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Comparative Study on the Environmental Impact of Traditional Clay Bricks Mixed with Organic Waste Using Life Cycle Analysis

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Abstract: The construction industry is responsible for 40–45% of primary energy consumption in Europe. Therefore, it is essential to find new materials with a lower environmental impact to achieve sustainable buildings. The objective of this study was to carry out the life cycle analysis (LCA) to evaluate the environmental impacts of baked clay bricks incorporating organic waste. The scope of this comparative study of LCA covers cradle to gate and involves the extraction of clay and organic waste from the brick, transport, crushing, modelling, drying and cooking. Local sustainability within a circular economy strategy is used as a laboratory test. The energy used during the cooking process of the bricks modified with organic waste, the gas emission concentrate and the emission factors are quantified experimentally in the laboratory. Potential environmental impacts are analysed and compared using the ReCiPe midpoint LCA method using SimaPro 8.0.5.13. These results achieved from this method are compared with those obtained with a second method—Impact 2002+ v2.12. The results of LCA show that the incorporation of organic waste in bricks is favourable from an environmental point of view and is a promising alternative approach in terms of environmental impacts, as it leads to a decrease of 15–20% in all the impact categories studied. Therefore, the suitability of the use of organic additives in clay bricks was confirmed, as this addition was shown to improve their efficiency and sustainability, thus reducing the environmental impact.

Keywords: life-cycle analysis (LCA); sustainable materials; sustainability; climate impact; bioclimatic architecture

1. Introduction

Building and road construction is responsible for the consumption of almost half of the raw materials and energy throughout the planet [1]. Consequently, construction has a great impact on the depletion of finite resources, in addition to the production of greenhouse gas emissions from the combustion of fossil fuels. In order to reduce the associated greenhouse gas emissions and resulting impact on the climate, it is necessary to use environmentally sustainable building materials [2,3].

The baked clay have been widely used in the construction of houses traditionally, since it is an economical product that uses cheap raw materials (clay, sand and water) and a simple manufacturing process of firing. However, since the arrival of clay bricks in the 1980s, the market for clay-based bricks has started to decrease, which is also partially due to construction systems that are based on exterior enclosures of concrete blocks. Nevertheless, the producers found technological barriers due to their limitation as insulating objects, in addition to an inability to use them in low height buildings due to weight limits [4–6].

Nowadays, in the context of sustainable development and with thermal regulations, it is necessary to develop new construction materials with high thermal and mechanical performance. The incorporation of by-products or waste from different origins has been evaluated to improve these properties [7].

Historically, there are studies that have applied LCA to the materials used for the construction of buildings since the 1970s, especially in Germany [8–10]. Thus, life cycle analyses have been carried out in residential sectors, such as houses [11] or single-family homes [12], to establish strategies for reducing gas the emissions in residential sectors through new construction structures in hot and humid conditions [13].

Following the above strategies, studies are being carried out in the United Kingdom using LCA, which have demonstrated that introducing materials of biological origin, such as hemp, into the manufacture of construction materials can reduce the environmental impact. Hemp is a natural resource that has recently been used as a low environmental impact material in a series of composite products and as an insulating element in exterior wall construction of buildings [14–16].

It should be noted that during the brick manufacturing process, the thermal decomposition of the pore-forming agents (drying and firing stages) leads to an increase in the porosity of the material [17] and thus increases its insulating capacity [18–20].

Current environmental sustainability policies and associated concepts of bioclimatic architecture as well as social concern for general environmental aspects (global warming, increased damage to the ozone layer and the accumulation of waste) have caused the construction industry to be increasingly sensitive and obliged to consider new construction materials that reduce energy consumption, which requires the creation of innovative products that are sustainable. In fact, in Europe, the construction sector is responsible for 40–45% of primary energy consumption, which comprises a significant proportion of greenhouse gas emissions [21,22]. The use of sustainable materials would contribute to reduce these gas emissions.

With such expectation, some studies were carried out that have applied the LCA methodology for analysing the production of cellulose nanofibers as an organic biofuel additive to prevent the use of plastic materials. A previous study found the reduction in greenhouse gases by up to 75%; the reduction in production costs by 12%; and a 2- to 5-fold improvement in the energy efficiency of production [23]. In addition, the LCA model is currently being applied in numerous studies, such as one by Tsinghua University that aims to calculate the life-cycle fossil energy consumption and greenhouse gas emissions in China [24]. These studies promote that it is necessary to evaluate the environmental impact of construction materials using the LCA technique. Many scientific studies that use the LCA methodology compare different materials, highlighting those with a smaller impact on the environment [25,26].

The manufacture of new materials that reduce environmental impact by incorporating organic waste from other processes allows economic and social development in rural areas that generate such waste products [27].

A smaller impact on human health results from the reduction of environmental impacts in the processes of extraction and use of resources, the reduction in energy consumption and consequently, a reduction in the emission of CO_2 into the atmosphere [28].

The improvement of local industrial activity, which is based on traditional and sustainable materials with a smaller environmental impact, is the basis of the new models of Sustainable Circular Economy [29].

The objective of this research is to apply the LCA methodology to new samples of clay with the incorporation of biomass in order to determine new construction materials from the viewpoints of sustainability [30,31].

2. Materials and Methods

In this study, different samples of ceramic material have been used in bricks, which are made with products and resources from the nearby geographic area (Bailén, Jaén). The manufacturing process, including extraction, sieving, drying and firing of the materials, has been carried out in a similar way to industrial manufacturing so that the results can be extrapolated to greater production levels.

LCA is an adequate methodology to determine the environmental impact that occurs throughout the life cycle of products, services or processes. It also allows the determination of the impact of any phase independently from the rest [6].

