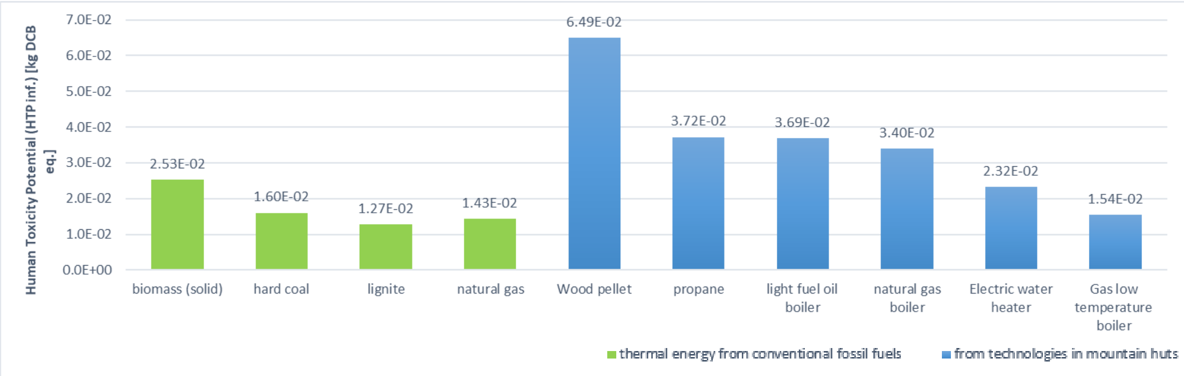

Figure 5.19: Human Toxicity Potential (HTP) according to heat generation technologies per 1 kWh

According to the results obtained, it can be observed that the pellet stove is the technology with highest impact on humans, followed by propane, light fuel oil boiler and natural gas boiler. The reason is because this technologies are producing emissions of formaldehyde which is considering as one of the principal responsible for the HTP. Formaldehyde is a volatile organic compound that is formed and emitted in the incomplete combustion of the fuel and natural gas, as well as, of the wood pellet [38].

Otherwise, the gas low temperature boiler is the device with lowest value, due to the VOC released during the combustion of gas low temperature have no significant emissions of toxic element.

Marine Aquatic Ecotoxicity Potential (MAETP)

Marine Aquatic Ecotoxicity Potential (MAETP) is one of the indicators which allow us to analyse the impact of aquatic eco-toxicity potential of the damaging effects on an ecosystem in where the emissions of nitrogen are analysed.

From the Figure 5.20, it is concluded that bigger quantities of kg DCB eq. comes mainly from pellet stove, although it is followed by the rest of technologies studied, except the gas low temperature boiler which shows the lower impact for this indicator. This is due to the fact that it is generated emissions of nitrogen oxides (NOx) in the atmosphere during the manufacturing and combustion of wood pellet, as well as in case of combustion to natural gas and fuel oil. The impacts of emissions which comes from electric water heater is related with the production of the electricity necessary to work.

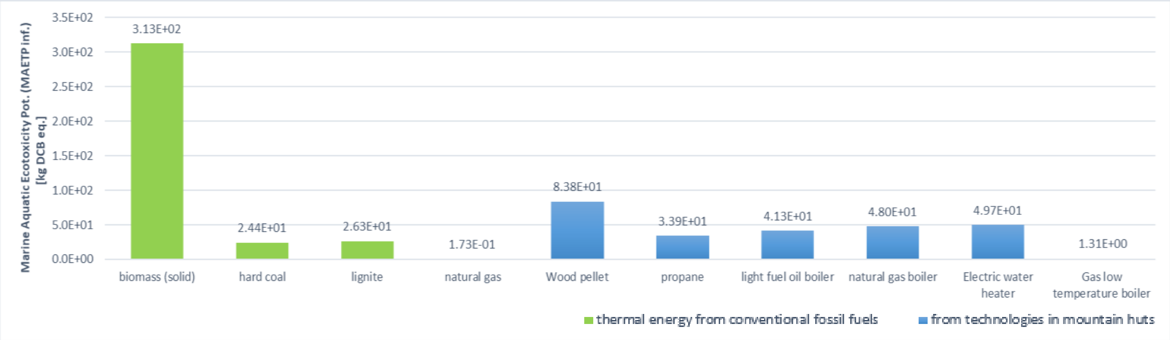

Figure 5.20: Marine Aquatic Ecotoxicity Potential (MAETP) according to heat generation technologies per 1 kWh

Freshwater Aquatic Ecotoxicity

The impact on aquatic eutrophication can also analysed by the impact of freshwater, in where the emissions of the phosphorous are evaluated.

From the Figure 5.21 is concluded that the pellet stove is the most harmful technology in terms of FAETP, followed by the natural gas boiler and the light fuel oil boiler. As expected, the high requirement of electricity for the production of wood pellet is associated with the higher effects in the emissions of phosphate in the freshwater, whereas the biomass. Besides, these emissions are related with the higher impacts for light fuel and natural gas boilers.

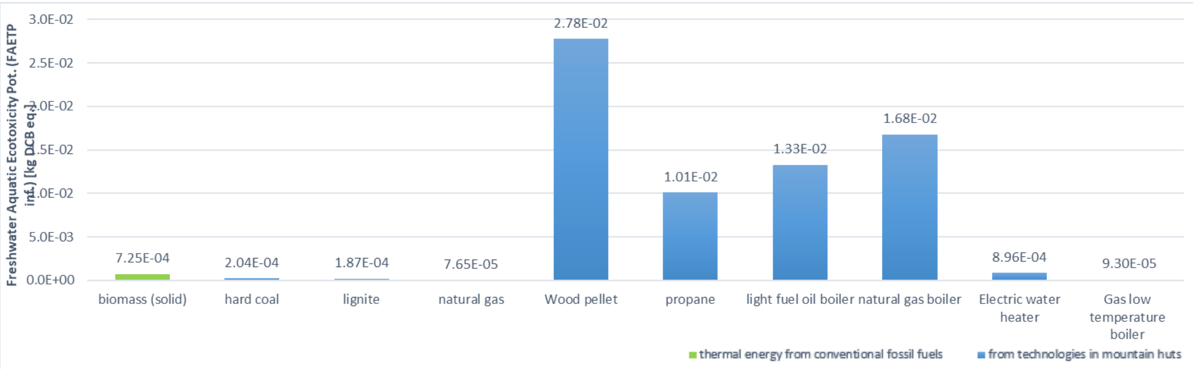

Figure 5.21: Freshwater Aquatic Ecotoxicity (DCB) according to heat generation technologies per 1 kWh

Terrestric Ecotoxicity Potential

The Terrestric Ecotoxicity Potential, TETP, is due to the emissions of nitrogen oxides and ammonia in the environment.

From the Figure 5.22, it is observed that the pellet stove has the highest impact for this category since in the combustion of wood pellets is generated several emissions of nitrogen oxides which produce this results. It is followed by the natural gas boiler and light fuel oil boiler, as expected the emissions are lower due to the combustion of natural gas generated less emissions of nitrogen oxides.

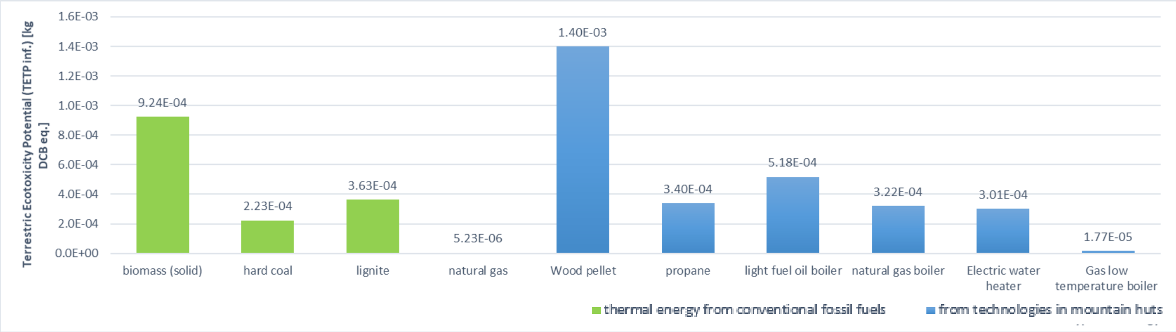

Figure 5.22: Terrestric Ecotoxicity Potential (TETP) according to heat generation technologies per 1 kWh

Acidification Potential

As it can be observed (Figure 5.23), in this case the electric water heater shows the highest impact, 29 % more than light fuel oil boiler, which is the second device with high AP.

