TECHNICAL AND ENVIRONMENTAL COMPARATIVE ANALYSIS BY LCA OF STONEWARE TILE AND MARBLE FLOORING

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1. ABSTRACT

The purpose of this study was to perform a comparative analysis, from a technical and environmental perspective, of flooring construction solutions with marble and porcelain stoneware tile.

The different types of flooring customarily used in residential building construction were defined and the regulatory requirements analysed. It was verified that the technical characteristics of both solutions met the minimum requirements for the use at issue (private residential use) and an analysis was conducted of the construction solutions with marble and ceramic floor tile from an environmental viewpoint. This was done by means of a life cycle assessment (LCA) using the Eco-indicator 99, EPS 2000, and CML 2 Baseline 2000 methods and defining the objectives and scope of the LCA study, performing the inventory analysis, life cycle impact assessment, and interpretation of the results. The SimaPro tool was used to perform the LCA.

The construction solutions to be analysed consisted of a resistant support or deck, impact-proof sheet membrane, mortar layer, bonding material, and finish material (marble or ceramic). Note that the environmental analysis was performed on the entire construction solution, establishing a functional unit of $1m^2$ construction solution of marble and porcelain stoneware tile flooring, respectively.

Although it was assumed that the flooring was installed in a building for residential use located in Castellón de la Plana, the inventory analysis conducted was representative of the whole national context, in terms of the technology used by the different Spanish ceramic tile manufacturing companies. When it was not possible to compile information on real data, the databases of the SimaPro program (BUWAL 250, ECOINVENT, ETH-ESU 96, and IDEMAT 2001) were used.

The results obtained by LCA indicate that the environmental impact of the stoneware tile construction solution was 3 times greater than that of the marble floor construction solution. The differences were even more noticeable when only the finish layer of the two construction solutions was considered. In the stoneware tile production process, a greater quantity of fossil fuel (mainly natural gas) is used than in the extraction and treatment of marble (mainly diesel). However, the latter has a greater environmental impact, particularly affecting the ozone layer depletion category.

The layer with the greatest impact throughout the entire service life cycle of both flooring construction solutions was that of the self-levelling cement mortar, so that to ameliorate the construction solution as a whole it is necessary to improve this layer. The stoneware tile finish layer in the flooring construction solution with stoneware tile also had a significant impact. The solution could be environmentally improved by using a thin ceramic because fewer raw materials would be used, with the ensuing reduction in impact owing to raw materials extraction. This reduction in thickness would also affect transportation, reducing its impact.

2. INTRODUCTION

The construction sector is responsible for the use of an important quantity of non-renewable resources and it is one of the main sources of waste and of air, soil and water pollution, the built environment accounting for 25 to 40% of energy consumption, a solid waste load of 30 to 40%, and a greenhouse gas emission load of 30 to 40% *(UNEP SBCI, 2009)*. It is therefore essential to reduce these percentages and to achieve more environmentally respectful construction, using resources in a sustainable way.

In the building design phase, a series of decisions are taken that affect the final building result. This is the phase in which every aspect of the building's construction solutions need to be evaluated, technically, as well as aesthetically, economically, and environmentally. This means that design is a singularly crucial phase for the incorporation of measures that foster sustainability, as it determines and conditions the activities that will subsequently be carried out. Although it is true that the technical criteria can (and must) be established in this phase of the construction process, there being legally binding regulations with relation to these technical criteria (and manufacturers are obliged to certify these), this is not the case with environmental criteria. This environmental aspect displays significant shortcomings. Project planners find it very difficult to incorporate environmental criteria because there are insufficient studies and too little information with scientific rigor quantifying the environmental impact of different construction solutions.

In order to make an appropriate decision when it comes to selecting a particular construction solution, the technical and environmental criteria must also be correspondingly related. That is, to enable comparison of the quantification of the environmental impact of one construction solution with that of another solution, the technical requirements of both must be equivalent.