To this end, a comparative study has been carried out between a sample made exclusively with 100% clay and a mixture composed of 15% barley components (leftovers that remain after the seed has been extracted from the cereal) and 85% of the base clay mixture (brick with red clay (BYRC)), which is called BB15 (Barley bagasse 15) [32].

These materials have been selected due to their low cost, availability and close location to the research centre. For this reason, the transport costs of the organic waste that are framed within a strategy of local circular economy, in which the Province of Jaén is involved in the recovery and reuse of this type of biological waste, have not been taken into account. Furthermore, during the firing process, the organic material degrades under the thermal effect, which produces pores that increase the sample's insulation capacity [33]. Thus, this results in reduced thermal bridging and improved energy efficiency in the construction of sustainable housing [34].

2.1. Development of Fired Clay Samples

The first sample is a reference sample without additives (BYRC). It contains 100% clay, which originated from Bailén (Jaén, Spain). Clay has been provided by a company in the sector. It was crushed to obtain a powder with particles of approximately 3 mm in order to promote thermal conductivity [35,36].

For the second sample (BB15), 85% of the reference sample (BYRC) was separated, to which 15% of barley bagasse was added as an additive and mixed in a laminator to improve the homogeneity, obtaining a sample with a biological basis.

The bagasse was provided by the Heineken brewery (Jaén, Spain) located in Jaén's capital. It was crushed and sieved to obtain a milling of less than 0.5 mm. The amount of incorporated additive was chosen to be consistent with previous studies [37–39].

The required amount of water was added to obtain the desired moisture and plasticity that are necessary to avoid defects in the structure during the process. Subsequently, the samples were modelled by an extrusion process in the form of tablets (175 × 79 × 17 mm), dried at the temperatures of up to 105 °C and finally fired by increasing the temperature progressively for 11 h until the maximum temperature of 920 °C was reached. The samples remained at this temperature for 1 h afterwards according to the industrial recommendations of the ceramic sector.

The clay and waste were milled with an analytical mill (IKA MF-10) and later separated by size using ASTM (American Society for Testing Materials) standard sieve series (ASTM mesh/size mm: 3.50/5.60, 4/4.75, 6/3.35 and 7/2.8) and a CISA (Cedaceria Industrial S.L., Barcelona, Spain) screening (model RP-15). The instrument had a tolerance error of ±2%. Besides, each used sieve had an error of ±5%. A sample of 100 g of solid was sieved. The analysis was conducted according to the standard UNE-EN 933-2.

After this, the samples were shaped using a pneumatic laboratory extruder Nannini Renato TP-01 model, dried at the temperatures of up to 105 °C in an oven (CR MARES S.A. 204 Model) and finally, the sintering of these test specimens was performed in an electric chamber furnace (NABERTHERM LA 60/14 model) with increases in temperature as follows: 3 °C/min from room temperature to 400 °C; 2 °C/min from 400 °C to 700 °C; 1 °C/min from 700 °C to 920 °C and maintaining the temperature steady at 920 °C for 1 h.

2.2. Life-Cycle Analysis (LCA)

The life cycle analysis was carried out using the ISO 14040 standards (Table 1) to define the principles and framework and according to ISO 14044 to describe the different stages of the analysis [40–42].

Table 1. ISO 14040. Resource AENOR.es.

Standard	Description	Edition
ISO 14040:2006	Environmental Management. Life Cycle Assessment. Principles and Framework.	2006
ISO 14044:2006	Environmental Management. Life Cycle Assessment. Requirements and Guidelines.	2006
ISO/TR 14047:2012	Environmental Management. Life Cycle Assessment. Illustrative examples on how to apply ISO 14044 to impact assessment situations.	2006

2.2.1. Objective and Scope

The LCA of the brick products including organic waste was carried out in the present study, which followed the process to obtain the clay samples. The study was aimed to analyse and compare the environmental impacts of the different formulations and identify the unit of the process that presents the strongest environmental impact in an ecological design approach, as the main environmental benefit in construction is to reuse the bricks and recycle the aggregates [43].

In order to build an inventory of production and establish the scope of the study, the functional unit is defined as the production of 1 kg of clay with a fixed thermal resistance.

The LCA methodology allows the determination of the environmental impact of the processes, products or systems analysed in different ways. Essentially, one can analyse certain stages of the life cycle or analyse the entire cycle. The present investigation focused only on the impact associated with the production of the new samples, thus performing the "cradle to gate" studies.

The studied system used the raw materials (clay, sand, water and vegetable matter) from the laboratory and takes into account the energy consumed in production (sieving, drying and firing). In order to overcome the potential limitations, the initial hypotheses are defined as follows:

- The electricity used considers that the production mix corresponds to the Spanish energy production system.
- The cleaning of the different devices used in the process is dismissed since it is not a considerable percentage.
- The transport of material has been considered. For each component of the material, the relevant distance covers from the point of processing or extraction of quarry to the study laboratory for calculation purposes [44].

The evaluation of the life cycle impact of the use of bagasse for brick construction was carried out using LCA SimaPro software 8.30 [45], which is widely used [46].

2.2.2. Life-Cycle Inventory

For the life cycle inventory, all inputs and outputs of the system were listed for the different stages of the life cycle. Figure 1 shows a flow diagram of the different steps of the process with the associated flows, while Figure 2 shows the inputs, which are also called foreground data that have their own life cycle. These environmental impacts (background data) are taken into account for the overall evaluation of the life cycle of the product [47,48].

The inventory data were obtained directly from the experiments or through the use of data collected from industrial producer partners or from bibliographic references. The consumption data of the different processes are shown in Table 2.