Since the emissions of nitrogen compounds, such as ammonia, ammonium and nitrogen oxides are the main cause in this impact. The combustion of the pellet produces higher emissions of NOx compared to produce by natural gas. Although, the electric water heater shows the highest value due to the fact of considering the electricity generation in where the emissions of nitrogen oxides are bigger. Reason why it should be obtained from the excess electricity of a renewable energy sources.

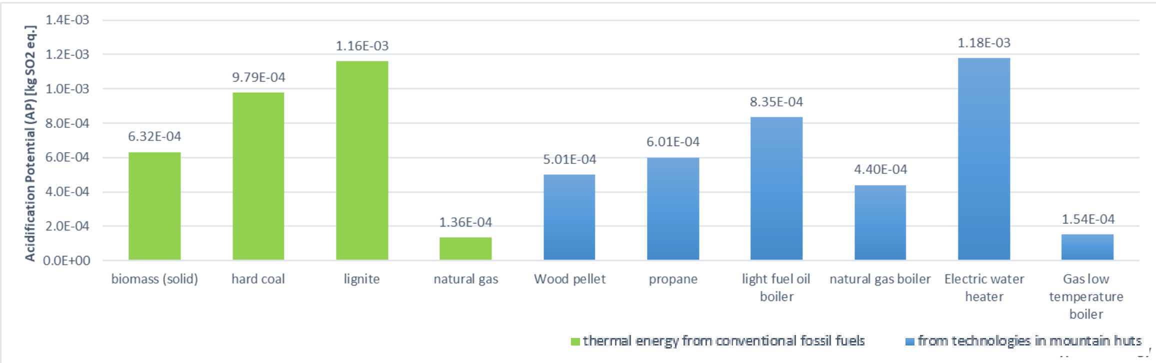

Figure 5.23: Acidification Potential (AP) according to heat generation technologies per 1 kWh

Results for heat generation

To sum up, about know which technologies could be considered in the Table 5.2 is summarized the results obtained with GaBi software according with CML 2001 methodology by each technology. As above, it can be seen the value of each impact category, in where the results are shown according two-colour legend. To reminder, the field in green shows the technologies which has a higher value than the mean value of all technologies for this indicator, while the red one means the opposite, the value is lower than the average value.

Table 5.2: Results of environmental impact indicator for the heat technologies studied

CML2001 - Jan. 2016	Wood pellet	propane	light fuel oil boiler	natural gas boiler	Electric water heater	Gas low temperature boiler
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.72E-07	5.81E-08	9.74E-08	1.01E-07	2.21E-07	1.70E-08
Abiotic Depletion (ADP fossil) [MJ]	6.95E-01	3.92E+00	4.86E+00	4.18E+00	4.42E+00	4.61E+00
Acidification Potential (AP) [kg SO2 eq.]	5.01E-04	6.01E-04	8.35E-04	4.53E-04	1.18E-03	1.54E-04
Eutrophication Potential (EP) [kg Phosphate eq.]	1.88E-04	1.52E-04	1.84E-04	8.29E-05	1.10E-04	2.23E-05
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	2.78E-02	1.01E-02	1.33E-02	1.71E-02	8.96E-04	9.30E-05
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	3.63E-01	3.11E-01	3.41E-01	2.87E-01	4.17E-01	2.78E-01
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	6.46E-02	3.10E-01	3.41E-01	2.87E-01	4.17E-01	2.78E-01
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	6.49E-02	3.72E-02	3.69E-02	3.47E-02	2.32E-02	1.54E-02
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	8.38E+01	3.39E+01	4.13E+01	4.89E+01	4.97E+01	1.31E+00
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4.07E-09	4.95E-08	6.19E-08	3.60E-08	1.84E-12	3.82E-14
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	7.39E-05	6.14E-05	6.76E-05	6.44E-05	7.38E-05	1.99E-05
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	1.40E-03	3.40E-04	5.18E-04	3.29E-04	3.01E-04	1.77E-05

For heat generation, the light fuel oil boiler shows the highest impact regarding all the technologies. The emissions which are produced in the fuel combustion are related with the higher values. Followed by pellet stove that during this project, it could be demonstrated that it had of 67 % of indicators studied were with highest negative emissions. Even though, the pellets are classified as a renewable energy. Then, the electric water heater shows in most of the cases highest impacts, which are related with the production of electricity required to their operation. For natural boiler and propane, it has obtained the same quantity of negative results as positive; in general, the main reason of a harmful emissions comes from the lower efficiency or even, the combustion of the fuel. Nevertheless, the gas low temperature boiler shows the best results studied, so only in 1 indicator out of 12 has obtained a lowest impact.

5.3. Transport

In this chapter, it will be analysed the means of transport continuing along the line of 12 indicators obtained from GaBi, following the methodology CML 2001.

The analyses will be done for two cases. In the first case, it will be compared the helicopter with the 6 Euro emissions standards of a truck. The Euro emissions standards go from Euro 1 (less retractive) to Euro 6 (actual standards). The functional unit in this case are 130 km and 5.5 t, so the truck chose is up to 7.5 t.

In the second case, it will be analysed the different ways to supply the huts. It will be considered the forms to access an specific hut in the project, in where it combines, first the truck and then the helicopter. It should be kept in mind the functional used to calculate this model. It has been taken into account the total number of travels which were needed in one year to supply a mountain hut involve in the project.

Global Warming Potential (GWP 100 years)

Regarding to the Global Warming Potential for a time range of 100 years, in the Figure 5.24 that the highest impact is due to helicopter. In relation with the use of truck Euro 6, the helicopter is emitting a 11 % of kg CO2 eq more than the truck euro 6, by 130 km rounds. The reason is because the helicopter required more amount of kerosene than the truck required it. The amount of kerosene vary on length of flight, and the landing increase the energy used, so for short flights in relation with longer flights are not a good investment.

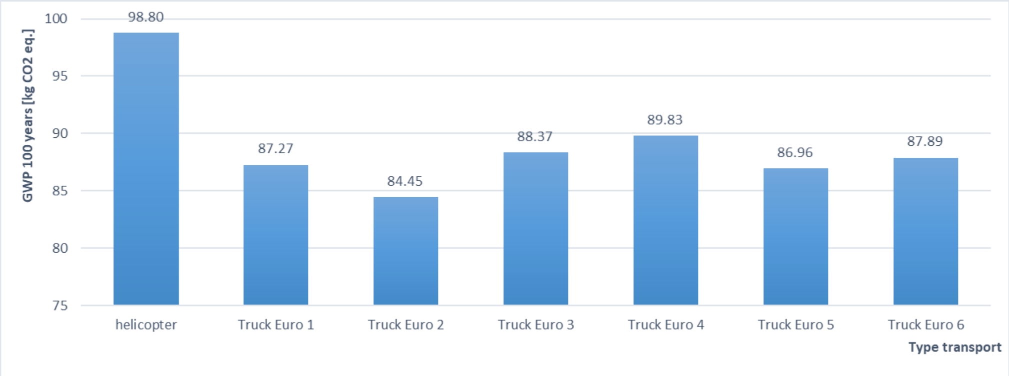

Figure 5.24: Global Warming Potential (GWP 100 years) according to means of transport

In the Figure 5.25 is observed that the used of truck and helicopter has less negative impact than the helicopter. The emissions of CO2 increased due to the helicopter increase the total amount of hour (more km done), so the emissions are directly related with the consumption of kerosene.