Performance of such a technical and environmental analysis of two flooring construction solutions involving marble and ceramic tile allows the environmental impact of both to be quantified. This study facilitates decision-making of the different actors in construction from a sustainability viewpoint, which in turn contributes to mitigating the environmental impact of the construction sector, enabling it to be more respectful of the environment.

The objectives of this study were therefore as follows:

- Analysis of two construction solutions, namely a marble and a ceramic tile flooring, whose technical performance features were equivalent, from an environmental point of view.
- Comparison of the two construction solutions, obtaining environmental indicators for each impact category.
- Enabling each analysed construction solution to be compared with different flooring construction solutions, analysed with scientific rigor according to the same criteria and methodology.
- Enabling the results to serve as the basis of environmental criteria for the selection of construction solutions in building construction, reducing the environmental impact of the building as a whole and, therefore, of the construction sector in general.

3. METHODOLOGY

The methodology used to perform the environmental analysis of the flooring construction solutions with marble and ceramic tile was life cycle assessment (LCA). In this study, the SimaPro tool was used to conduct this LCA.

The requirements set out in standards UNE-EN ISO 14040 and UNE-EN 14044 were applied in performing the life cycle assessment (LCA).

The function of the construction solutions to be analysed was that of floor coverings, so that certain basic requirements of liquid tightness, slipperiness, soundproofing, and durability must be assured, these being established by different UNE standards and Spanish Technical Building Code (TBC) regulations.

The functional unit is defined as the quantified work performance of a product system for use as a reference unit. That is, the reference functional unit to which the two construction systems can be related. This reference establishes a common basis for system comparison. The functional unit must be measurable and is defined below.

In addition, to define the functional unit, the different solutions must also meet TBC requirements, as well as of those of the applicable UNE standards for the cases at issue.

The floorings to be studied were considered to be installed in interiors for use in dry zones in domestic dwellings. The functional unit was therefore considered to be as follows:

1m^2 flooring construction solution intended for general domestic use in a dwelling, according to the construction solution shown in *Figures 1* and *2.*

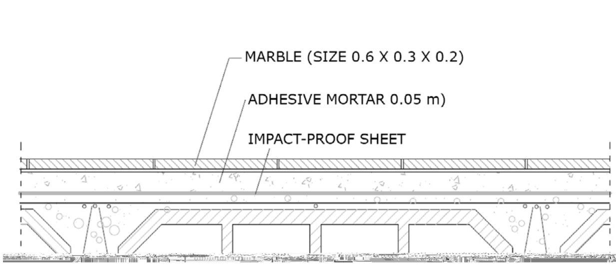

Figure 1. *Marble flooring construction solution.*

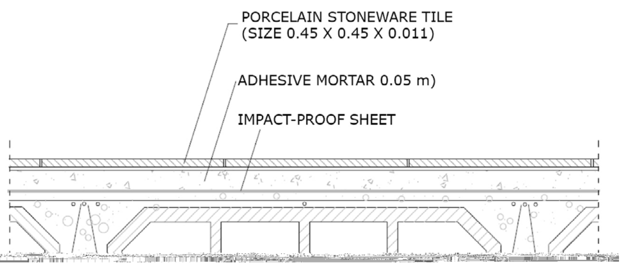

Figure 2. *Porcelain stoneware flooring construction solution.*

This dwelling is assumed to be in an apartment building located in Castellón de la Plana, consisting 6 floors and 400m^2 per floor, with a service life of 50 years.

The flooring solutions detailed above were selected for several reasons:

- The mechanical performance features of marble and stoneware tile are similar and comparable, as set out in the comparative analysis in Section *6. Regulations applicable to floorings*.
- Two widely used materials in the Spanish construction sector are involved, in buildings for public use as well as in buildings for private use.
- The extraction and production of both materials are of great significance in the Spanish economy, as the importance of the industries engaged in these activities is considerable, particularly in the Eastern region.

In order to draw up the inventory, all inputs of each element involved in each type of flooring, as well as maintenance for 50 years' service life, were considered for the building, in addition to disposal at the end of the building's service life.

