Lozano-Miralles, José A., López-García, Rafael, Palomar-Carnicero, José M., Rey-Martínez, F.J. **Comparative study of heat pump system and biomass boiler system to a tertiary building using the Life Cycle Assessment (LCA).** *Renewable Energy* 2020. Vol: 152. pp: 1439 – 1450. ISSN: 0960-1481. DOI: 10.1016/j.renene.2019.12.148

Article

Comparative study of heat pump system and biomass boiler system to a tertiary building using the Life Cycle Assessment (LCA).

Abstract: The high emissions of substances harmful to the environment associated with the activity of people, has become a point of extreme importance, since it depends on the subsistence of life on the planet [1]. Manufacturing processes and the application of new technologies improve substantially the life, but some processes contribute more to the damage to the environment. These manufacturing processes require a high consumption of energy and resources, which entail environmental impacts, some of them not quantified. For this reason, the reduction of emissions has become the battlefield in the fight for the preservation of planet.

To determine and quantify the impacts that occur in a product, process or system, it is necessary to perform an analysis of the flows of energy and resources that occur throughout its life cycle. That is why the LCA has become a very important tool in the process of transition to a low-emission production economy. [2] There are systems that, although considered renewable, also produce impacts on the environment. That is why, the present work, and through the LCA, determines the impacts produced by two heat generation systems, to later be able to compare them with each other.

Key words: LCA, environmental impact, sustainability, resources, heat pump, boiler.

---

1. *Introduction*

At present, the importance for the subsistence of life on the planet is professionally, theoretically and even people in the street in the public eye, to cope with high emissions of substances harmful to the environment associated with the action of people. For this reason, the reduction of emissions has become the battleground in the fight for the preservation of the environment. [3]

Industry is in constant innovation, production and application of new technologies that contribute to one´s comfort, but paradoxically, this increases the damage to the environment. To cut back on risks and environmental damages, there are effective methods, which identify the weaker factors of each process, and that must be developed. One of these methods is LCA which due to the systematic, objective and global nature constitutes a more appropriate methology for environment order [4] [5]. The intense industrial activity and manufacturing processes require a high consumption of energy and have a significant influence on greenhouse gases (GHG) emissions, which has a negative impact on the preservation of resources and the environment, due to its contribution to global warming. These impacts include of GHG emissions, such as carbon dioxide (CO_2), the main worldwide polluting gas, and other gases like methane, nitrous oxide and chlorofluorocarbons which can be measured in units of CO_2 equivalent to (CO_2-eq) [6] [7].

LCA has become a highly important tool for providing in-depth analyses of this kind, for instance in studies concerned with the replacement of fossil fuels by renewables in electricity production, and a significant option in the process of transition towards a low-emission production economy. It has used the Life Cycle Assessment used as a methodology which assesses environmental impacts caused by products, processes or systems.

According to ISO 14040 standards, LCA is defined as the collection and evaluation of the inputs and outputs for determining possible environmental impacts of a product, process or system during its life cycle. Thus, LCA is a tool for the analysis of the environmental burden of products in all phases of its life cycle, from the extraction of resources, production of materials, pieces, and the product itself, until the use of the mentioned product and residue management after being discarded, whether re-purposing, recycling or final disposal. [8]

The main parts of the LCA are the following:

a) Discuss the purpose and definition of the scope of application of this approach;

b) Make an inventory of the inputs and outputs of the system;

c) Assess all types of impacts on the environment; and

d) Interpret the results and evaluate the impacts.

There are LCA studies and works include enviromental issues about energy productions systems, but few comparative between different systems that cover the same demands and are considered renewable. One of them is LCA comparative of wood pellets and wood split logs for residential heating which provides information on the impacts generated by the combustion of the wood and its by-products in three types of places, a pellet boiler, a waterproof stove and a traditional fireplace [9], other study is LCA Comparative of electric generation by different wind turbine types which shows us that most enviromental impacts are associated with the manufacture of fundament, tower and nacelle [10] and last example is LCA comparative of fixed and single axis tracking systems for photovoltaics to understand the enviromental differences between both systems [11]. These studies have used different software and different methods of analysis, which gives us information to contrast with the results of this studies.

The present work deals with the comparative study of the environmental impacts caused by an air-to-air heat pump and a biomass boiler, both considered renewable energy systems. The heat pump system was installed in a tertiary building of the University of Jaén and the biomass boiler has been simulated in the same conditions as the previous system. Emissions produced by the processes during the extract of materials, manufacture, operation and end-of-life stage of both systems have been considered. To complete the comparative, a sensitivity study was carried out based on the comparison between two evaluation methods, Eco-Indicator99, which focuses in determining the impacts to human health and the EPS 2000, which mainly approaches impacts due to energy and non-energy resources.

According to the previous approach, the first objective of this work will be to determine the impacts produced by two energy production systems (heat pump and pellet boiler) through two methods, the Eco-indicator99 and the EPS2000, which it would give us information about the amount and importance of CO_2 Emissions to the atmosphere. So that the information provided by the LCA, allow us to determine investment policies and reduce the impacts on the environment.

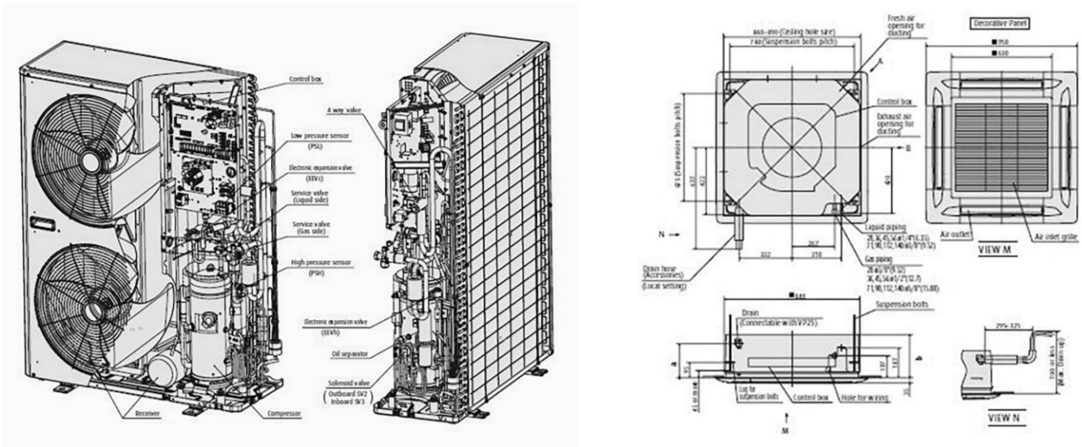
Eco-Indicator99 was performed for eleven impact categories- carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, Ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels and EPS 2000 was performed for thirteen impact categories- life expectancy, severe morbidity, morbidity, severe nuisance, nuisance, crop growth capacity, wood growth capacity, soil acidification, production capacity irrigation, production capacity drinking, depletion of reserve and species extinction.

There are several reasons why these methods have been selected. The impact categories provided by both methods allow us to check whether the results are consistent. Eco-indicator99 is an evaluation method based on scientific and pragmatic knowledge for eco-design and is central to the final damage, using a two-level weighting system. The first within each protection area (resources, ecosystem and human health) and the second one of the panel type. The ultimate goal is to obtain the total environmental burden of a product or system through a single score [12] [13]. Another reason is that both methods give us a similar level of aggregation of the results. Important data for the compression of the results.