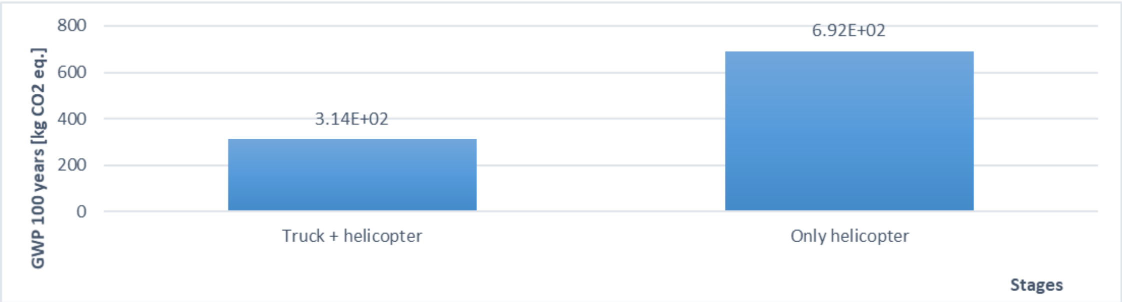

Figure 5.25: Global Warming Potential (GWP 100 years) according to different stages

Global Warming Potential excl. Biogenic carbon (GWP 100 years)

If no account is taken in the GWP the biogenic carbon, as it can be observed in the Figure 5.26, the results are quite similar than if it is consider the biogenic carbon. So, it can conclude that the biogenic carbon do not have impact in this case.

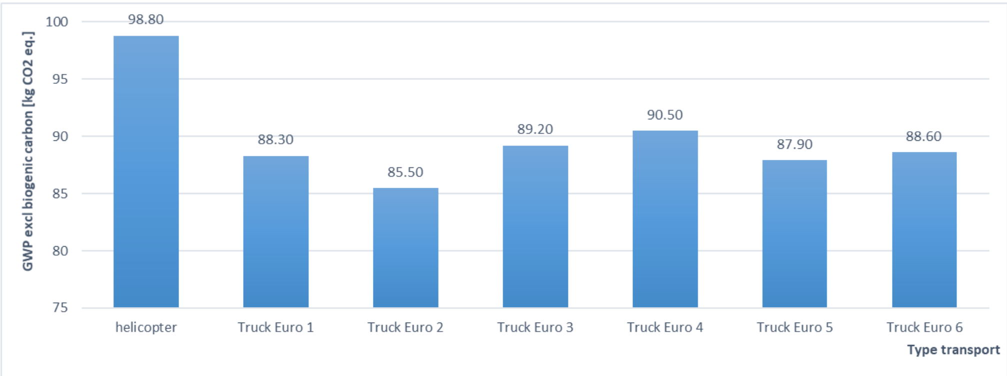

Figure 5.26: Global Warming Potential excl. biogenic carbon according to means of transport

Like before, in the second case the results showed are the same.

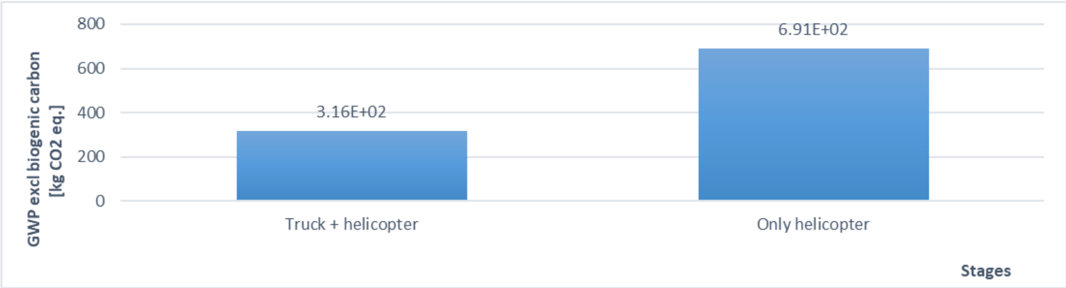

Figure 5.27: Global Warming Potential excl. biogenic carbon according to different stages

Ozone Layer Depletion Potential

The warming of the earth's surface is one of the long-term effects produces by Ozone Layer Depletion Potential ODP, based on this statement in the Figure 5.28, it can be observed that the highest impact is due to helicopter. The emissions are 100 % higher, when the helicopter is used than when the truck is used. This is related with the quantity of volatile organic compounds (VOCs) which are in the transportation emissions, as well as CFCs (Chlorofluorocarbon), solvents and halocarbon refrigerants which carries out with the use of helicopter.

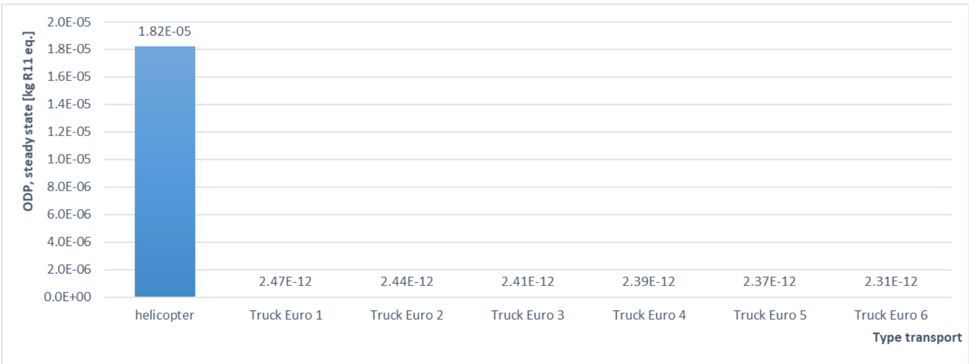

Figure 5.28: Ozone Layer Depletion Potential (ODP) according to means of transport

In the Figure 5.29, it can be observed as when the truck is used in combination with the helicopter the emissions are increased, even though, this emissions come from the use of helicopter, as it was analysed above.

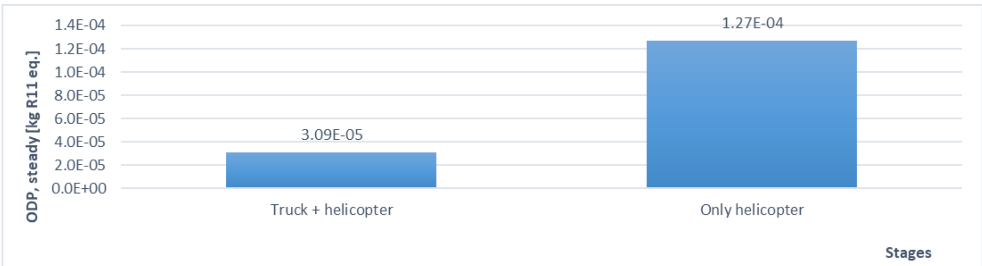

Figure 5.29: Ozone Layer Depletion Potential (ODP) according to different stages

Abiotic Depletion Potential elements

From the results obtained to ADP elements in the Figure 5.30, is observed that between the standard emissions for the truck are in the range of 7 % from Euro 1 to Euro 6. According to the use of euro 6 respect the helicopter there is a difference of 42 % less, if the truck is used. The main reason of this is due the consumption of fuel which is directly related with the ADP, for this the helicopter has higher value, because consumes higher quantities of kerosene than the required by the truck.

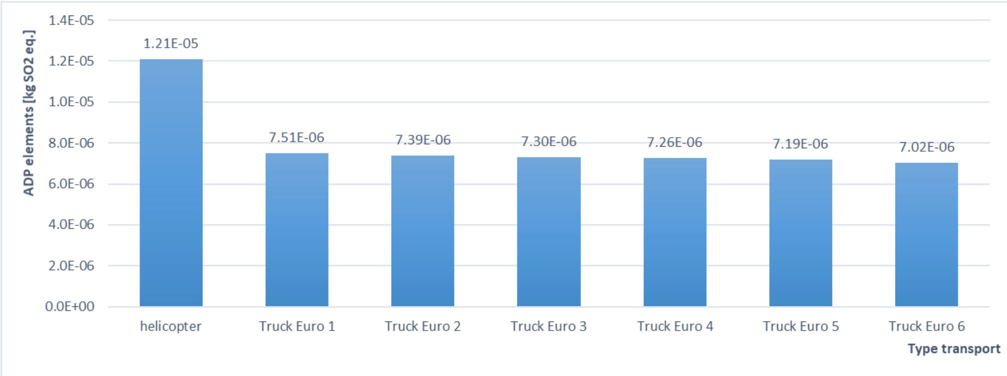

Figure 5.30: Abiotic Depletion (ADP) according to means of transport

Otherwise, in the Figure 5.31 is observed an increase of 61 % when the helicopter is the only way used. The reason is how was commented above.