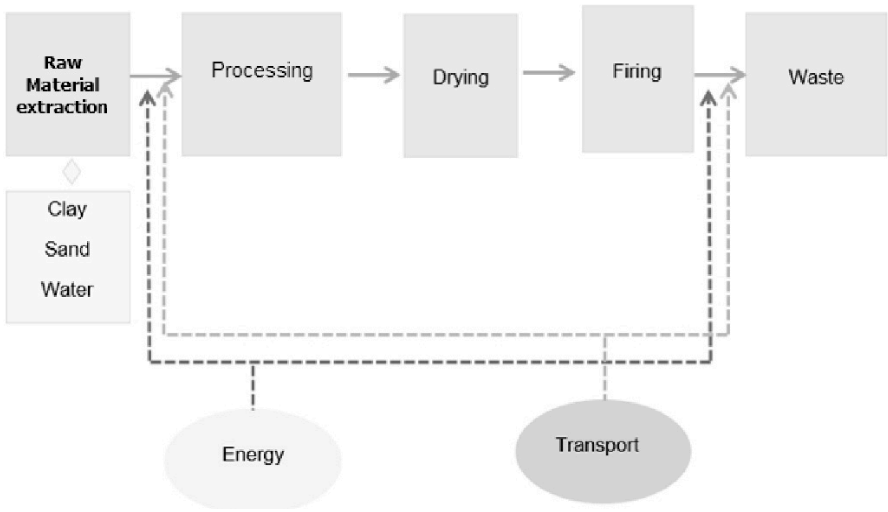

Figure 1. Clay cycle.

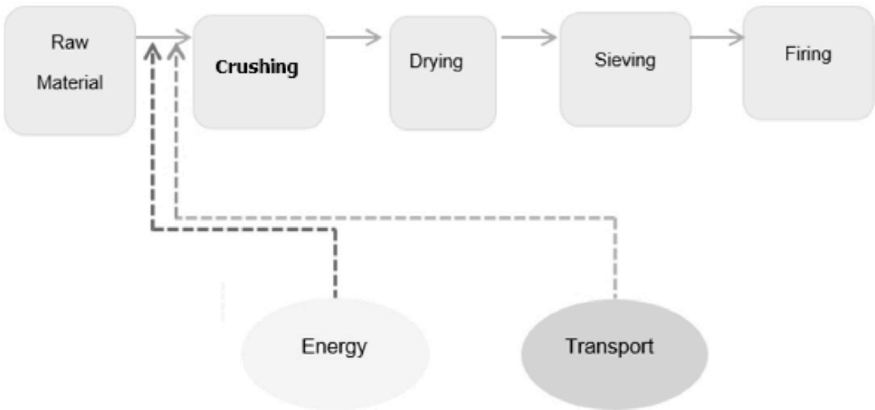

Figure 2. Barley cycle.

Table 2. Inventory data of the different processes.

Inventory Data				
Concept				
Raw Materials (kg)	**BYRC (kg)**	%	**BB15 (kg)**	%
Mix clay + sand	0.683	68.30	0.662	66.20
Barley			0.021	2.10
Water	0.317	31.70	0.317	31.70
Total	1.00	100.00	1.00	100.00
Energy (MJ)				
Cutting			0.335	
			0.121	
Crushing	0.250		0.333	
Drying	0.083			
Firing	25.400		21.515	
Total	25.733	100.00	22.304	100.00
Transport (tKm*)				
Lorry (3.3 t)	6.66×10^{-5}		1.88×10^{-5}	

tKm*: This unit represents the transport of 1 tonne of material for 1 km.

2.2.3. Impact Evaluation

The objective of the present study is to compare the results obtained by the two methods. On the one hand, the IMPACT 2002+ method considers the four categories of damage-oriented impact—human health, ecosystem quality, climate change and resources—separately. On the other hand, the ReCiPe Endpoint v1.12 method considers only three categories of damage-oriented impact: human health, ecosystem quality and resources.

With the data previously provided, an evaluation of the environmental impact of the samples was carried out using software SimaPro 8.30. A comparative study was performed using two evaluation methods to check for possible differences in the results. The ReCiPe Endpoint v1.12 method was used first [49]. This method evaluated the damage caused in four impact categories, whose characteristics are described in Table 3 [30,44,50–52]. Impact 2002+ v2.12 was the second analysis method [53,54].

Table 3. Indicators of impacts according to ReCiPe Endpoint v1.12.

Impact Category	Category Indicator	Measurement Units
Quality of the ecosystem	FDP *	FDP/m^2 × year
Human health	DALY **	People/year
Natural resources	Damage to resources	MJ/Kg
Abiotic resources ***	Exhaustion	Kg

* Fraction of potential disappearance of the ecosystem per m^2 and year. ** Disability-adjusted life year: Reduction of years of life per person/year. *** Climatic, geological and geographical resources. Biodiversity.

3. Results

The objective of the study was to compare the environmental impact of the two formulations developed. The functional unit has been defined as the production of 1 kg of the porous sample, corresponding to that of the reference sample without the vegetable agent [19].

The brewing process consumes a considerable amount of energy and uses large volumes of water. The beer is fermented by selected yeasts from the barley malt, which is used alone or mixed with other starchy products that can be transformed into sugars by enzymatic digestion. Subsequently, the beer is subjected to a cooking process and added with hops and/or its derivatives [38].

Next, a mass balance is presented regarding water and energy inputs, as well as the outputs with respect to waste and by-products, liquid effluents, and emissions to the atmosphere (Figure 3) [39].