2. *Materials and Equipment.*

2.1. Heat Pump (System 1). The selected heat pump has the following features according to the requirements of thermal heating required for four classrooms 93.90 m² lecture rooms situated in a building of the University of Jaén. The heat pump MITSUBISHI ELECTRIC, model FDCA224HKXE4 is composed of the compressor (outdoor unit), the interconnection pipes, two fans, heat exchanger, air flow chamber, mechanical chamber, the housings, refrigerant R410a, oil, electronic expansion valves and smalls materials. The four evaporators celling cassette (indoor machines) model FDT36KX, whose components are plastic housing, air unlet grille, air outlet, suspensions bolts, liquid connection piping, electronic materials, control box and small materials. The technical diagrams of the system are represented in figure 1. [14]

Figure 1. Technical scheme of the compact compressor and evaporators.



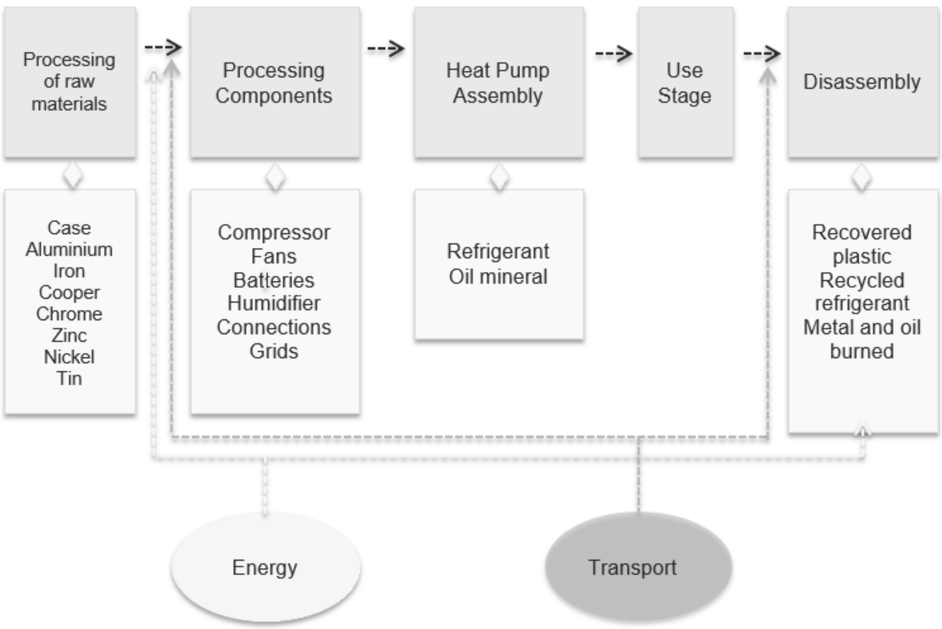
2.1.1. Technical Specifications. It have been obtained the quantities, powers and characteristics necessary for study. The data on elements, raw materials and consumptions form a basic part of the inventory of the systems to be studied. Technical specifications system 1 are shown in table 2.

Table 2. Technical specifications of the heat pump. [15]

Operating in cooling or heating mode				
Model			FDCA224HKXE4	FDT36KX
Capacity	Cold	Kw	22,4	3.6
		Kcal/h	22.400	3,150
	Heat	Kw	25	4
		Kcal/h	25,000	3,500
Electricity Consumption	Cold	Kw	5.7	
	Heat		5.98	
Sound Level		dB (A)	57	31
External Dimensions		mm	1,690 x 1,350 x 720	246 x 840 x 840
Weight		kg	240	22
Air flow (standard)		m³/min	220	18
Type of compressor			GT-C5150ND71 x 1	
The Compressor Motor		Kw/ud	5.6 x 1	
Fan Motor		W x ud	120 x 2	50 x 1
Refrigerant Oil		L	1.75 (M-MA32R)	
Coolant			R410A	
Quantity of Refrigerant		kg	11.5	
Fan type and amount			2 x axial fans	
Drives Connected		Ud	1	4

2.1.2. Flow Diagram. To acquire knowledge about the system, a flow diagram of each process related to the heat pump is show in Figure 2. The figure shows a diagram of the life cycle of a heat pump, from the extraction of materials to its end of life. In some cases it consists of disambiguation of some elements, and in others, the transfer to landfill. The inputs and outputs of both materials and energy, occurs throughout the cycle, being essential in the study a rigorous collection of these quantities.

Figure 2. Process flows of the heat pump. [16]



One of the main points of the LCA methodology consists of an inventory of the major inputs and outputs. To achieve this objective, it have been used various sources among which are the manufacturer's catalogues, information in the literature and databases of environmental data of the SimaPro. In addition, the following databases from ELCD, EU & DK Input Output Database, Industry data 2.0 and Methods have been consulted. These databases offer a significant amount of data relating to resource consumption and emissions during manufacturing. The most import raw materials which are involved in the processes of the cycle of life have been considered. [17] [18]

2.1.3. Inventory Analysis. The distance between the process of the parts of the heat pump and the place where the heat pump is going to operate is also important, in this case the central distribution is in Seville. It is considered that all the metals present in the new heat pump can be entirely recycled, and plastics incinerated. Table 4 shows the most representative values of the heat pump.

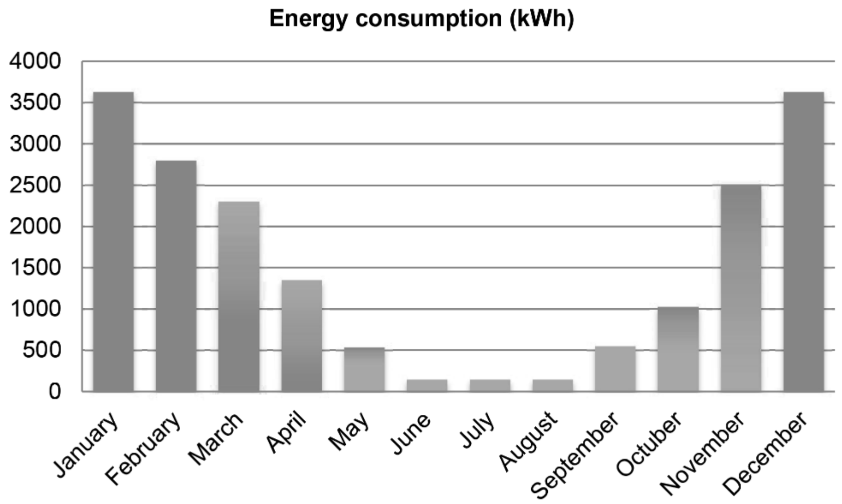
Table 3. Inventory of materials of the heat pump system. (Own compilation)

Inventory				
Concept	Outside	Inside	Connetions	Total
Raw Materials (kg)	FDCA224HKXE4	FDT36KX	4 ud	1 out + 4 ins
Housing (Plastic)	86,897	0	0	86,897
Iron	78,074	35	0	112,933
Aluminium	40,171	38	0	77,959
Copper	17,114	9	16,350	42,795
Nickel	3,481	0	0	3,485
Lead	3,486	0	0	3,496
Chrome	2,897	0	0	2,897
Polyethylene	5,826	6	0	11,365
Zinc	1,112	0	0	1,467
Tin	0,022	0	0	0,042
Pvc	0,099	0	0	0,195
Rubber	0,828	0	0	0,828
Total	**240,00**	**88,00**	**16,35**	**344,36**
Energy				MJ
Oil (Boiler, 1 MW)	1.538,814	618,578	154,644	2.312,036
Industrial natural gas (>100 kW	1.538,814	618,578	154,644	2.312,036
Medium Voltage Electricity	112,833	45,367	11,342	169,541
Transport				tKm*
Truck (40 t)	23,917	8,800	1,635	34,352
Van (<3,5 t)	55,010	20,240	3,761	79,010
Train	47,834	17,600	2,616	68,050
BASURA (incinerador público)				Kg
Polyprolpilene	5,826	5,535	0	11,361
PVC (Polyvinyl Chloride)	0,099	0,095	0	0,195
Rubber	0,828	0,000	0	0,828
Atmosphere emissions				MJ
Residual heat	112,841	45,363	21,120	179,323

tKm*. This unit is the transport of 1 ton of material per 1 Km. For the calculation of transport, the factory in Seville has been considered.