The figures on the different materials and machinery involved were drawn from the manufacturers' technical information sheets. Further information, such as the location of the waste treatment plants or the final disposal of the construction elements after their service life, was obtained from the relevant Authorities responsible for each matter. With regard to the aspects relating to the actual execution of the construction solutions, the specifications of the applicable standards or regulations and the manufacturers' recommendations were taken into account. In addition, data were also used from the Buwal 250, Ecoinvent, ETH-ESU 96, and Idemat databases included in the SimaPro tool. In the case of the stoneware tiles, the inventory data compiled by 35 Spanish companies were used *(Figure 3),* whose representation of the Spanish ceramic sector has been statistically demonstrated, with a level of confidence of the average and standard deviation ranges of 95% (*Ibáñez et al., 2011).*

	Mine	Atomising plant	Glaze plants	Tile factories	Distribution	Installation and use	C&D waste
Non-renewable energy							
Electricity (kWh/m^2)	6.16E-03	−2.59E+00	9.99E−02	1.95E+00	0	7.88E−02	5.03E−02
Diesel (L/m^2)	2.00E-02	6.86E−03	1.26E−03	9.55E−03	5.07E−01	0	2.46E−02
Natural gas (kWh/m^2)	0	1.58E+01	1.29E+00	1.83E+01	0	0	0
Airborne emissions							
kg/m^2							
[illegible]							
CO	1.86E−05	2.12E−03	7.72E−05	9.90E−03	–	–	–
HF	0	3.69E−04	6.04E−06	1.80E−05	–	–	–
Pb	0	0	2.59E−05	3.25E−04	–	–	–
As	0	0	5.30E−09	5.48E−08	–	–	–
Hg	0	0	4.41E−09	3.49E−08	–	–	–
Cu	0	0	2.39E−07	2.16E−07	–	–	–
Cr	0	0	6.32E−08	1.46E−07	–	–	–
Hazardous and non-hazardous waste (kg/m^2)							
HW	5.46E−04	6.23E−04	3.90E−02	2.78E−03	–	–	0
NHW	8.82E−04	1.03E−02	2.17E−03	2.86E+00	–	–	4.15E
Water inputs and outputs (m^3/ m^2)							
Incoming water	5.39E−04	1.10E−02	7.25E−04	5.74E−03	–	–	0
Outgoing water	0	1.09E−03	1.84E−04	4.44E−03	–	–	0

Figure 3. *Inventory data for each life cycle stage of 1m^2 ceramic tile (Ibáñez et al., 2011).*

The environmental impact assessment of each type of construction solution was performed using the following standard life cycle assessment methods:

- Eco indicator 99
- EPS 2000
- CML 2 Baseline 2000

Using the three methodologies it was sought to compare the construction solutions in a more objective way, as several indicators were being used in different impact category scenarios.

4. RESULTS

The calculation of the results of the indicator involved the conversion of the results of the LCI (life cycle inventory) to common units and the sum of the converted results within the same impact category. This conversion used the characterisation factors. The calculation output was the numerical result of an indicator, the indicator varying according to the methodology used.

The results of the characterisation for each methodology used are shown in *Figures 4, 5* and *6* in the form of comparative graphs, jointly analysing the flooring construction solution with marble (green) and stoneware tile (red).