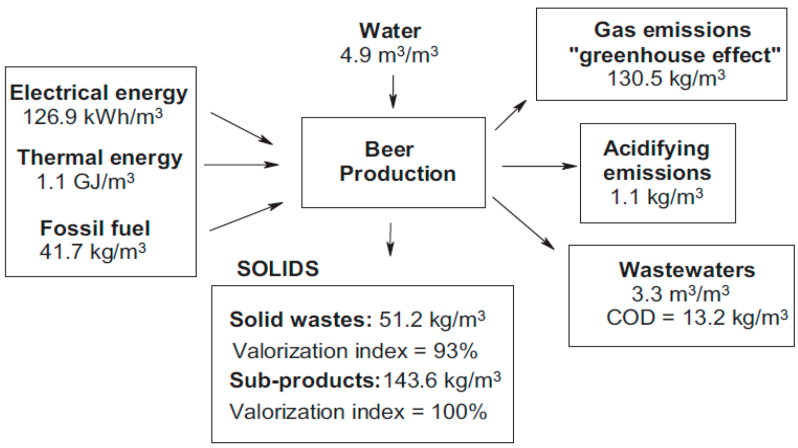

Figure 3. Mass balance with respect to brewing [39].

Bagasse is an organic fraction solid waste. During the total process of obtaining beer, 16.99–23.09 kg of waste is obtained for each hectolitre of bottled beer. As indicated above, this bagasse is a by-product of the brewing industry that results from the pressing and filtering process after the saccharification of cereal grain (barley, basically) malting. Its content in dry matter is 20–25%.

The residue from the brewing industry has a protein content of around 24–26% in dry matter. It is also rich in fibre as it has NDF (Neutral Detergent Fiber) content of 44% (cellulose, hemicellulose and lignin content of the cell wall) and FAD (Acid Detergent fiber) content of 20% (cell wall content estimator in cellulose and lignin). On the other hand, it has a lignin content of 5%, ash content of 7%, P content of 6 g/kg and Ca content of 3 g/kg. The metabolizable energy content is 2.86 Mcal/kg [38,39].

3.1. Method ReCiPe Endpoint v1.12

Once the inventory data have been entered, the SimaPro software and the ReCiPe Endpoint v1.12 method provides the results shown in Table 4 and Figure 4, where the contribution amounts provided by the different clay samples can be analysed in each impact category. These data were provided by the program once the different amounts of raw materials and processes were introduced [55].

Table 4. Analysis of the energy and non-energy resources of the comparative cycle of clay samples as a base.

Non-Energy Resources	BYRC	BB15	Energetic Resources	BYRC	BB15
Ammonium (g)	0	3.10	Low radioactive waste (mg)	399.75	344.64
NH4 (Kg)	0	0.026	Water power (g)	317	317
Calcite (g)	0	1.94	Barley (Kg)	0	0.15
Crushed stone (g)	14.43	10.54	Electric mix (MJ)	92.62	79.85
Ni (Kg)	16.15	13.92	Urea (g)	1.60	1.82

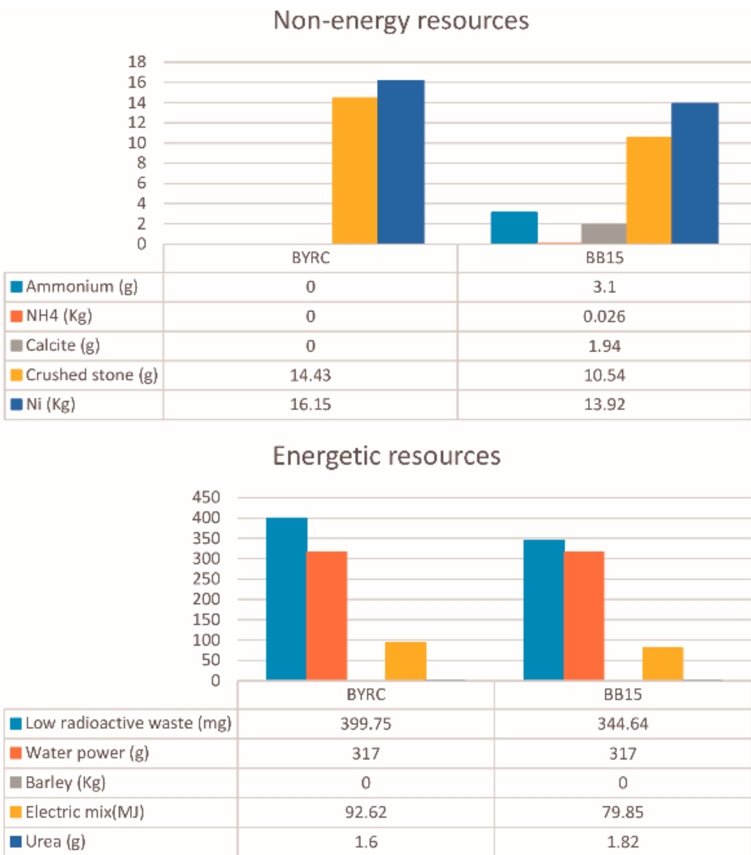

Figure 4. Comparative graphic analysis of the energy and non-energy resources of the comparative cycle of clay samples as a base using the first method, the ReCiPe Endpoint v1.12.

The general comparison of the scenarios represents the relative percentage in each impact category. The most impressive scenario in the category represents 100% and the others are calculated according to the latter. The comparison with the scenario of the BB15 sample using the ReCiPe Endpoint v1.12 method is presented in Figure 5.

The reference sample without a pore-forming agent shows a maximum impact in the 12 impact categories. Therefore, in the three categories of damage, namely human health, ecosystem and resources, there is a gap or difference of 10–22% compared to the other scenarios. In Figure 5, the impacts of the two samples are compared, which shows that the base sample (BYRC) usually produces a greater impact than the sample to which biological material has been added (BB15). Likewise, the electricity consumption is higher in the base sample, so the aspects related to resources are affected in the final result.

Figure 5. Comparative impact of the samples analysed with ReCiPe Endpoint v1.12 method.

In Figure 6, the impact of the samples on human health, ecosystem and resources is observed. In the base sample (BYRC), the impacts are slightly higher on human health, ecosystems, and resources, as compared with BB15 sample.