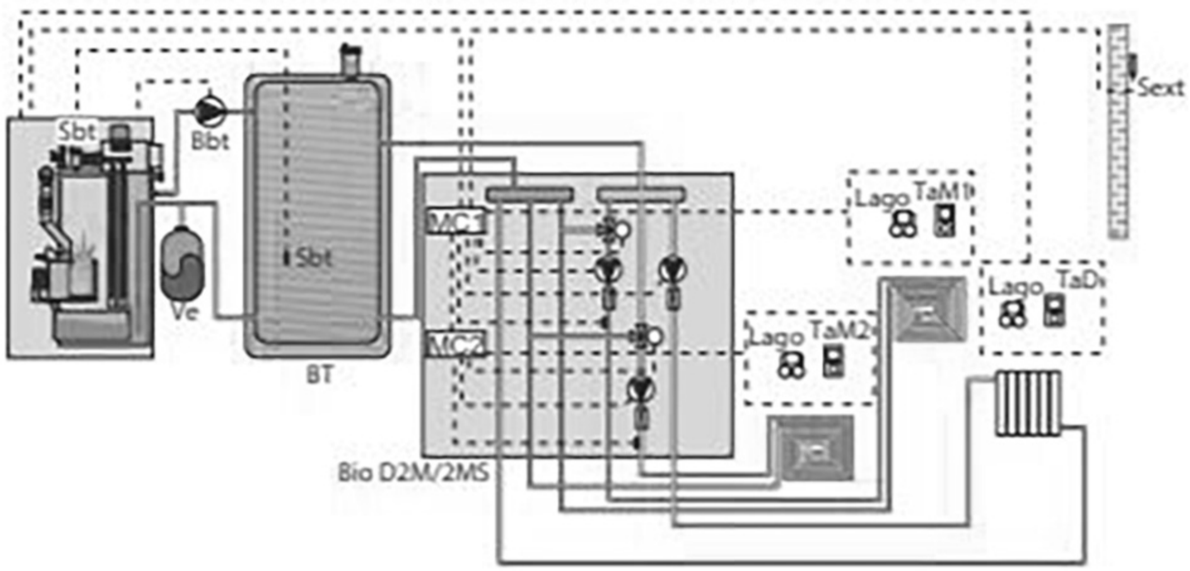
2.1.4. Energy consumption. The calculation of the annual energy consumption have been considered within the following limits: the operating temperature selected for inside buildings is 22°C in winter and 24 ºC in summer, considering the Spanish legislation on design of thermal machines [19]. The work schedule (teaching rooms), is from 09.00 h to 20.00 h. The calculation of the school days is developed as follows: 2 semesters of 22 days / month, have been obtained a use of 176 days. So the total working hours of the system is 3,036 hours / year. Considering a life expectancy of the Pellets Caldera for 10 years, have been obtained a total of 19,360 hours. Therefore, the energy consumption in this period would be 115,772.80 kW, or what is the same, 0.4167 TJ.

Figure 3: Seasonality of consumption (Own preparation).



2.2. Biomass boiler (System 2). The selected biomass boiler is the make DOMUSA, model BioClass HM. This model is available in a power range from 10 kW to 43 kW and it can be used with pellets hoppers consumption. There is the possibility of using several types of biomass granules, depending on the model, you can use pine pellets, leafy pellets, olive stone or hazelnut peel [20].

Figure 4. Technical scheme of the biomass boiler. (System 2)



2.2.1. Technical Specifications. The technical specifications of these components are shown in table 3. The boiler is composed of a main housing body, control unit, where the burner, buffer tank, electric heating element, the expansion vessel, heating expansion vessel, the recirculation pump, electric heating element an accumulator for hot water, fuel silo and heat radiators are located and are represented in figure 3. [20] [21]

Table 4. Technical specifications of the biomass boiler. (System 2)

Model		BioClass HM
Useful power	Kw	91,4
Nominal power	Kw	25,3
Performance	%	95
Power partial load	Kw	6,9
Electric power	W	485
Minimum return temperature	ºC	25
Minimum chimney shot	Pa	10
Minimum chimney shot	Pa	20
Water chamber volume	L	73
Fuel 100%	Kg	5
Pellet fuel capacity	Kg	180
Weight	Kg	300

2.2.2. Flow Diagram. The basic installation to cover the same energy demand conditions as the heat pump, is described in figure 2 and 3, where the most significant components are shown. To acquire knowledge about the different processes that occur in the biomass boiler are shown in figure 5 and 6.

Figure 5. Process flows of the biomass boiler.

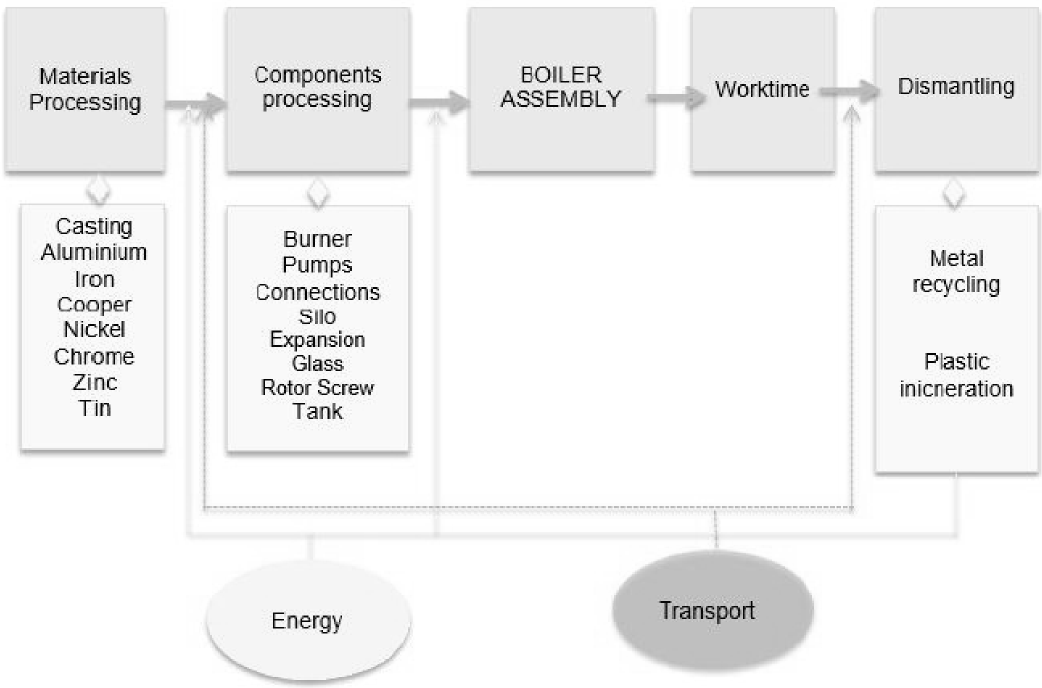
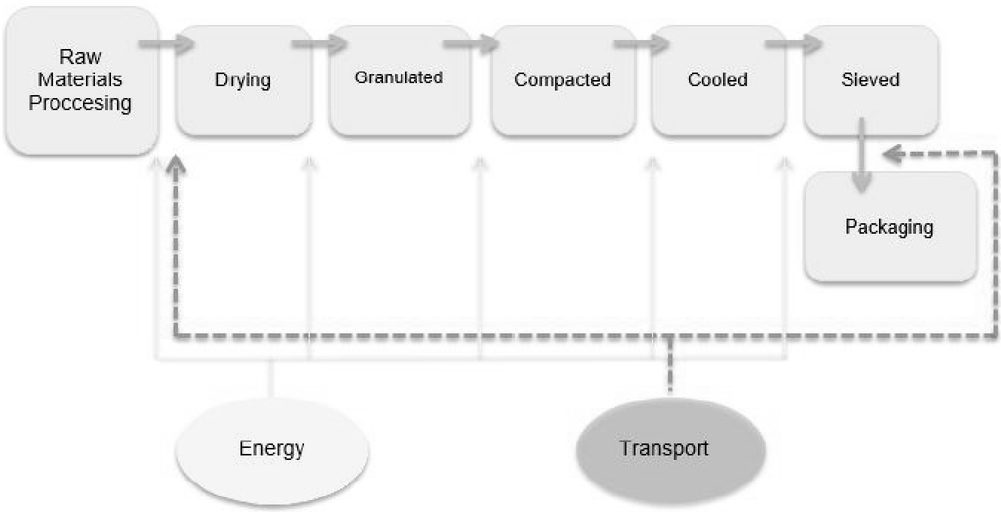