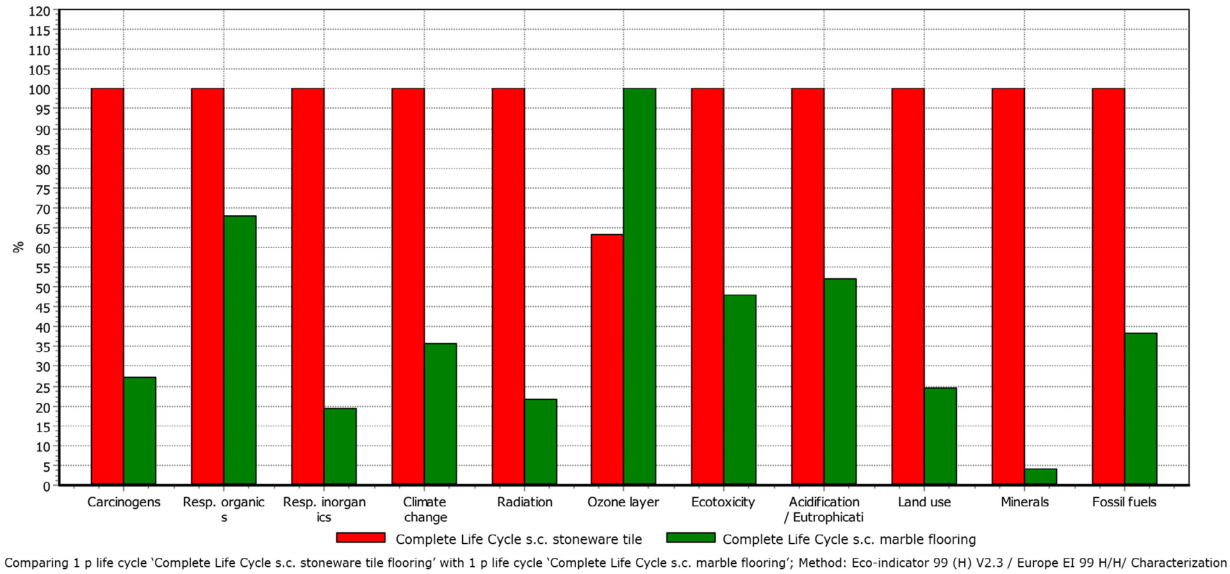

Figure 4. *Results of the characterisation with the ECO INDICATOR 99 methodology*