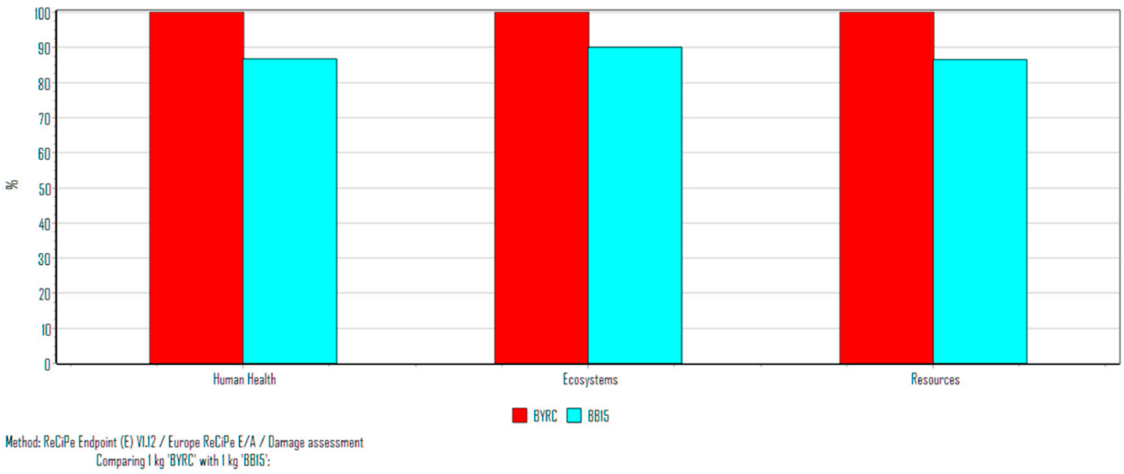

Figure 6. Damage assessment of the samples with ReCiPe Endpoint v1.12 method.

By performing an analysis of the samples using the single score, it is easy to determine the impact that each sample has on the three aspects with the ReCiPe Endpoint v1.12 method. As seen in Figures 7 and 8, the base sample (BYRC) has the greatest impact.

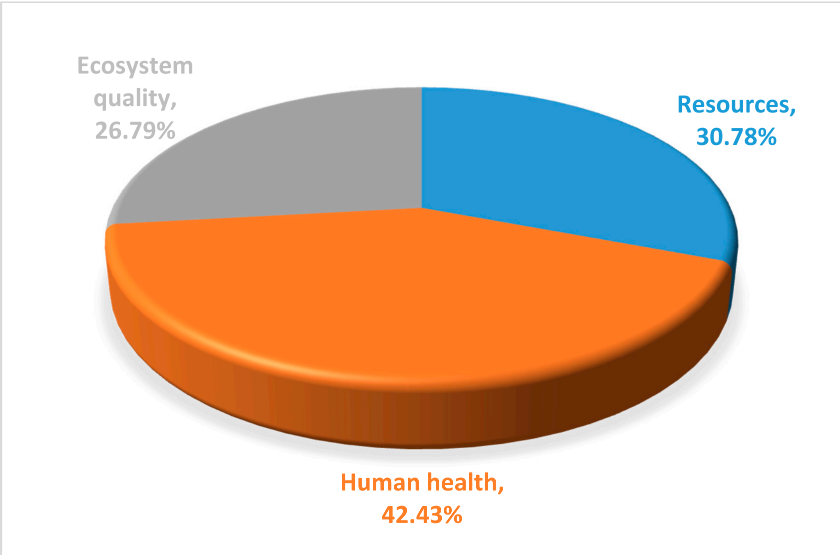

Figure 7. Contribution of BYRC base to each damage category as calculated using the ReCiPe Endpoint v1.12 method.

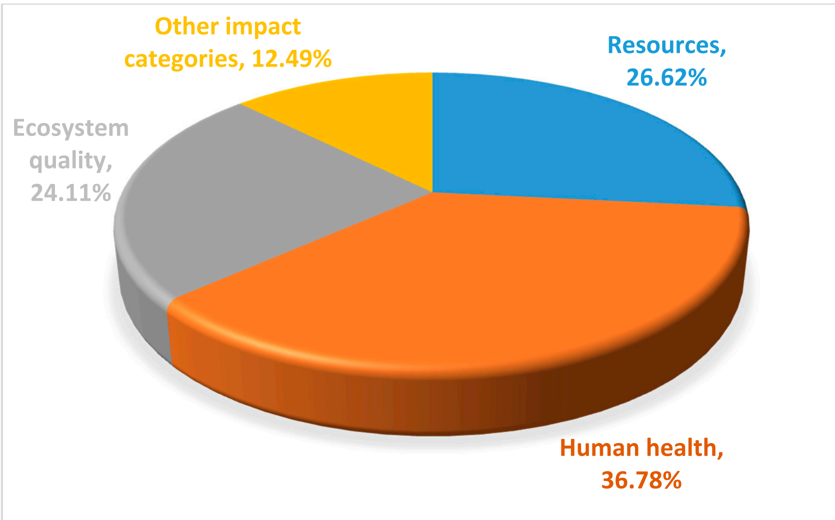

Figure 8. Contribution of BB15 base to each damage category as calculated using the ReCiPe Endpoint v1.12 method.

The results in Figures 7–9 and Table 5 show the quantities of the flows that have the greatest impact on resources, air emissions, and human health. The greatest impact is the emission of CO_2 into the atmosphere, which is mainly due to the electrical energy consumed in the firing phase, followed by the emissions of Methane, Sulfur Dioxide and Nitrogen Dioxide.

By analysing the different stages of the processes studied, the software gives the information about those that are responsible for the greatest impacts. The results are presented in Figure 9 and Table 5.