Figure 6. Process flows of the pellets [22] [23]



2.2.3. Inventory Analysis. Next, it have been described the most significant parts and materials which the studied system is composed, expressing the quantities of each element and the entire set, as it can observed in Table 5. These data have been obtained from the manufacturer by means of estimating the consumption during their life cycle and of the databases from SimaPro software. This way, all the necessary data is obtained which is needed for the subsequent introduction in the calculation software. The manufacturing and distribution site of the boiler in Ezerril (Guipúzcoa, Spain) has been considered.

Table 5. Inventory during the life cycle of the biomass boiler.

Inventory			
Concept	Boiler + Accumulator	Silo	TOTAL
RAW MATERIALS (kg)	BIOCLASS NG 25	Tipe S	
Dimensions	670 x 670 x 1310	405 x 685 x 1525	
Iron	147,4	66,93	214,28
Aluminium	72,88	5,39	78,28
Cooper	30,8	16,12	46,93
Níquel	17,88		17,88
Crome	10,24		10,24
Polyethilene	8,43	2,1	10,53
Zinc	5,65		5,65
Tin	3,44	3,68	7,12
Lead	1,47		1,47
PVC	0,99		0,99
Rubber	0,87	0,43	1,3
Total	**300**	**94,67**	**394,67**
Energy			MJ
Oil (Boiler, 1 MW)	2.145,35	830,52	2.975,87
Industrial Natural gas (>10	1.850,07	875,55	2.725,62
Medium Voltage Electricity	242,2	55,98	298,18
Transport			tKm*
Truck (40 t)	25,9	2,35	28,25
Van (<3,5 t)	32,75	3,1	35,85
Train			
Waste (public incinerator)			KG
Polypropylene	7,64	1,92	9,56
PVC (Polyvylchloride)	0,12		0,12
Rubber	0,65	0,21	0,86
Atmosphere emissions			MJ
Residual Heat	224,15	87,9	312,05

tKm*. This unit is the transport of 1 ton of material per 1 Km.
For the calculation of transport, the factory in Guipúzcoa, Spain has been considered.

2.2.4. Energy consumption. To make a correct comparative study, it is necessary that the energy demand of the two systems is the same. Thus, it have been calculated the amount of biomass consumed by the boiler from the data obtained in the section "annual energy consumption of system 1".

3. *Methods*

In this section it have been analysed and quantified the results of the inventory. This process will allow to obtain environmental indicators from the list of emissions and consumed resources caused by two systems during their life cycle. In this way it will find it easier to understand. For this transformation it have been used two methods of impact evaluation, which will change the way in which results are classified and presented.

Table 6. Presentation of different methods (according to reference [24])

Methods	**Information**
CED	Non-renewable and renewable impact categories
Greenhouses gas protocol	GHG Emissions
IPCC 2013	GWP (global warning Potential)
USEtox	Human and eco-toxicological impacts
Ecological footprint	Nuclear energy use, CO_2 emissions, Land occupation

CML-IA	Midpoint approach
IMPACT 2002+	Combination midpoint/Damage approach
ReCiPe	Combination midpoint/damage oriented (endpoint) approach
EPS 2000	Damage-oriented product declaration
EI99	Damage-oriented approach

Analysis of environmental impact. The aim of this section is to determine all the possible environmental impacts related to the parameters obtained in the previous section. This study will be carried out in accordance with priority strategies of the two methods, the Eco-indicator99 and the EPS 2000 [25] [26], and to the following sequence of tasks: classification, characterization (indicators are selected according to each category of impact), standardization and valuation. The choice of these methods is due to several reasons. 1) Perform a sensitivity analysis. 2) Compare similar impact categories, and 3) Obtain a final impact value.

3.1 LCA methods applied to the systems

3.1.1. Eco-Indicador99 Method. Classification and hazard characterization. For human health by means of Disability-adjusted life years (DALY), using estimates of the number of years lost. Damages to the quality of the ecosystem are expressed in relation to species which have disappeared in a defined area and time, principally vascular plants and simple organisms. The following categories of impact are added in damages to the ecosystem: Ecotoxicity, acidification, eutrophication and the occupation of the land. From the obtained values, and which are summarized in Figure 5, it can see the greatest impacts on climate change, depletion of the ozone layer and fossil resources in the boiler system, while human health relative impacts and to ecosystems are higher in the heat pump boiler. [27] [28]

3.1.2. EPS 2000 method. This methodology has as priority environmental strategies for the design of products and was developed in 1989 by the Environmental Research Institute of Sweden in cooperation with Volvo and the Swedish Federation of Industries. Since then, it has been modified several times, offering a more effective and extensive. The latest version of the EPS method evaluates the impact on the environment through its effects in one or several human health themes. The categories of impact are identified from the following issues: production capacity of the ecosystem (including information relating to agriculture, fish or meat, and the decrease in timber field), protection of human health (including human diseases), natural resources and abiotic resource in stock, with the environmental cost, resources and biodiversity (including the extinction of species). [29] [30]

Table 7. EPS 2000 method

	Factor categories	**Units**
Ecosystem Production Capacity	FDP*	$PDFm^2yr$
Human Health	DALY**	Person/yr
Resources	Resources Damage	MJ/Kg
Biodiversity***	Agotamiento	$PDFm^2yr$

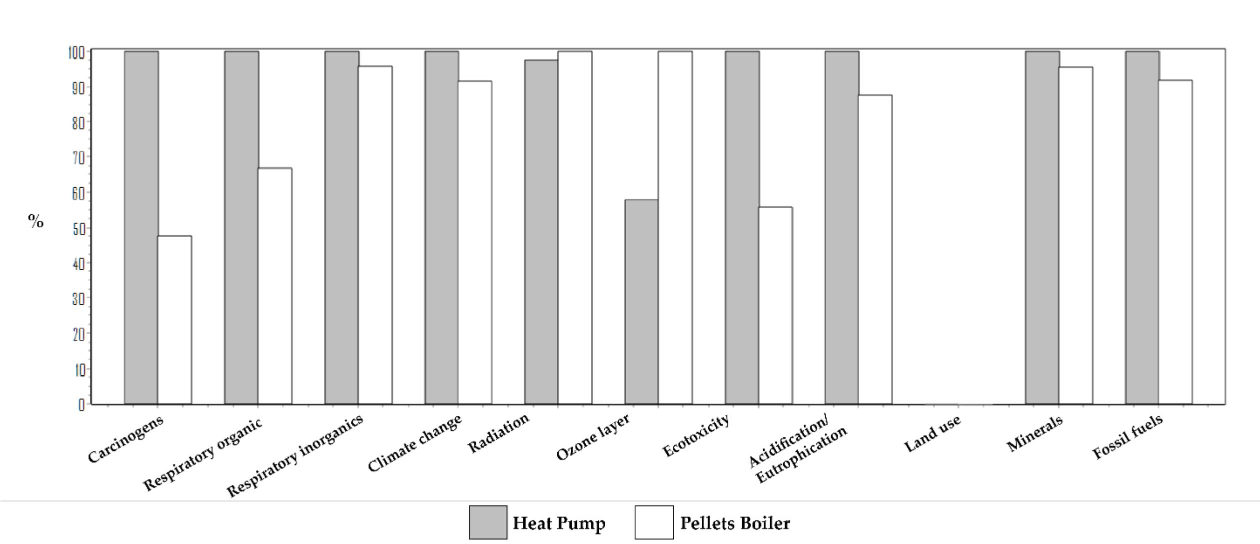
* Potencially Disappered Fraction per area and year
**Disability-adjusted life year.
***Climatic resources, geological and geographical features. (Biodiversity)

4. *Results*

4.1.1. Eco-Indicador99 Method results. It have been obtained global results and proceed to compare the different impact categories.