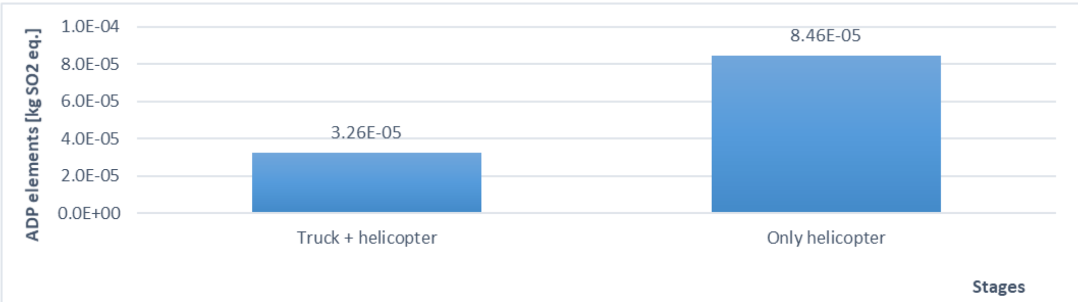

Figure 5.31: Abiotic Depletion (ADP) according to different stages

Abiotic Depletion Potential fossil

First, from the **Figure 5.32**, it can be remarkable that in terms of energy, the emissions due to the different standards of truck is the same, so despite current regulation, this indicator do not impact in each standard of truck, due to the ADP fossil is related with the loss of fossil energy availability, therefore each truck according to its standard loss the same quantity of fuel. While the helicopter has an increase of 42 % of emissions respect the truck.

In the Figure 5.33, the combination of truck and helicopter represents a decrease of 19 % in relation with the option to use only the helicopter as transport mode.

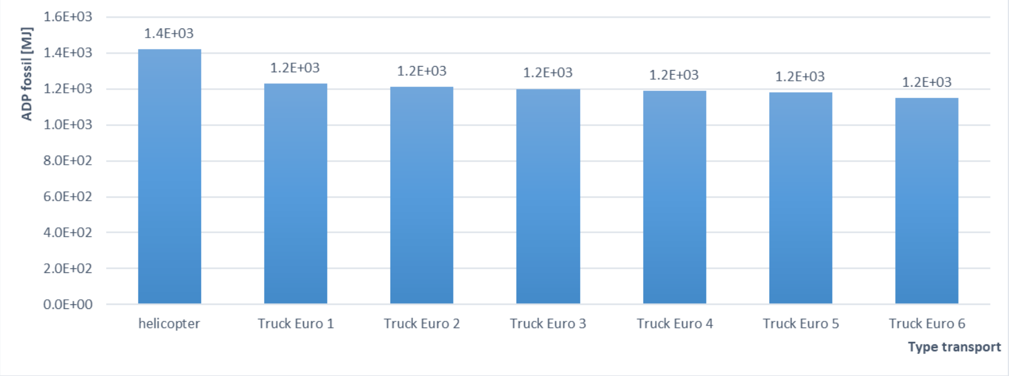

Figure 5.32: Abiotic Depletion (ADP fossil) according to means of transport

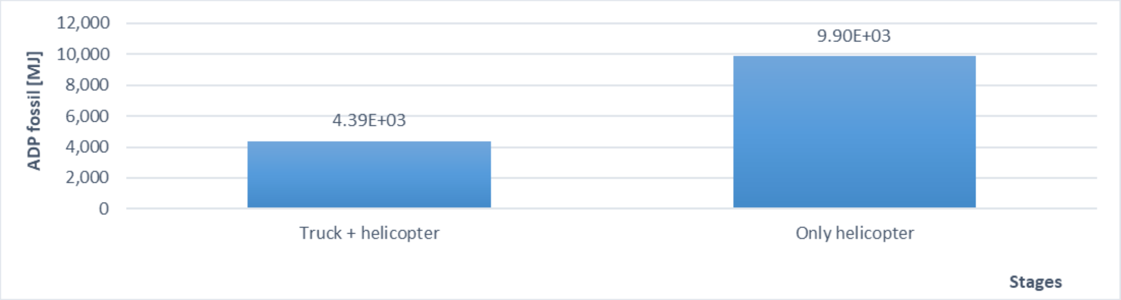

Figure 5.33: Abiotic Depletion (ADP fossil) according to different stages

Eutrophication Potential

A truck with a Euro class 6 get the lowest eutrophication potential followed by truck with euro 5 and the helicopter. In both cases, it is emitted nitrogen oxide due to the combustion of fossil fuels which contribute to the EP (Figure 5.34). A truck with a euro class 1 engine had worst efficiency which implies higher emissions than the current helicopter now,

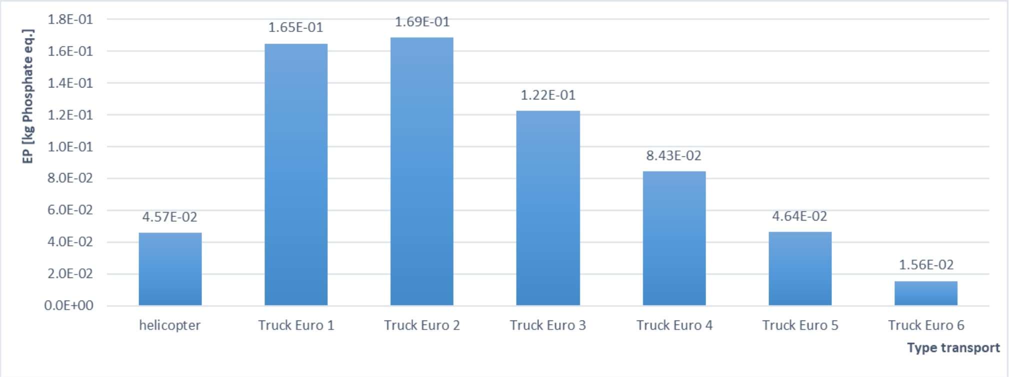

Figure 5.34: Eutrophication Potential (EP) according to means of transport

From the Figure 5.35, it is clearly concluded that the use of helicopter contributes 65 % more than the combination of truck and helicopter. This is because the longer distance of transportation is carried out by the truck with a standard emission of 6 which allow reduce the emissions of EP.

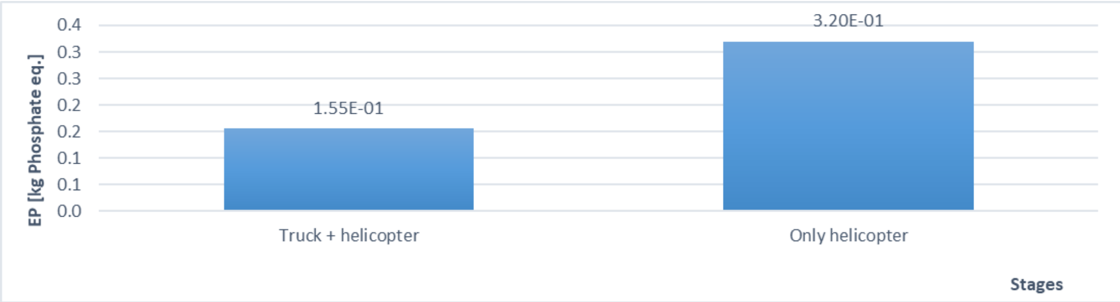

Figure 5.35: Eutrophication Potential (EP) according to different stages

Photochemical Ozone Creation Potential

In the Figure 5.36, it is shown that the helicopter raise to the highest value, so the truck euro 6 is the best option to choose.