It appears that the cutting and the firing steps have the most significant impact on the life cycle of the products, representing 92–98% in the 15 categories of impacts (Figure 5).

Similar results were observed with Impact 2002+ methods (Figure 10). These results can be explained by the large consumption during cutting and firing, which is reduced in the BB15 sample due to the incorporation of organic matter.

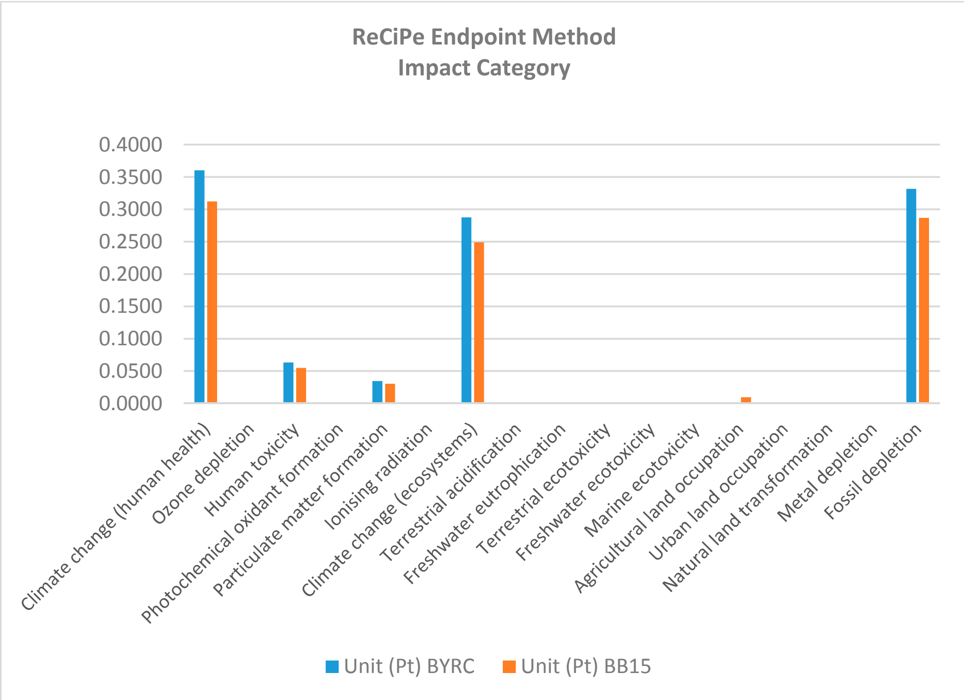

Figure 9. Impacts on the ecosystem as calculated using the ReCiPe Endpoint v1.12 method.

Table 5. Analysis of Impact category results calculated using the ReCiPe Endpoint v1.12 method.

ReCiPe Endpoint Method	Unit (Pt)	
Impact Category	**BYRC**	**BB15**
Climate change (human health)	0.3603	0.3122
Ozone depletion	0.0000	0.0000
Human toxicity	0.0633	0.0547
Photochemical oxidant formation	0.0000	0.0000
Particulate matter formation	0.0347	0.0304
Ionising radiation	0.0003	0.0002
Climate change (ecosystems)	0.2875	0.2491
Terrestrial acidification	0.0011	0.0010
Freshwater eutrophication	0.0000	0.0000
Terrestrial ecotoxicity	0.0002	0.0004
Freshwater ecotoxicity	0.0000	0.0000
Marine ecotoxicity	0.0008	0.0007
Agricultural land occupation	0.0000	0.0094
Urban land occupation	0.0000	0.0000
Natural land transformation	0.0000	0.0000
Metal depletion	0.0010	0.0008
Fossil depletion	0.3317	0.2869
Total	**1.0809**	**0.9459**

3.2. Impact 2002+ v2.12 Method

The Impact 2002+ method provides additional information about the factors that influence climate change. Figure 10 shows that of the 15 indicators, 11 contribute the greatest impact and correspond to the base sample (BYRC), while the samples with biological material show a higher impact in only 4. These results are practically similar to the impacts shown in Figure 11, which also includes the information on the damage of the samples due to climate change.

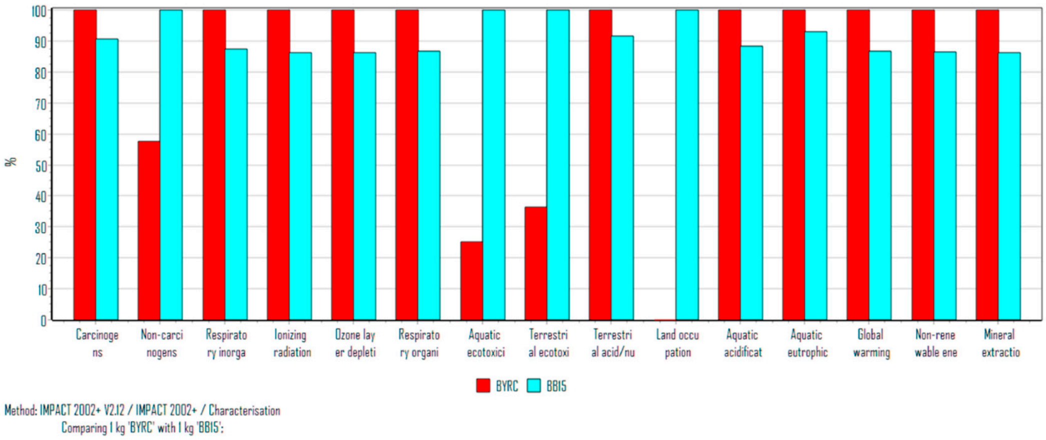

Figure 10. Comparative impact of the samples analysed with Impact 2002+ v2.12 method.