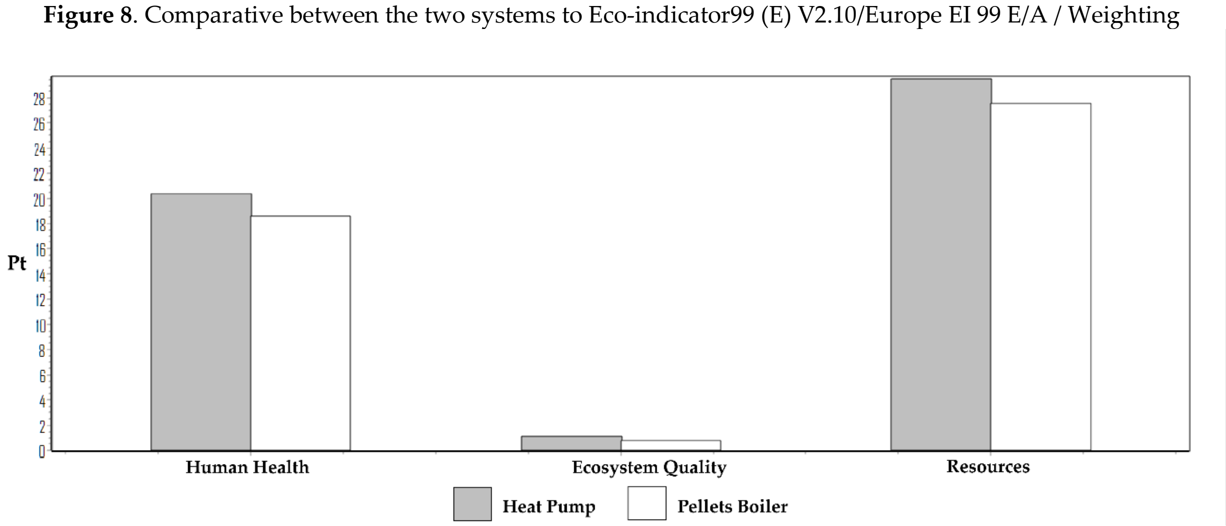
Characterisation. In this method eleven damage categories can be study and they are measured in different units. The figure 7 shows the comparative diagram and it can be performed a first analysis of the results. System 1 (heat pump) has greater impacts on 8 indicators, while the system 2 (pellets boiler) exceeds it by 2 (radiation and ozone layer).

Figure 7. Comparative analysis of impact indicators according to the Eco-indicator99 (E) V2.10/Europe EI 99 E/A /Characterisation



Weighting. The three categories, human health, ecosystem quality and depletion of damaging resources have different units [31] [32]. The calculation of values of normalization is based on emissions data measured in various European countries, and then carry out an extrapolation at European level to estimate the total European emissions per year/inhabitant. Figure 8.

Figure 8. Comparative between the two systems to Eco-indicator99 (E) V2.10/Europe EI 99 E/A / Weighting



Single score. In this step, the relative importance of each category of impact is determinate. The unit called the Eco-point indicator (Pt) is used. It should be noted that the absolute value is not very relevant, because the main objective is to compare the relative differences between the products or components.

Figure 9. Comparative using the Eco-indicator (E) V2.10 / Europe EI 99 E/A Single Score

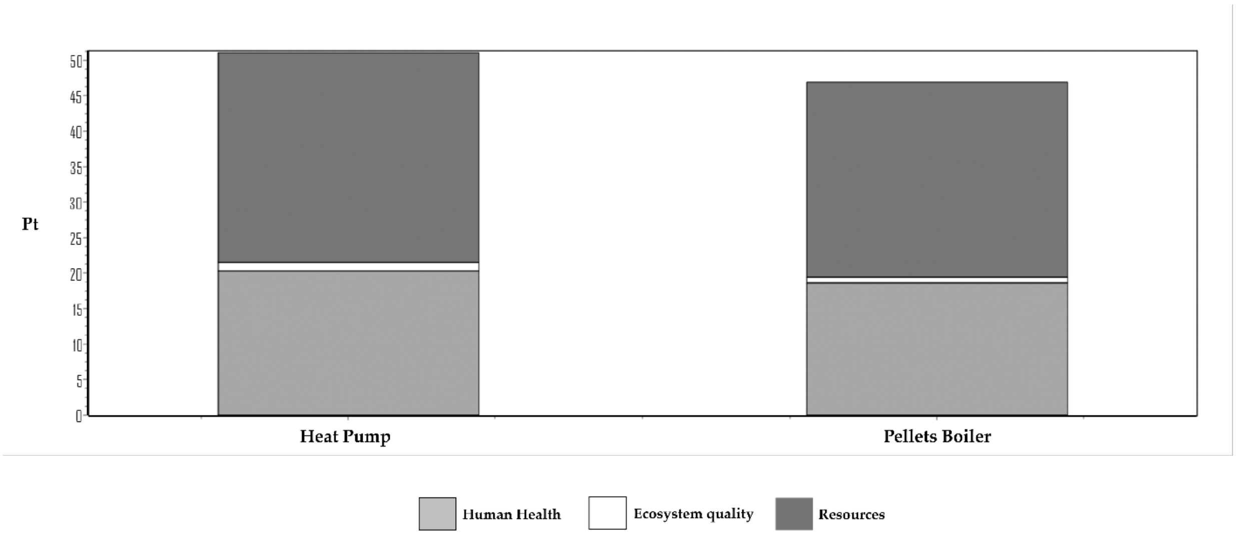


Table 8 summarizes the obtained values for the systems and the % of products that cause the greatest environmental impact, obtained through the single score.

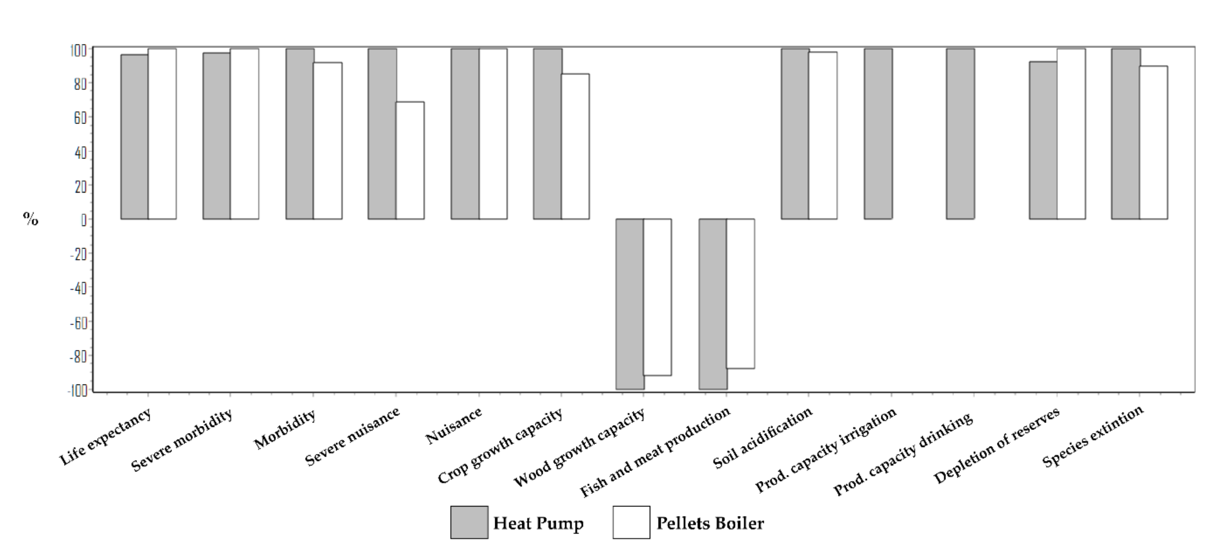
Table 8. More affected categories and the more weighed factors related to the Energetic consumption (Eco-indicador99)