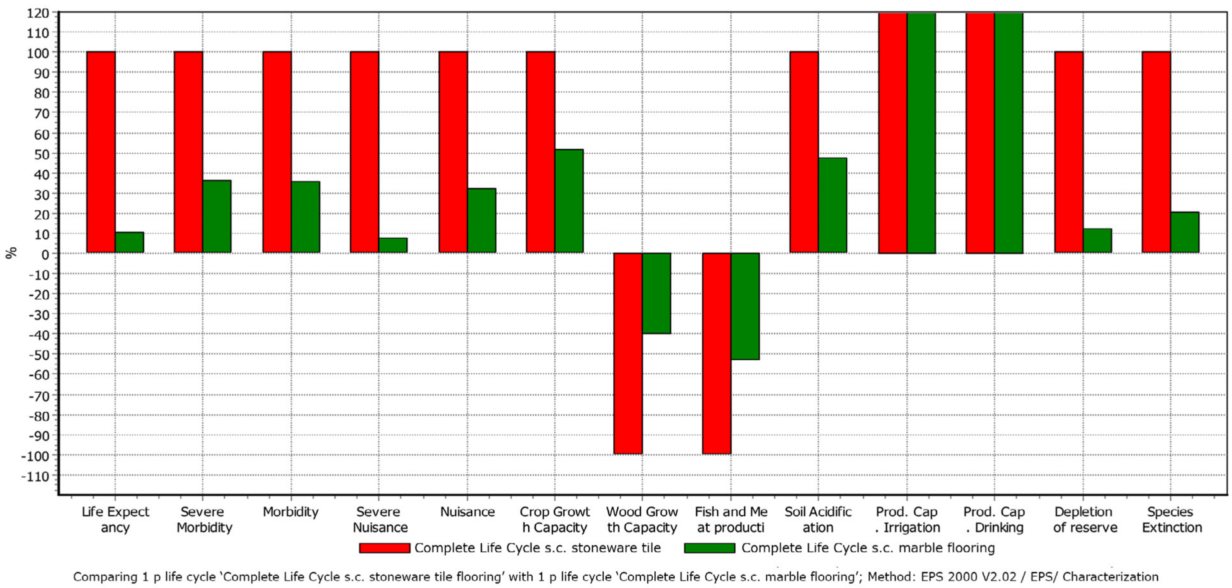

Figure 5*. Results of the characterisation with the EPS 2000 methodology*

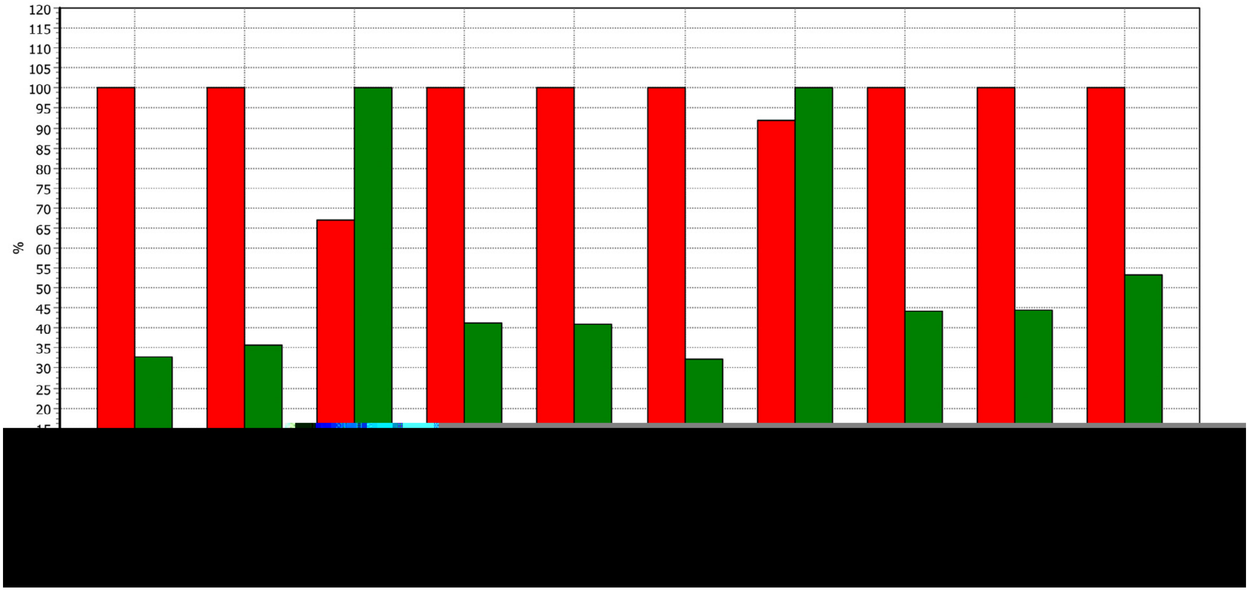

Figure 6. *Results of the characterisation with the CML2 BASELINE 2000 methodology*

The results of the normalisation, understood as the calculation of the magnitude of the results of the category indicator with relation to certain reference information, which allows the relative magnitude of each indicator result to be better understood, are shown in *Figures 7* and *8*.