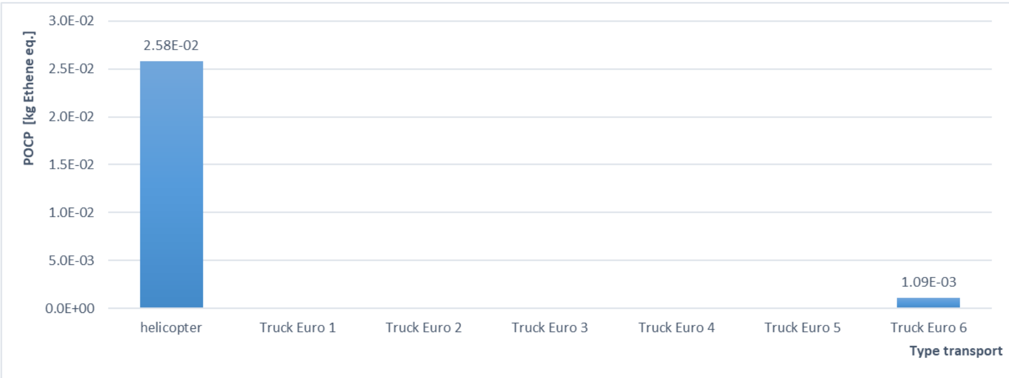

Figure 5.36: Photochemical Ozone Creation Potential (POCP) according to means of transport

From the scenario shows in the Figure 5.37, it is concluded that the far better alternative is the combination of truck and helicopter.

Figure 5.37: Photochemical Ozone Creation Potential (POCP) according to different stages

Human Toxicity Potential

The results obtained from GaBi software are shown in the Figure 5.38. The highest impact comes from helicopter, while the truck with a standard of euro 6 has the lowest value. This values are related with the main following substances that are generated in the fuel combustion, such as nitrous oxides (NOx), Sulphur dioxide (SO2) or nmVOC (Volatile organic compounds) from truck. All of them increase the toxicity.

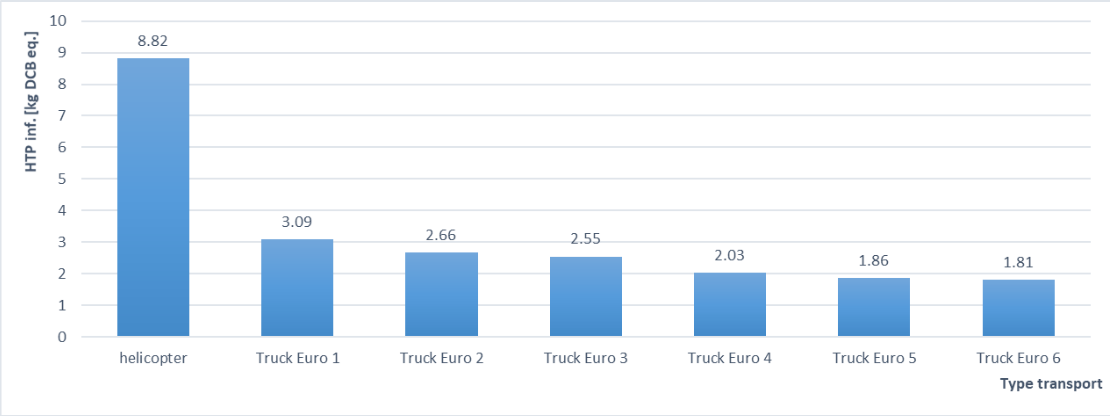

Figure 5.38: Human Toxicity Potential (HTP) according to means of transport

In the Figure 5.39**,** it can be observed that the helicopter increase the emissions in terms of HTP in a 71 % more than the combination of truck plus helicopter because in its length the helicopter required more consumption of kerosene that increase the substances emissions.

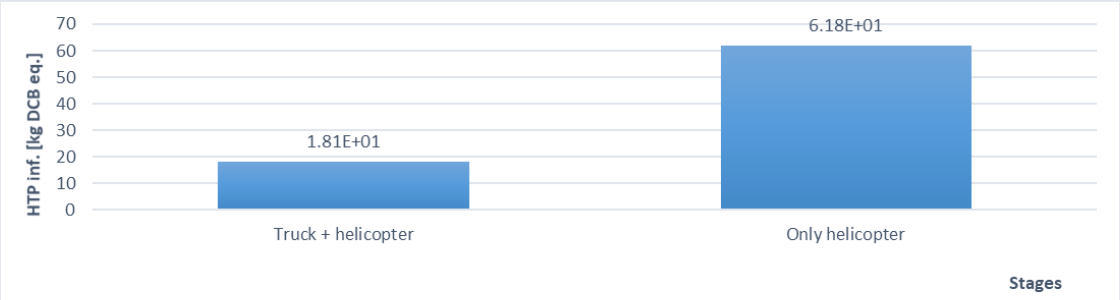

Figure 5.39: Human Toxicity Potential (HTP) according to different stages

Marine Aquatic Ecotoxicity Potential (MAETP)

Marine Aquatic Ecotoxicity Potential (MAETP) is one of the indicators which allow us to analyse the impact of aquatic eco-toxicity potential of the damaging effects on an ecosystem in where the emissions of nitrogen are analysed.

In this case the helicopter is the transport which has higher impact respect the truck. The reason of this higher impact are largely related with the emissions generated in the kerosene combustion (Figure 5.40).

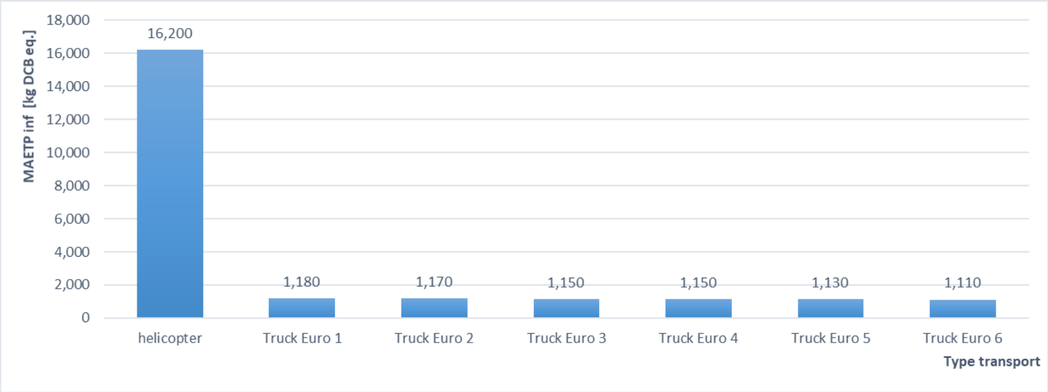

Figure 5.40: Marine Aquatic Ecotoxicity Potential (MAETP) according to means of transport

Regarding to the second diagram (Figure 5.41), it can be observed the notable difference between the option of supplying only by helicopter with the use of truck and helicopter. In where the difference arise to 74 % in case of using only helicopter, due to the fact above commented.

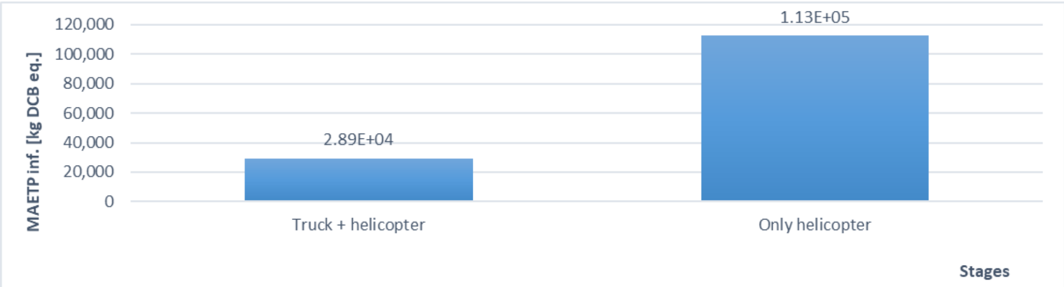

Figure 5.41: Marine Aquatic Ecotoxicity Potential (MAETP) according to different stages

Freshwater Aquatic Ecotoxicity

The Freshwater Aquatic Eco-Toxicity (FAETP) allows the evaluation of eco-toxicity where the emissions of phosphorous are directly related with FAETP.