Damage Category	Units (Pt) Bomb	Units (Pt) Boiler	% of the greater environmental impacts
Inorganic substances (respiratory effects)	60,91	63,94	Emissions to the air NO_x (45,23%), SO_x (42,56%), Particulate <10um (12,21%)
Combustibles	66,93	50,76	Mining Petroleum (60.55%), Natural gas (23,54%), Coal (15,91%)
Carcinogenesis	30,99	64,42	Emissions al water As (12,78%), Ni (3,45%), Phenol (2,34%) Emisiones al aire As (44,55%), Ni (26,65%), Cd (10,23%)
Climatic Change	27,05	23,20	Emissions al air CO_2 (78.56%), CH_4 (12.55%), HCFC-22 (8.89 %)

4.1.2. EPS2000 Method results.

In Figure 10 it can observe how it have been obtained very similar results of environment impact between two systems, and show two negative values due to the renewable nature of the systems and the fuel used as heat generation. The graphic shows process units with negative characterization factors (%). They are wood growth capacity and fish and meat production Information related to thirteen environmental indicators are obtained too.

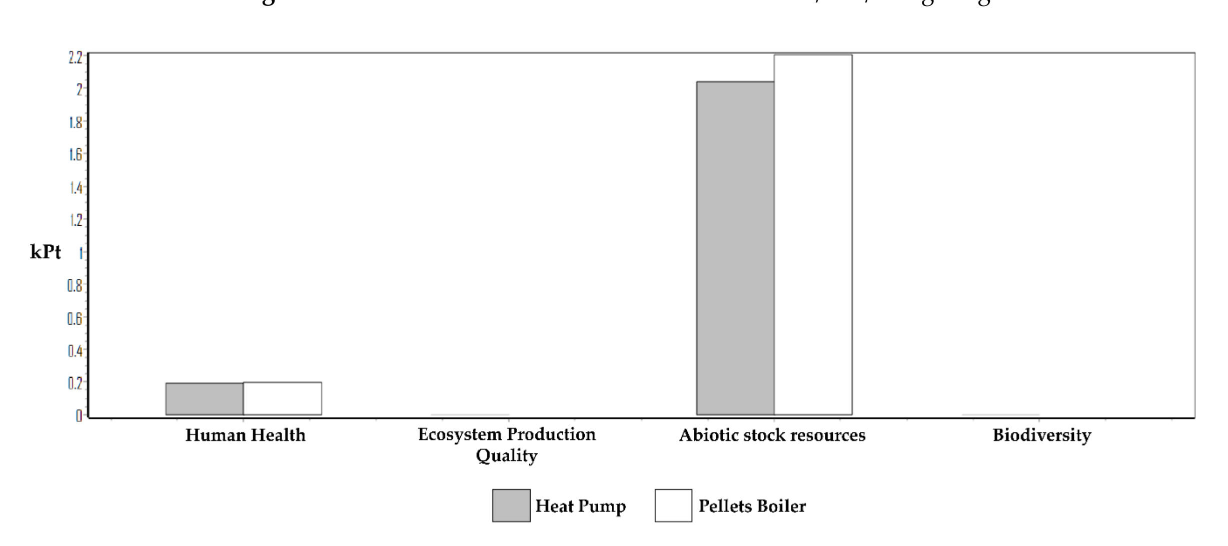
Figure 10. Comparative contribution with the methodology EPS2000 V2.08/ EPS /Characterisation



Weighting. For the four categories, which this methodology considers, ecosystem quality, human health, natural resources and depletion of the resources, it have been obtained obtain the necessary information in figure 9. In this method, the weighting is performed through valuation. Environmental reference is the current state of the environment, being ELU (environmental loading unit) the indicating unit. This methodology allows an anticipated study of the systems to the obtaining of a better design and additional information with regard to the choice of the systems.

Figure 10 indicates the greatest impact takes place in the reduction of abiotic resources and corresponds to the biomass boiler system. The other category of important impact would be human health, being the impacts practically negligible in the quality of ecosystems and biodiversity.

Figure 11. Consideration with EPS2000 Method V2.08 /EPS/ Weighting



Single score. In this step, the relative importance of each category of impact is determinate. A unit called Eco-point indicator (kPt) is used. It should be taken into account that the absolute value of the points is quite irrelevant, as the main aim is to compare relative differences between the products or components. Figure 12.

Figure 12. Single puntuation with Method EPS2000 V2.08 /EPS/ Single Score

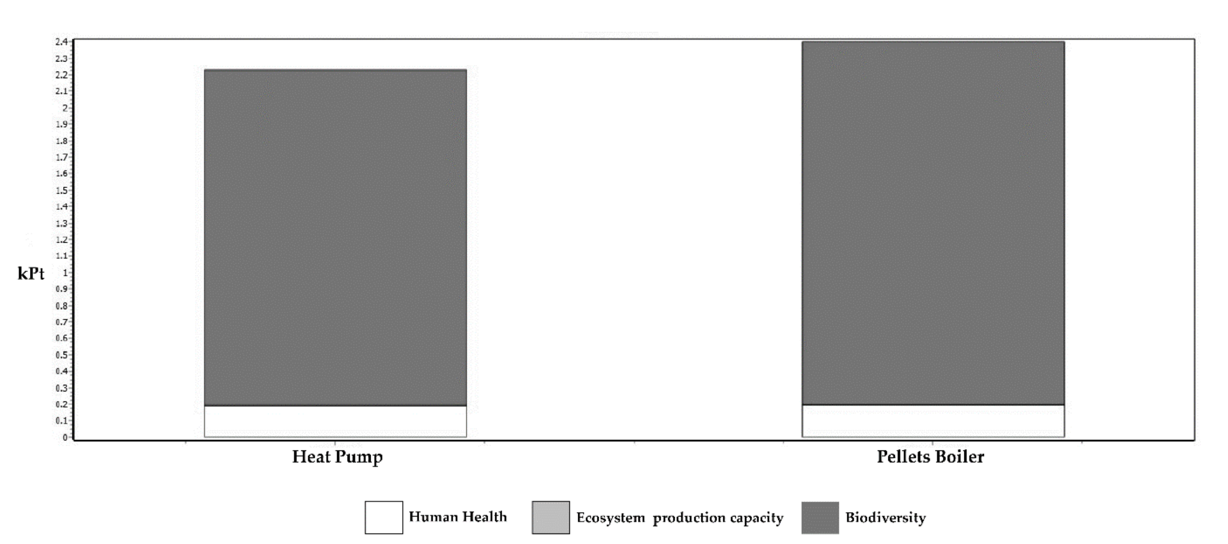


Table 8 shows the values for the methodology, as well as the products they produce these impacts.