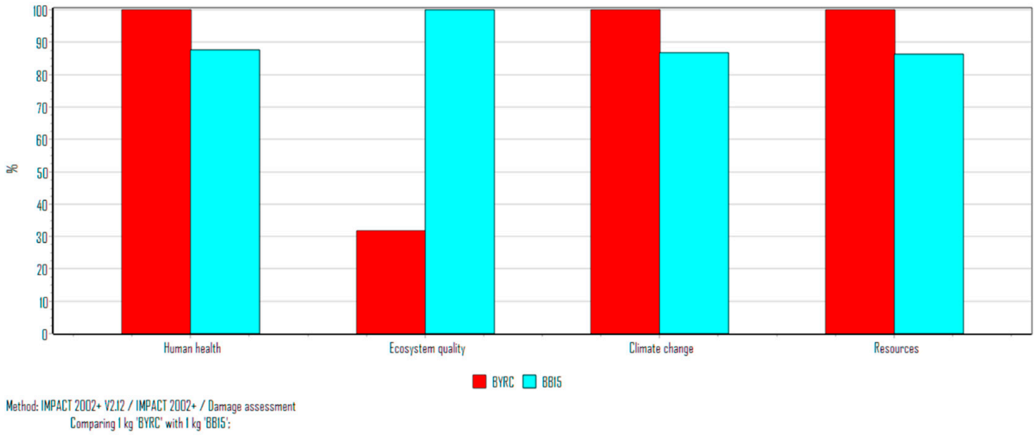

Figure 11. Evaluation of the damage of the samples with Impact 2002+ v2.12 method.

Figures 10 and 11 show how the results give similar percentages in the three categories of impact that are common to the two methods. There is a lower percentage in the sample with organic matter. However, the data given by the method of Impact 2002+ in terms of the quality of the ecosystems show that a much higher value was obtained for the sample BB15 (Figures 6 and 11).

Figure 12 and Table 6 show how the greatest impact on resources occurs, both for the extraction of raw materials and for obtaining the raw materials that are necessary to produce the electrical energy needed in the manufacturing processes of the new material.

Table 6. Analysis of Impact category results with Impact 2002+ v2.12 method.

Impact 2002+ Method	**Unit (Pt)**	
Impact Category	**BYRC**	**BB15**
Carcinogens	0.0005	0.0004
Non-carcinogens	0.0021	0.0036
Respiratory inorganics	0.6948	0.6077
Ionizing radiation	0.0048	0.0041
Ozone layer depletion	0.0001	0.0000
Respiratory organics	0.0006	0.0005
Aquatic ecotoxicity	0.0000	0.001
Terrestrial ecotoxicity	0.0035	0.0095
Terrestrial acid/nutri	0.0118	0.0108
Land occupation	0.0000	0.0275
Global warming	1.0675	0.9250
Non-renewable energy	1.2555	1.0851
Mineral extraction	0.0001	0.0001
Total	**3.0411**	**2.6744**

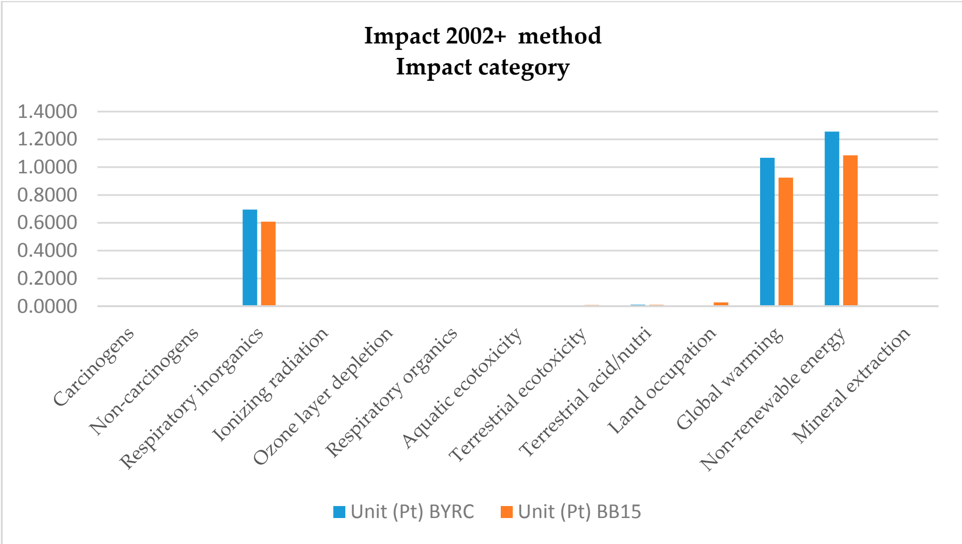

Figure 12. Impacts on the ecosystem with Impact 2002+ v2.12 method.

Comparing Figures 13 and 14, it was observed that a considerable improvement can be achieved in the reduction of the impacts in all categories, with the greatest improvement in resources.

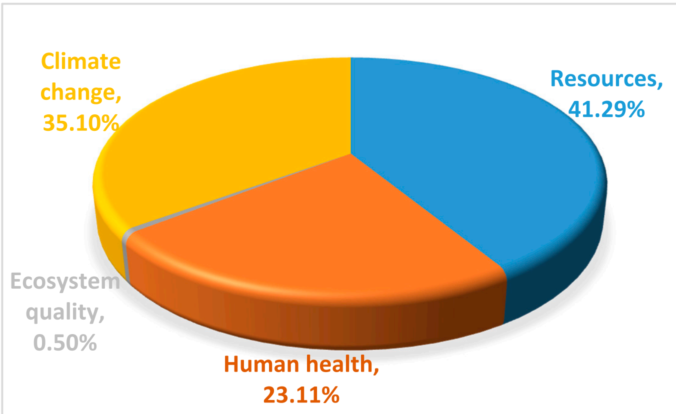

Figure 13. Contribution of BYRC base to each damage category as calculated using Impact 2002+ v2.12 method.