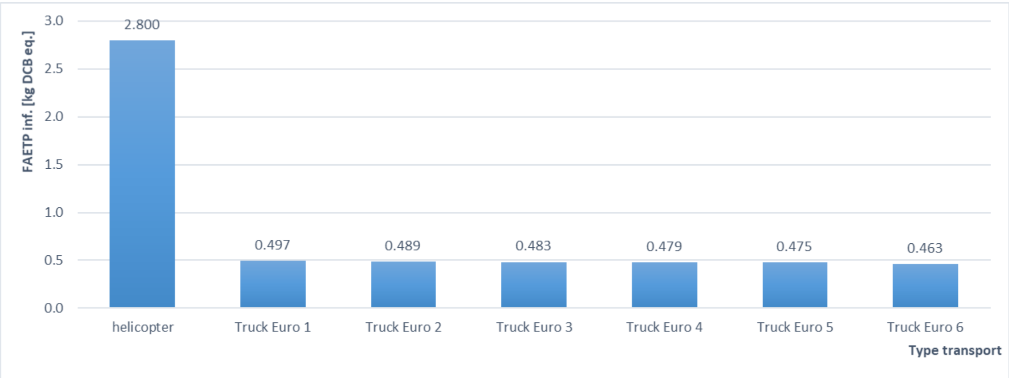

Figure 5.42: Freshwater Aquatic Ecotoxicity (FAETP) according to means of transport

From GaBi, the results shown in Figure 5.42 concluded that the Euro standard for the truck in this impact is largely unchanged. It is observed a reduction of 83 % of FAETP impact when the truck euro 6 is used instead of helicopter. This effects are related with the emission of phosphorous which comes from the helicopter .

According to the reason above mentioned, in the Figure 5.43, it is observed that the helicopter has highest impact than if it is combinate with truck.

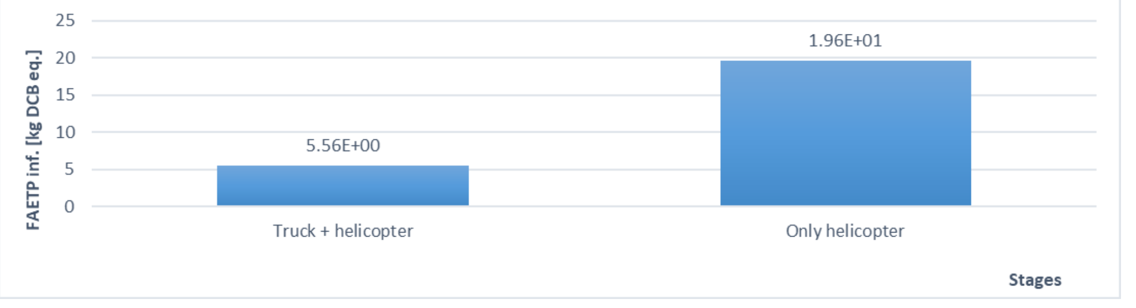

Figure 5.43: Freshwater Aquatic Ecotoxicity (FAETP) according to different stages

Terrestric Ecotoxicity Potential

In the Figure 5.44, it should be noted that there is a reduction impact of TETP to 6 % in relation to use the truck euro 6 instead of euro truck 1. In the same graph, it is also seen that the helicopter has the lowest impact 63 % less than truck euro 6. The truck euro 6 has this results due to the exhaust emissions of nitrogen oxides (NOx) and ammonia (NH3) generated from the combustion of motor fuel truck which are the emissions which lead this impact.

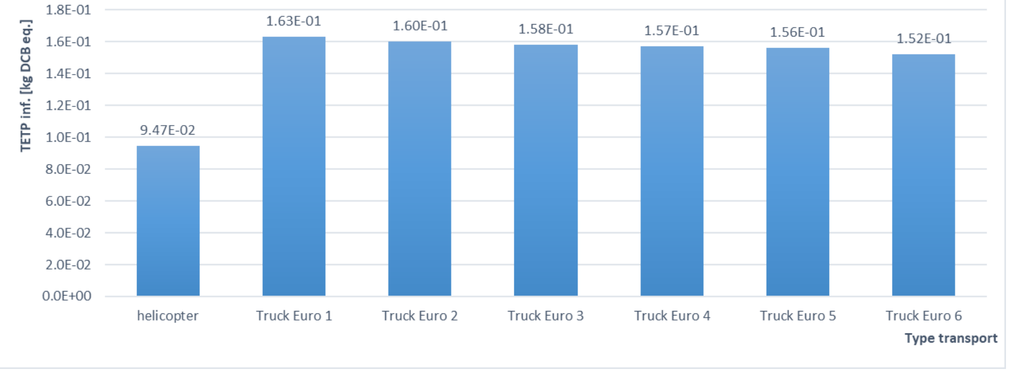

Figure 5.44: Terrestric Ecotoxicity Potential (TETP) according to means of transport

In this line, it is also observed in the Figure 5.45 that the combination of truck plus helicopter is less harmful than the option of only helicopter. Therefore, like the length of flight in case of using only helicopter is much higher than the length that the helicopter has to do when it is combined with the truck, so this is the reason because the combination of both transport is the best option. Besides, the pollutants increase in the terrestrial environment through direct application or by long-range transport.

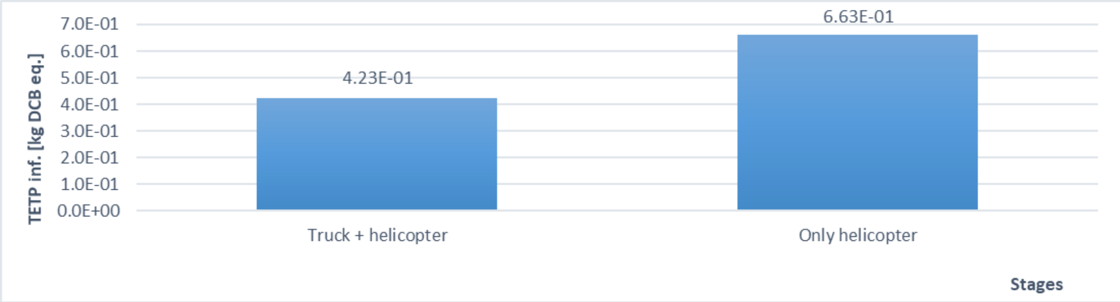

Figure 5.45: Terrestric Ecotoxicity Potential (TETP) according to different stages

Acidification Potential

In the Figure 5.46, it is observed that the truck with an Euro 6 standard shows highest value. The reduction of emissions from Euro 1 to Euro 6 is considered. The use of helicopter increase in a 84 % than the use of truck euro 6. Although, the helicopter in relation with the emissions produced by truck euro 1 are 58 % lower. This can be due to the efficiency in the combustion of oil for the truck with the standard euro 1 is lower than the efficiency in the case of helicopter. However, the helicopter leads off more quantity of emissions off, such as sulphur dioxide and nitro oxides that leads to acidification than Euro 6 truck.

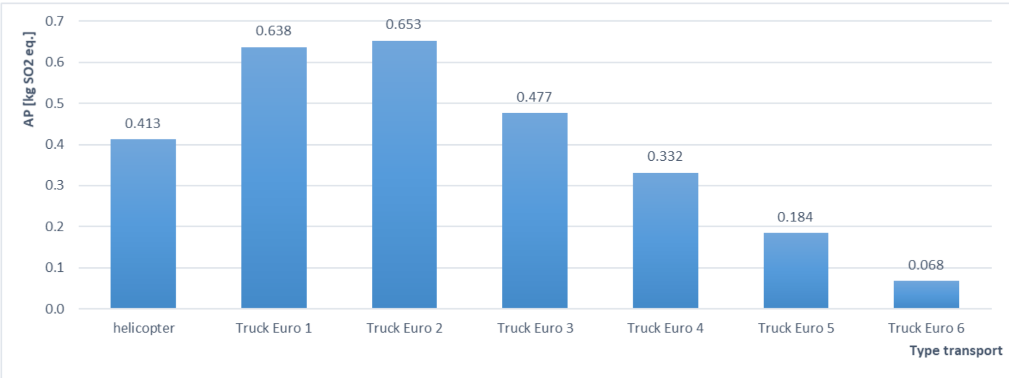

Figure 5.46: Acidification Potential (AP) according to means of transport

The combination of truck and helicopter to supply the hut is the option which less negative impact has it, as it can be observed in the Figure 5.47. As it was commented above, the length of helicopter increase when it is the only way to supply the mountain hut, so consequently it is leading more emissions off.