Table 9. Most significant values of environmental impacts (EPS2000)

Damaged Categories	Units (kPt) Bomb	Unit (kPt) Boiler	% of the greater environmental impacts
Human health	0,195	0,215	Emissions to air CO_2 (60,15 %), PAH Polycyclic aromatic hydrocarbons (66,5%)
Exhaustion of Resources	2,05	2,28	Mining Petroleum (62,55%), Coal (22,98%), Natural gas (14,47%)

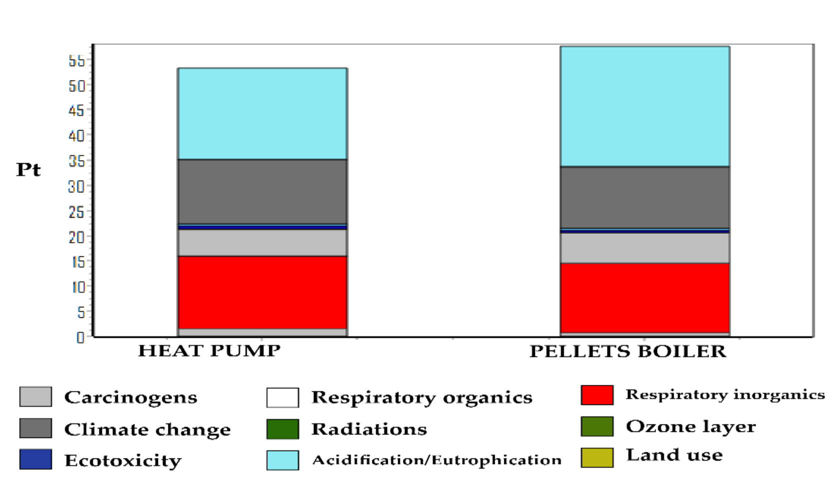
4. Discussion

Once the results on environmental impacts of two systems of heat production are obtained and carrying out a study by using two methodologies, it can be analyze and determine the most significant conclusions. To simplify results, contributions to environmental impact indicators, the values have been sorted into four groups. The performed analysis included the different stages of life of each one of the constituents of the heat pump and boiler, but it must be borne in mind that the variation of conditions of their use as well as the length of operational lifetime may change the results.

As common point to the results obtained thought both methodologies, it can be determine, according Figure 12 that energetic consumption in the form of electricity is the most relevant factor for the LCA heat pump, being the impact in biomass boiler lower, due to the use of pellets combustion material. On the other hand, air emissions to the atmosphere produced by the boiler system are quite more significant than in a heat pump.

The Eco-indicator99 indicates that the consumption of fossil resources are the 41.92 % for biomass boiler and a 34.34% for heat pump, and are the main impact factor, which is increased to 58.3% with the consumption of minerals, respiratory effects caused by inorganic substances air emissions such as SOx and NOx, together with climatic change due to CO_2 emissions, which show higher values for biomass boiler system with a value of 23.6%. Finally, with lower values, carcinogenic, with a 5.10%, due to heavy metals emissions in air and water. The quality of ecosystems is mainly affected by Ecotoxicity (4%), acidification and eutrophication (1.8%) and land occupation (0.2%). Damages caused by Ecotoxicity are chiefly because of heavy metals emissions in air and water, while the damages by acidification and eutrophication are principally owing to NOx and SOx emissions.

Figure 13. Relative importance system with the Eco-indicator99 (E) V2.10 /Europe EI99E/A /Single score

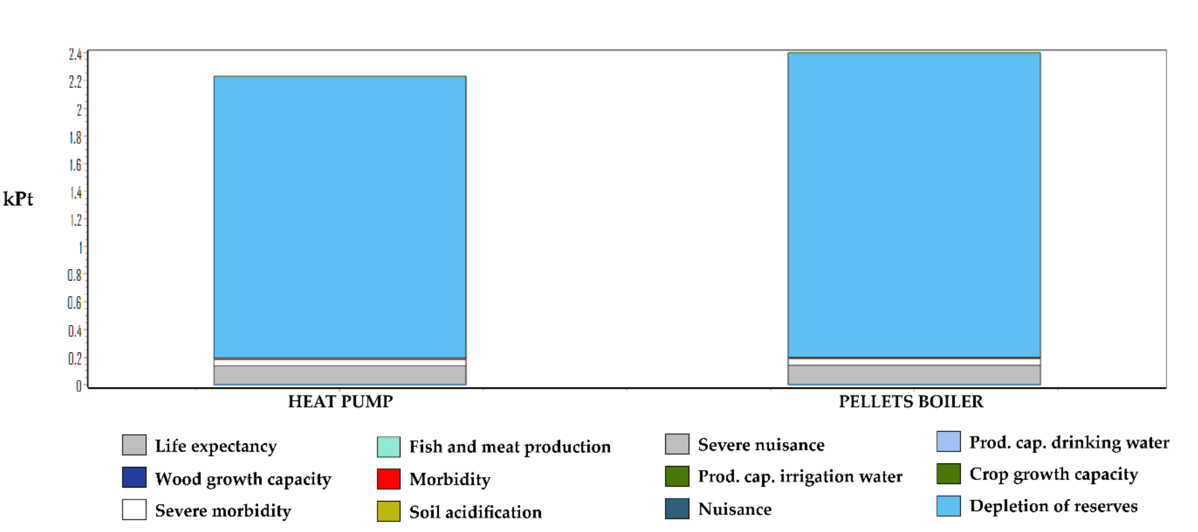


Another negative factor of the heat pump system are the copper minerals (mainly present in batteries and pipes) which represents the elements with greater weight, as well as the impact on the reduction of the ozone layer, which has been reduced with respect to other studies [33], with a 22% of the contributions because of the use of R410a coolant.

EPS2000, on the basis of figure 14, it can be taken into account that the results are quite similar for both systems. Highlighting the energy consumption, the use of the coolant, CO_2 emissions to the atmosphere and the use of resources for their manufacture, as aspects of greater impact. The variation in the climatic conditions is an important point to take into account, since it directly affects the consumptions of the heat pump system and therefore depletion of reserves impacts.

According to this methodology, and unifying the similar values for both systems, the main damage take place with the exhaustion of resources during the manufacturing and their operation, reaching 72% of the total contribution. Life expectancy implies of the 6.22%, principally affected by CO_2 emissions during the generation of electricity, while the severe morbidity represents only 3% of the total.

Figure 14. Relative importance system with method EPS2000 v2.08/EPS/Single Score



5. Conclusions

The building sector and specifically the tertiary buildings have one of the greatest influences in Climate change. For this reason, this comparative research LCA is carried out. The study, analysis and redesign of energy production systems in this sector could reduce their emissions and reduce their environmental impact. [34]. LCA methods with two methodologies has been used in the present work to determine the impacts of two systems of production of heat, a heat pump system and a biomass boiler system. Despite different methodologies used, the result has confirmed that:

1. Similar impacts occur in the systems, appearing differences in individual components. [35].
2. The main damage of the two systems take place during the manufacture and operation of the boiler pellet, in the category of resource depletion, as well as CO_2 emission, which causes climate change.
3. In addition it have been obtained impacts on human health, respiratory effects caused by the emission into the air of inorganic substances such as SOx and NOx and carcinogenesis that are practically are similar in the two systems.
4. There are significantly different in specific aspects like the use of material, product or fuel, as for instance, coolant, oils or pellets.
5. In response to % of mayor value, it can affirm that the pellet boiler cause higher impacts during its manufacture, because of great quantities of materials and energy for the manufacture of their components, as well as the necessary extraction of resources, rising CO_2 emissions. While other minor impacts are, on life expectancy and the use of coolant in the heat pump.

References

[1] IEA (International Energy Agency), Energy Efficiency Market Report 2015, OECD/IEA, 2015.

[2] Edwards, B. *Rough guide to sustainability*. 3rd ed. RIBA Enterprises, London, 2010.