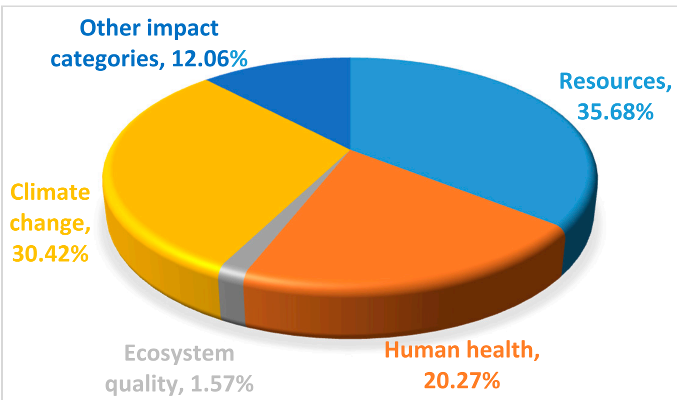

Figure 14. Contribution of BB15 base to each damage category as calculated using Impact 2002+ v2.12 method.

4. Discussion

To deduce the results of environmental impact, the physical and mechanical properties and heating values of the bagasse for both bricks were analysed (Tables 7–9).

Table 7. Physical and mechanical properties.

Firing Temp. (°C)	Waste (%)	Linear Shrinkage (%)	Weight Loss (%)	Suction (kg/m^2·min)	Water Absorption 24 h (%)	Boiled Water Absorption (%)
920	0	0.10 ± 0.05	9.20 ± 0.04	2.416 ± 0.068	13.78 ± 0.18	15.86 ± 0.14
	10	–0.16 ± 0.12	19.49 ± 0.05	4.174 ± 0.088	26.71 ± 0.16	33.34 ± 0.41

Table 8. Physical and mechanical properties.

Firing Temp. (°C)	Waste (%)	Open Porosity (%)	Bulk Density (kg/m^3)	Compressive Strength (MPa)	Thermal Conductivity (w/mK)
920	0	29.15 ± 0.26	1837.3 ± 1.10	42.00 ± 1.61	0.68 ± 0.02
	10	46.86 ± 0.40	1405.4 ± 0.99	9.20 ± 0.37	0.47 ± 0.01

Table 9. Heating Value (HV) of Bagasse.

Higher HV (Kcal/kg)	4761.5
Lower HV (Kcal/kg)	4362.9

Bulk density decreased but open porosity increased by the addition of residue. The addition of bagasse generated greater porosity due to its high content of organic matter. This can be seen in the weight loss of approximately 20%.

The samples of bagasse with addition of 10% of residue do not meet the minimum value of compressive strength of 10 MPa for ceramic bricks, which is the limit set by the Spanish Association for Standardization and Certification (AENOR), although this value is close to the required limit. This material could be used for the construction of the elements that should not withstand high loads.

The use of organic waste in the studied percentage decreases the capacity of bricks to the values of acceptable compressive strength. This is because the burning of organic waste creates more porous bricks [56]. However, the use of waste from brewing industries can provide environmental and economic benefits since it could be considered as raw materials to produce some new products. As shown in the aforementioned figures, the addition of organic waste can save energy because this waste has a higher heating value and, therefore, it could be said that the inclusion of waste in building material may contribute to sustainability from an environmental point of view [57,58].

These obtained results are consistent with the findings of other research that studied the potential environmental effect of waste valorisation through the development of ceramic materials compared with traditional ceramic materials [59].

5. Conclusions

In this investigation, the environmental impacts of two brick samples have been studied using life cycle analysis: one with a traditional sample and the other with a mixture of clay and organic waste. In addition, the results have been verified using two different methods.

For the biological sample, a vegetable additive, which was specifically barley bagasse, was incorporated into a traditional clay base in order to check for improvement in the aspects of weight and environmental contamination without modification of the physical and mechanical properties. The study focused on the environmental impact, which required Life Cycle Analysis using the ReCiPe Endpoint v1.12 characterization method and the Impact 2002+ method. It was observed that the incorporation of plant additives into the matrix decreases the impact by 15–20% compared with the reference sample.

The reduction in the impacts results from the lower use of the original raw materials since the incorporation of organic waste reduces the extraction of fossil materials. This occurs in the extraction phase.

In the production phase, the sample with organic waste needs to reach a lower temperature compared to the BYRC base. This is because the organic waste is burned and the pores are produced during the brick manufacturing process.

The two most important impacts that are reduced with the BB15 sample are the levels of CO_2 and Methane released to the atmosphere, which are responsible for the ozone layer depletion.

With the damage assessment, the obtained data show that the improvement in the quality of ecosystems was quite significant due to the use of organic waste, which could also lead to reduce the impact of climate change. Therefore, a clear reduction of the environmental impact is possible using a biological vegetable and clay mixed brick. It shows a reduction in the impact generated by obtaining and transforming the raw materials.

The use of organic waste in brick production would be a very interesting innovation in the field of sustainable construction as waste can be utilized to reduce its impact on environment. In the future, new sustainable building materials could be used in construction to study their real behaviour.

According to the results obtained and taking into account both sustainable development and the regulations on energy efficiency, it can be deduced that the development of new materials using by-products or wastes is necessary to facilitate their incorporation into the cycle of industrial life. This would reduce energy and resource consumption as well as greenhouse gas emissions.

The use of materials with a low cost and of a plant origin, which are also located close to the production centres, and their reincorporation into the manufacturing processes through the use of waste in a circular economy environment could become an opportunity for improvement and sustainable development in the future.

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