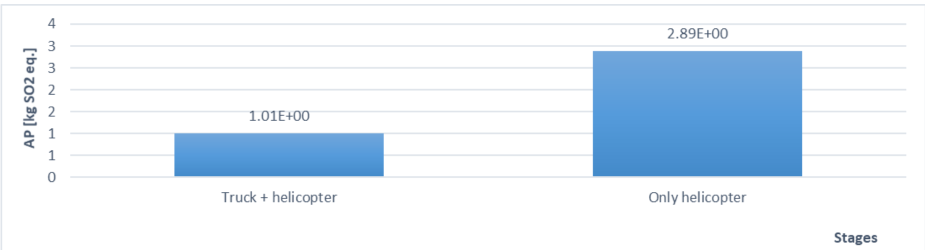

Figure 5.47: Acidification Potential (AP) according to different stages

Results for transportation

Regarding to transportation model in the Table 5.3 is summarized the results obtained with GaBi software according with CML 2001 methodology by each means of transportation. For this case, it can be seen the value of each impact category, in where the results are shown according two-colour legend. The field in green shows the means of transportation which has a higher value than the mean value between the helicopter and the euro standards studied for each indicator, in contrast, the red one means that the value is lower than the average value.

Of this study, it can be concluded that the helicopter has the highest impact in the environment in relation with a truck, which is categorized with a euro 6 (current standard). It should be in mind that this study was done for 130 km with a cargo of 5,500 kg (5.5 t). The highest impact of helicopter comes from the huge quantity of kerosene required. Also, it can be deduced that the helicopter consumed much fuel (kerosene) than a truck (diesel), therefore the impact is higher.

Table 5.3: Results from GaBi software to means of transport

CML2001 - Jan. 2016	helicopter	Truck Euro 1	Truck Euro 2	Truck Euro 3	Truck Euro 4	Truck Euro 5	Truck Euro 6
Abiotic Depletion (ADP elements) [kg Sb eq.]	1.21E-05	7.51E-06	7.39E-06	7.30E-06	7.26E-06	7.19E-06	7.02E-06
Abiotic Depletion (ADP fossil) [MJ]	1.42E+03	1.23E+03	1.21E+03	1.20E+03	1.19E+03	1.18E+03	1.15E+03
Acidification Potential (AP) [kg SO2 eq.]	4.13E-01	6.38E-01	6.53E-01	4.77E-01	3.32E-01	1.84E-01	6.77E-02
Eutrophication Potential (EP) [kg Phosphate eq.]	4.57E-02	1.65E-01	1.69E-01	1.22E-01	8.43E-02	4.64E-02	1.56E-02
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	2.80E+00	4.97E-01	4.89E-01	4.83E-01	4.79E-01	4.75E-01	4.63E-01
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	9.88E+01	8.73E+01	8.45E+01	8.84E+01	8.98E+01	8.70E+01	8.79E+01
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	9.88E+01	8.83E+01	8.55E+01	8.92E+01	9.05E+01	8.79E+01	8.86E+01
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	8.82E+00	3.09E+00	2.66E+00	2.55E+00	2.03E+00	1.86E+00	1.81E+00
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	1.62E+04	1.18E+03	1.17E+03	1.15E+03	1.15E+03	1.13E+03	1.11E+03
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1.82E-05	2.47E-12	2.44E-12	2.41E-12	2.39E-12	2.37E-12	2.31E-12
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2.58E-02	-2.94E-01	-3.05E-01	-2.12E-01	-1.21E-01	-5.89E-02	1.09E-03
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	9.47E-02	1.63E-01	1.60E-01	1.58E-01	1.57E-01	1.56E-01	1.52E-01

From the second scenario, in where it has studied the possibility of replacing the combination of truck and helicopter to use of only helicopter. The results that can be observed in the Table 5.4 shows that the option considered to use only helicopter is not the most appropriate in terms of sustainability for the environment in the mountain hut.

Table 5.4: Results from Gabi Software of supplying a mountain hut with different combination of transport

CML2001 - Jan. 2016	Truck + helicopter	Only helicopter
Abiotic Depletion (ADP elements) [kg Sb eq.]	3.26E-05	8.46E-05
Abiotic Depletion (ADP fossil) [MJ]	4.39E+03	9.90E+03
Acidification Potential (AP) [kg SO2 eq.]	1.01E+00	2.89E+00
Eutrophication Potential (EP) [kg Phosphate eq.]	1.55E-01	3.20E-01
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	5.56E+00	1.96E+01
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	3.14E+02	6.92E+02
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	3.16E+02	6.91E+02
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.81E+01	6.18E+01
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	2.89E+04	1.13E+05
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	3.09E-05	1.27E-04
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	-5.46E-02	1.81E-01
Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	4.23E-01	6.63E-01

6. Conclusions

In the master thesis the main goal was to identify and assess the environmental impacts of all technologies used in huts for energy generation and transport to the huts. There were 9 mountain huts involved in the study in 4 countries all in the scope of the SUSTAINHUTS Life+ project. After the initial status evaluation of the mountain huts also the future investments in terms of new and alternative technologies were assessed. All technologies were modelled in Gabi Thinkstep software environment. Environmental impacts were assessed using LCA with the help of CML 2001 impact assessment methodology with 12 environmental impact indicators in order to discuss the impact of each technology.

From the analysis results, it has reached the following conclusions which are summarized:

- The obtained results for the current technologies used to electricity generation show that the diesel generator is the largest contributor to environmental impacts in the mountain huts achieving 85 % of highest impact values in relation with the other technologies. Despite being the best economic way to generate electricity, this conventional device should be replaced by an alternative technology to decrease the global emissions in each of mountain hut. The main reason of this highest values are due to the emissions generated from its fuel combustion, and also the lower efficiency which is considered. It was found that there are two alternative technologies with hardly any harmful environmental impact: The hydro-turbine shows for all the indicators the lowest values, followed by the wind turbine.

- From the types of PV panels studied per 1 kWh of electricity generated according to their installation. It is concluded that the PV panels with a slanted-roof installation has lower environmental impact than facade installation. To produce the same quantity of electricity, the photovoltaic facade installation requires more m^2 in order to produce the same amount quantity of energy than it is produced with slanted-roof installation. Besides, the manufacturing of photovoltaic panels is also related with the higher emissions of this renewable energy which does not lead to a decisive advantage for install it.

- Regarding the heat generation, the light fuel oil at boiler is the technology which has the biggest environment impact: in 10 out of 12 indicators analysed, this highest impacts are related with the emissions produce in the fuel combustion. On the other hand, the natural gas boiler has better results respect the present technologies installed in the mountain hut; the emissions comes from the lower efficiency or even, the combustion of gas.

- In relation with the alternative technologies studied, the results obtained for the pellet stove does not contribute in a properly sustainable way, even though, the wood pellets are classified as a renewable energy, from the results is concluded that the used of hardwood trees and pellets which are made from virgin grow, it is contributed to increase the emissions. Besides, the electric water heater has shown to be one of the alternative devices with more negative emissions; this is because it is considered that the electricity used by the heater comes from a conventional technology. Although, if it is demonstrated that the electricity used in the heater comes from an excess of energy produced by an alternative technology, such as micro-hydro, the emissions considered from the production of electricity can be neglected and consequently, the highest values are going to be reduced. Nevertheless, the gas low temperature boiler shows the best results studied, so only in 1 indicator out of 12 has obtained a lowest impact.