[3] European Commission, Communication from the Commission. Europe. 2020-A Strategy for Smart, Sustainable and Inclusive Growth, Brussels, 3.3.2010 COM, 2010, 2020 final.

[4] Chr. Lamnatou, D. Chemisana. Concentrating solar systems: Life Cycle Assessment (LCA) and environment issues. Renewable and Sustainable Energy Reviews. http://dx.doi.org/10.1016/j.rser.2017.04.065.

[5] Análisis de diversas metodologías de evaluación del impacto del ciclo de vida. Vivancos Bono, JL.; Collado Ruiz, D.; Bastante Ceca, MJ.; Gómez Navarro, T.; Capuz Rizo, S. Departamento de Proyectos de Ingenieria. Universidad Politécnica de Valencia. jvivanco@dpi.upv.es.

[6] Ferguson G. Subsurface energy footprints. Environ Res Lett 2013; 8(1). Art. No.014037.
Cherubini F, Bright RM, StrØmman AH. Global climate impacts of forest bioenergy: what, when and how to measure? Environ Res Lett 2013; 8(1) art.no.014049.

[7] European Commission (EC), On Resource Efficiency Opportunities in the Building Sector, COM, Brussels,2014,Available,htpp://ec.europea.eu/environement/eussd/pdf/SustainableBuildingsCommunication.pdf

[8] ISO 14000. https://www.aenor.com/certificacion/medio-ambiente/gestion-ambiental.

[9] P. Quinteiro, L. Tarelho, P. Marques, M. Martín-Gamboa, F. Freire, L. Arroja y A. Cláudia Dias. «Life cycle assessment of wood pellets and wood split logs for residential heating». Science of the total environment. Elservier. 2019.

[10] A. Schereiber, J. Marx y P. Zapp. «Comparative life cycle assessment of electricity generation by different wind turbine types». Journal of cleaner production. Elsevier. 2019.

[11] J. Antonanazas, M. Arbeloa-Ibero y J.C. Quinn. «Comparative life cycle assessment of fixed and single axis tracking systems for photovoltaics». Journal of Cleaner Production. 2019.

[12] P. Fullana y R. Puig, Análisis de Ciclo de Vida, Barcelona, España: Rubes, 1997, p. 144.

[13] I. P. o. C. Change, Climate Change, Geneva, Switzerland: IPCC, 2014.

[14] Catálogo técnico de la empresa Mitsubishi. https://es.mitsubishielectric.com/es/

[15] IDAE. (2016). Ministry of Industry, tourism and commerce. Technological map: renewable heat and cold. Technology area: biomass and waste. http://www.idae.es/

[16] F. J. Rey, J. Martín-Gil, E. Velasco, D. Pérez, F. Varela, J. M. Palomar y M. P. Dorado, «Life cycle Assessment and External Environmental Cost Analysis of Heat Pumps,» ENVIRONMENTAL ENGINEERING SCIENCE, vol. 21, nº 5, 2004.

[17] Study of the Technical Feasibility of Increasing the Amount of Recycled Concrete Waste Used in Ready-Mix Concrete Production. Fraile-García, E.; Ferreiro-Cabello, J .; López-Ochoa, L.M.; López-González, L.M. Materials. 2018.10, 7, 817, DOI: 10.3390/ma10070817.

[18] Ruiz Amador, Diego; Zúñiga López, Ignacio. Análisis de ciclo de vida y huella. UNED. ISBN-13: 978-8436265637.

[19] RITE, Reglamento de Instalaciones Térmicas de los Edificios y sus instrucciones complementarias., Decreto 1027/2007, 31 de julio. Directiva 1751/1998.

[20] Technical documentation of manufacturer. https://www.domusateknik.com/es/gestor/recursos/uploads/.../catalogos/.../bioclass.pdf

[21] Díaz-García, A.; Martínez-García, C.; Cotes-Palomino, T. Properties of Residue from Olive Oil Extraction as a Raw Material for Sustainable.

[22] L. Paolotti, G. Martino, A. Marchini, A. Boggia. Economic and environmental assessment of agro-energy wood biomass supply chains. Biomass and bioenergy. 2017. 0961-9534 Elsevier. http://dx.doi.org/10.1016/j.biombioe.2016.12.020.

[23] M.C. McManus. Life cycle impacts of waste wood biomass heating systems: a case study of the three UK based systems. 2010. Elsevier. 0360-5442/$. http://10.1016/j.energy.2010.06.014

[24] Lamnatou, C. ; Lecouvreur, B.; Chemisana, D.; Cristofari, C.; Canaletti, JL. Concentrating photovoltaic/thermal system with thermal and electricity storage: CO_2.eq emissions and multiple environmental indicators. *Journal of Cleaner Production*. **2018.** *192*, 376-389. DOI: 10.1016/j.jclepro.2018.04.205.

[25] Souliotis, Manoils; Arnaoutakis, Nektarios; Panaras, Giorgios; Kavga, Angeliki; Papaefthimiou, Spiros. Experimental study and Life Cycle Assessment (LCA) of hybrid Photovoltaic/Thermal (PV/T) solar system for domestic applications. Renewable Energy. 2018. DOI: 0960-1481. Hppts://foi.org/10.1016/j.renene.2018.04.011.

[26] Pieragostini, C.; Mussati, M.C.; Aguirre, P. On process optimization considering LCA methodology. *Journal of Environmental Management* **2012**, *96*, 43-54. DOI: 10.1016/j.jenvman.2011.10.014.

[27] Jolliet, O.; Margni, M.; Charles, R;. IMPACT 2002+: A new life cycle impact assessment methodology. *International Journal of Life Cycle Assessment*. **2003.** *8*, 324. DOI: 10.1007/BF02978505.

[28] Steen, B. (1999b). A systematic approach to environmental priority strategies in product development (EPS). Version 2000. General system characteristics. Gothenburg. Chalmers University of Technology, p.67. Disponible en http://pre.nl/simapro/impact_assessment.metods.htm.

[29] M. Goedkoop y R. Spriensma, «Teh eco-indicator 99. A damage oriented method for Life Cycle Impact Assessment: Metholodogy annex. 17 april.,» p. 142, 2000ª.

[30] Laso, J.; García-Herrero, I.; Margallo, M.; Vázquez-Rowe, I.; Fullana, P.; Bala, A.; Gazulla, C. ; Irabien, A.; Aldaco, R. Finding an economic and environmental balance in value chains based on circular economy thinking: An eco-efficiency methodology applied to the fish canning industry. *Resources Conservation and Recycling*. **2018.** *133*, 428-437. DOI: 10.1016/j.resconrec.2018.02.004.

[31] Marique, Anne-Francoise; Rossi Barbara; Cradle-to-grave life-cycle assessment within the built environment: Comparison between the refurbishment and the complete reconstruction of an office building in Belgium. Journal of Environmental Management. 2018. DOI: 0301-4797. Hppt://doi.org/10.1016/j.envman.2018.02.055.

[32] Bare JC, Hofstetter P, Pennington DW, de Haes HAU (2000) Midpoints versus endpoints: the sacrifices and benefits. Int J Life Cycle Assess 5(6):319-326.

[33] Kumbhar, S.; Kulkarni, N.; Rao, A.B.; Rao, B. *4º International Conference on Advances in Energy Research* (ICAER 2013). Indian Inst Technol Bombay, Dept. Energy Sci & Eng. **2014.** Mumbai, INDIA. *54*, 260-269. DOI: 10.1016/j.egypro.2014.07.269.

[34] D. Ruíz, G. San Miguel, B. Corona, F.R. López. LCA of a multifunctional bioenergy chain based on pellet production. 2017. 00167-2361. Elsevier. https://doi.org/10.1016/j.fuel.2017.11.050.
[35] Construction Materials. Part I: Physical Properties. *Materials*. **2017.** *10,* 2. 100. DOI: 10.3390/ma10020100.