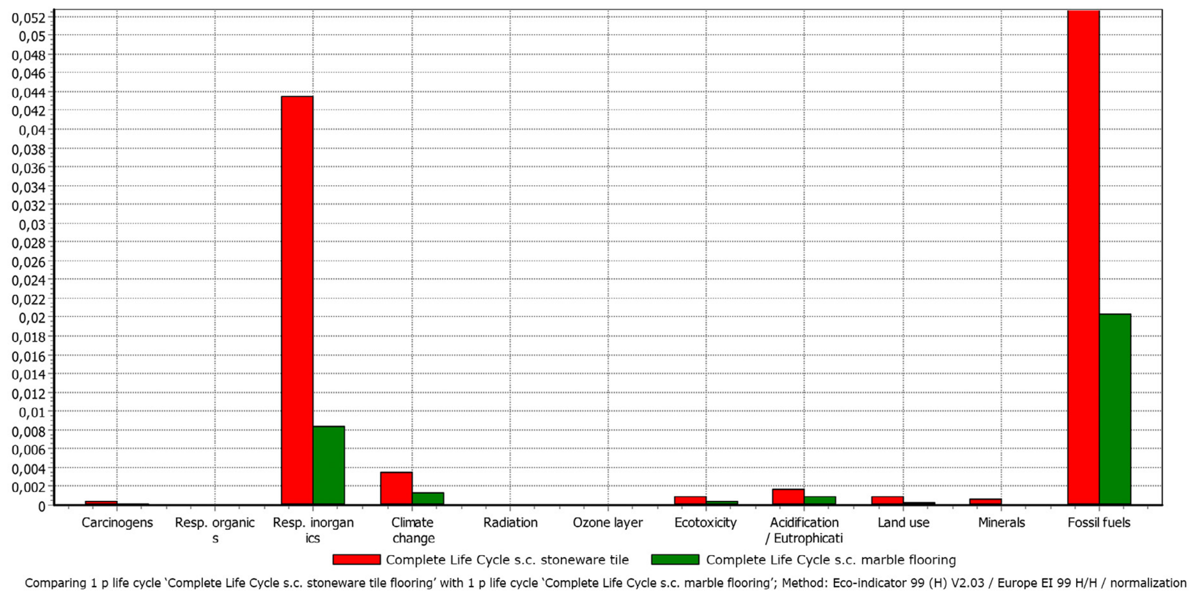

Figure 7. *Results of the normalisation with the ECO INDICATOR 99 methodology*

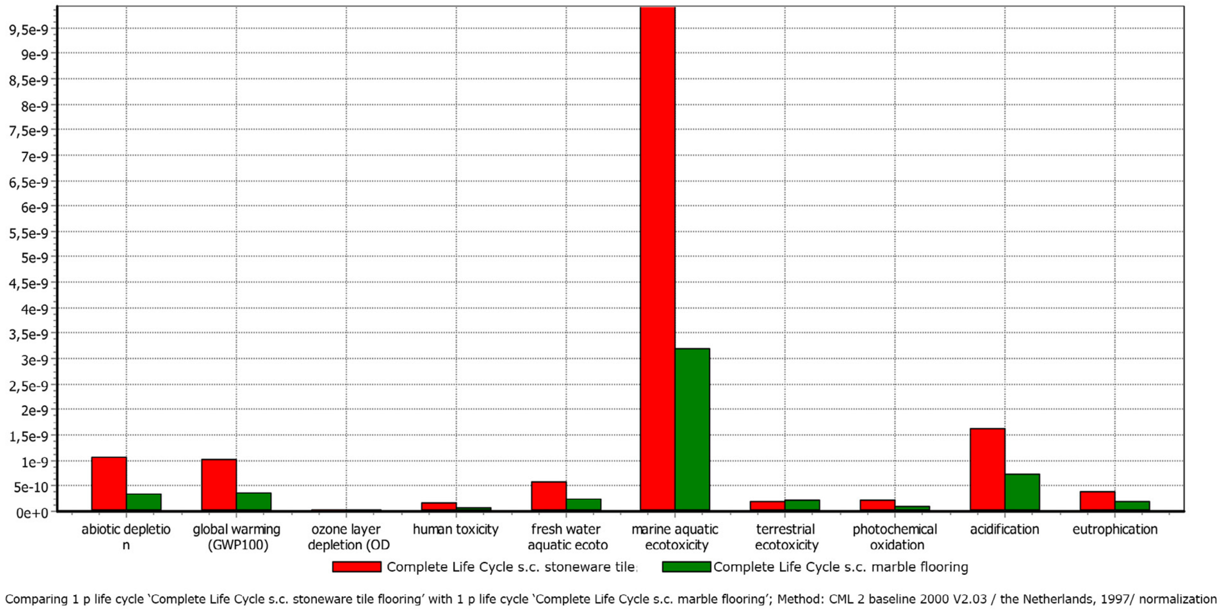

Figure 8. *Results of the normalisation with the CML2 BASELINE 2000 methodology*

The weighting, or conversion of the results of the values characterised of the different impact categories to a common and summable unit, multiplying by its weighting factor for the values to be added up and a single total score to be obtained for the environmental impact of the system, is reflected in the results expressed graphically in *Figures 9* and *10.* Using the ECO INDICATOR 99 methodology, the score obtained for the flooring construction solution with stoneware tile was 31.57 compared to 9.61 points obtained for that with marble, involving a difference of 69.56%. When the EPS 2000 methodology was used, the flooring construction solution with stoneware tile continued to have a much greater impact, scoring 318.22 points compared to 39.08 points of the marble flooring solution, in this case representing a difference of 87.72%.