- From the results obtained in the comparation of European Standards Emissions for the trucks, it has demonstrated that the current standard (Euro 6) is the most restrictive, although the reduction of emissions in relation with the Euro 5 is slightly lower (2 %). However, it must be made sure that the truck used for supplying the mountain huts is Euro 6. On the other hand, the study of the helicopter has carried out some assumptions which cannot allow us to reach clear conclusions, although if it is taken into account the results obtained, it is concluded that the helicopter has to be avoid as far as possible, and in the case in where it is the only way for accessing to mountain hut, it should be recommended to reduce the distance in where the helicopter has to go with a cargo, due to have the higher emissions than when the helicopter is empty.

- Regarding to the study of freight cableway transport, it must consider that it has not found any process to model with GaBi software. However, it is known that in Pogačnikov the cargo ropeway works with a diesel engine, while in Torino the cableway works from electricity. Therefore, it can be concluded from the numerical model used by the electricity generation that the use of a cableway in where is connected to grid is 83 % less harmful for the environment that the ropeway work with a diesel engine.

To sum up, the sustainability in the mountain huts still needs to be carefully studied to assess its improvement, it can carry out not only through the integration of renewable energies but the improvement of the insulation, with all these targets it could achieve an improvement in energy efficiency and a reduction of CO_2 emissions. Moreover, besides to reduce the emissions also will be contributed in the improvement of the livelihood of mountain inhabitants.

Recommendations for future research

Considering that SUSTAINHUTS + project still be life until 2020, during this period it should be considered to include the technologies which was proposed in order to get better sustainable huts.

From the modelling point of view it will be interesting to have the possibility get additional data in LCA databases that will give even more precise results.

7. Bibliography

[1] Google. (n.d). [Map of Kocbekov Dom hut, Slovenia in Google maps]. Retrieved March 21, 2018.

[2] *Alpine Association of Slovenia* (2018). Retrieved March 21, 2018 from https://en.pzs.si/koce.php

[3] *Capestral*. (2011). Retrieved March 21, 2018, from: http://www.capestral.com/clima-tiempo-eslovenia.php

[4] Mori M., Lotric A., Stropnik R., Drobnic B., Sekavcnik M. (2017, Nov 13). *C5.2 Life cycle inventory analysis (LCIA): Mass and energy balances of mountain huts*. LIFE SUTAINHUTS: Sustainable Mountain Huts In Europe. LIFE15 CCA/ES/000058

[5] Jurjevčič, Boštjan, Lotrič, Andrej, Stropnik, Rok, DROBNIČ, Boštjan, Sekavčnik, Mihael, Mori, Mitja, Prašnikar, Dušan, Auer Tadej. Demo huts initial conditions report: Kocbekov dom initial conditions. [Ljubljana: Faculty of Mechanical Engineering, 2017].

[6] Jurjevčič, Boštjan, Stropnik, Rok, Lotrič, Andrej, Drobnič, Boštjan, SEKAVČNIK, Mihael, Prašnikar, Dušan, Auer Tadej, Mori, Mitja. Demo huts initial conditions report: Pogačnikov dom initial conditions. [Ljubljana: Faculty of Mechanical Engineering, 2017].

[7] Fiorot, Sabina, Fausone, Marco. Demo huts initial conditions report: Rifugio Torino initial conditions.

[8] Gracia, Lorién, Capacés, Daniel, Casero, Pedro. Demo huts initial conditions report: Lizara hut

[9] Gracia, Lorién, Capacés, Daniel. Demo huts initial conditions report: Llauset hut initial conditions.

[10] Gracia, Lorién, Casero, Pedro. Demo huts initial conditions report: Estós hut.

[11] Gracia, Lorién, Casero, Pedro. Demo huts initial conditions report: Montfalcó hut SH-A11-DLV-FHA-001

[12] Gutiérrez, Manuel. Demo huts initial conditions report: Ayous hut.

[13] *Sustain Huts*. (2015). Retrieved April 17, 2018, from: http://sustainhuts.eu/

[14] Jurjevčič, Boštjan, Lotrič, Andrej, Stropnik, Rok, Drobnič, Boštjan, Sekavčnik, Mihael, Mori, Mitja. Identification of technologies used in mountain huts and specifications of huts construction in Pyrenees, Alps and Carpathian mountains. [Ljubljana: Faculty of Mechanical Engineering, 2017]. 34 f., graf. prikazi. [COBISS.SI-ID 15325979].

[15] Google. (n.d). [Map of Pogačnikov dom, Slovenia in Google maps]. Retrieved April 18, 2018.

[16] Google. (n.d). [Map of Refugio de Torino, Italy in Google maps]. Retrieved April 18, 2018.

[17] Rifugio Torino. (n.d.). Retrieved April 17, 2018 from: http://www.rifugiotorino.com/Index.php?lang=en

[18] *Viajar a Italia*. Retrieved March 21, 2018, from: https://www.viajaraitalia.com/clima-de-turin/

[19] Google. (n.d.). [Map of Bachimaña hut, Spain in Google maps]. Retrieved April 19, 2018.

[20] Lorién Gracia, P. (2017, Jul 31). A1.1. Demo huts initial conditions report: Bachimaña hut initial conditions. LIFE15 CCA/ES/000058. LIFE SUSTAINHUTS: Sustainable Mountain Huts In Europe.

[21] *Albergues y refugios de Aragón* (n.d.). Retrieved April 17, 2018, from: http://www.alberguesyrefugiosdearagon.com/index.php

[22] Agencia Estatal de Meteorología, AEMET. Retrieved April 17, 2018, from: http://www.aemet.es/es/portada

[23] Google. (n.d.). [Map of Lizara hut, Spain in Google maps]. Retrieved April 16, 2018.

[24] Google. (n.d.). [Map of Cap de Llauset, Spain in Google maps]. Retrieved April 19, 2018

[25] Google (n.d.). [Map of Estós hut, Spain in Google maps]. Retrieved April 19, 2018.

[26] Google (n.d.). [Map of Montfalcó hut, Spain in Google maps]. Retrieved May 7, 2018

[27] Google (n.d.). [Map of Refuge D’Ayous, France in Google maps]. Retrieved May 8, 2018.

[28] Casero, Pedro, Gutiérrez, Manuel. Micro Grid Specifications Report. "*Lizara*"

[29] Casero, Pedro, Gutiérrez, Manuel, Drobnič, Boštjan. Micro Grid Specifications Report. *"Kocbekev"*

[30] Casero, Pedro, Gutiérrez, Manuel, Drobnič, Boštjan. Micro Grid Specifications Report. *"Pogacnikov"*

[31] "International Organisation for Standardisation (2006a) ISO 14040: Environmental management – Life cycle assessment – Principles and framework," 2006.

[32] "International Organisation for Standardisation (2006b) ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines," 2006.

[33] GaBi Paper Clip Tutorial (n.d.). Part 1. Introduction to LCA and modelling using GaBi. PE INTERNATIONAL. University of Stuttgart

[34] Thinkstep GaBi. (n.d.). *Description of the CML 2001 Method*. Retrieved April 26, 2018, from: http://www.gabi-software.com/support/gabi/gabi-lcia-documentation/cml-2001/

[35] Institut für Kunststoffprüfung und Kunststoffkunde der Universität Stuttgart, Abteilung Ganzheitliche Bilanzierung, 2003

[36] Thinkstep GaBi. (n.d.). *GaBi LCA Databases*. Retrieved May 02, 2018, from: http://www.gabi-software.com/america/databases/gabi-databases/

[37] Božek, Josef (2014). Study of exhaust emissions reduction of a diesel fuel operated heater during transient mode of operation. Vehicle Centre for Sustainable Mobility, Czech Technical University in Prague, Czech Republic.

[38] (n.d) Wood Pellets: Green Energy or new source of CO2 Emissions. Yale school of forestry&environmental studies. Retrieved May 16, 2018, from: https://www.politesi.polimi.it/bitstream/10589/51561/3/2012_04_Corrado.pdf