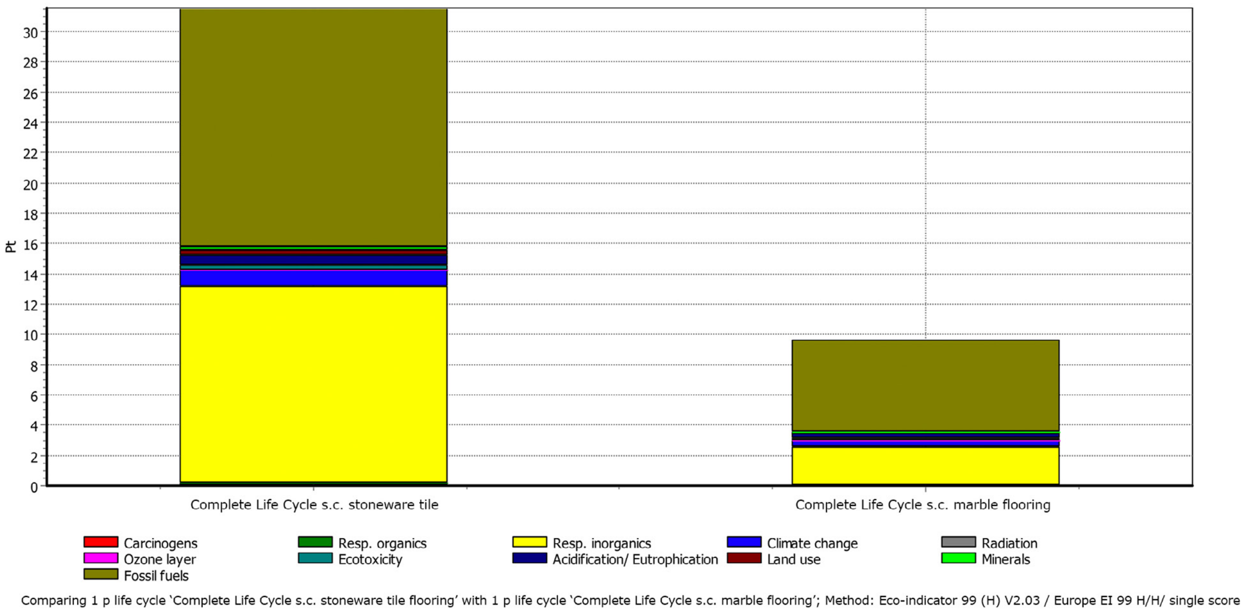

Figure 9. *Results of the weighting with the ECO INDICATOR 99 methodology*

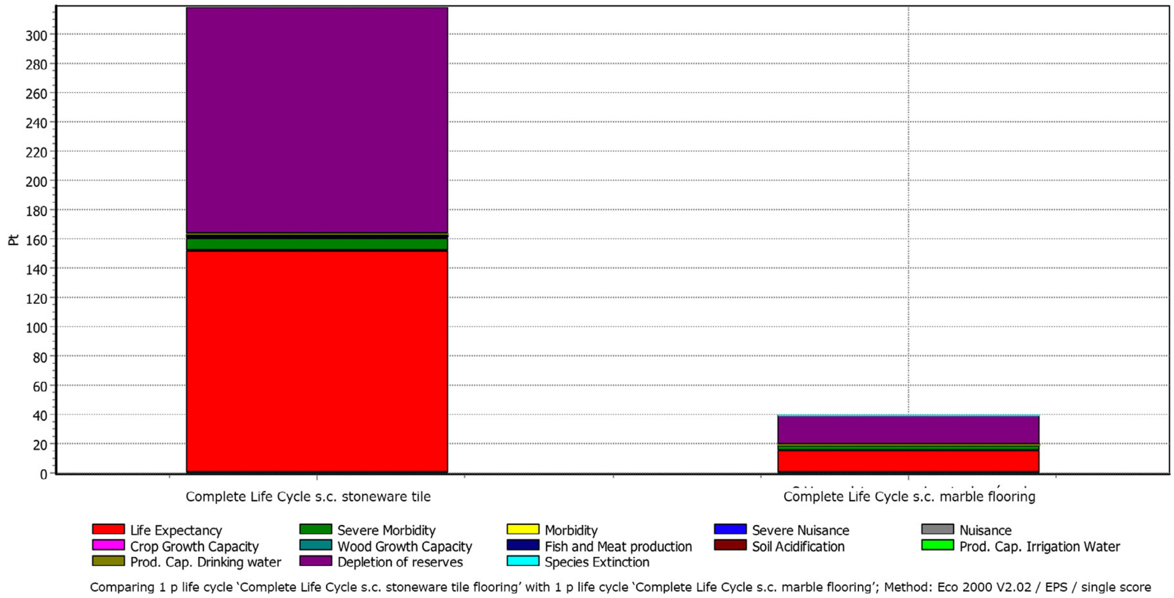

Figure 10. *Results of the weighting with the EPS 2000 methodology*

Finally, weighting was performed between the different layers in each construction solution, in an independent form for the flooring solution with marble and with stoneware tile. The results are shown in *Figures 11, 12, 13,* and *14*.

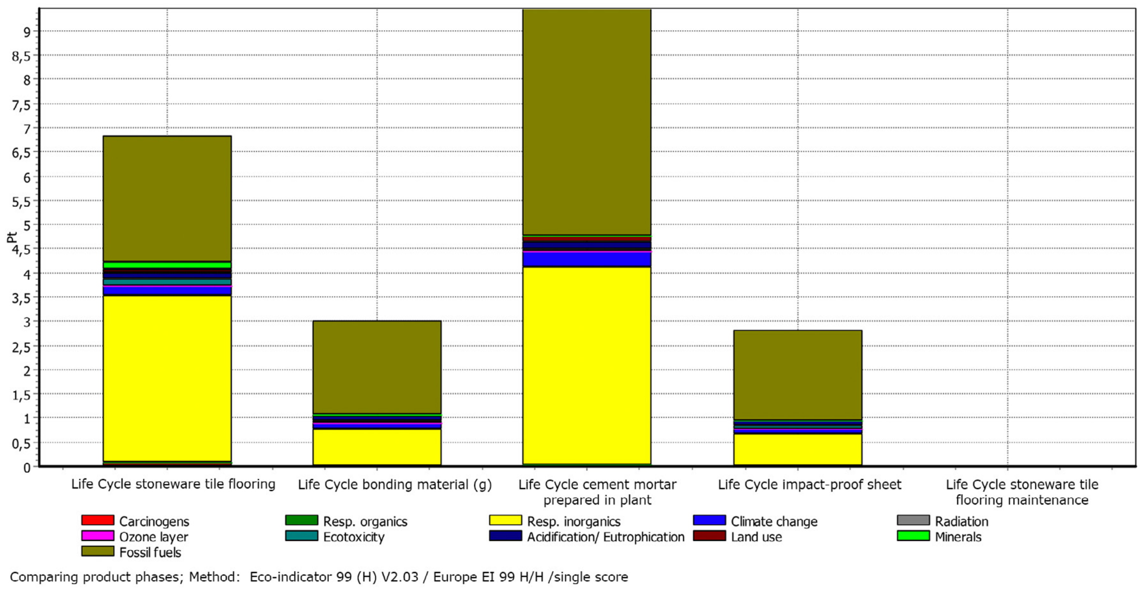

Figure 11*. Results of the weighting by layers s.c. stoneware tile with the ECO INDICATOR 99 methodology*

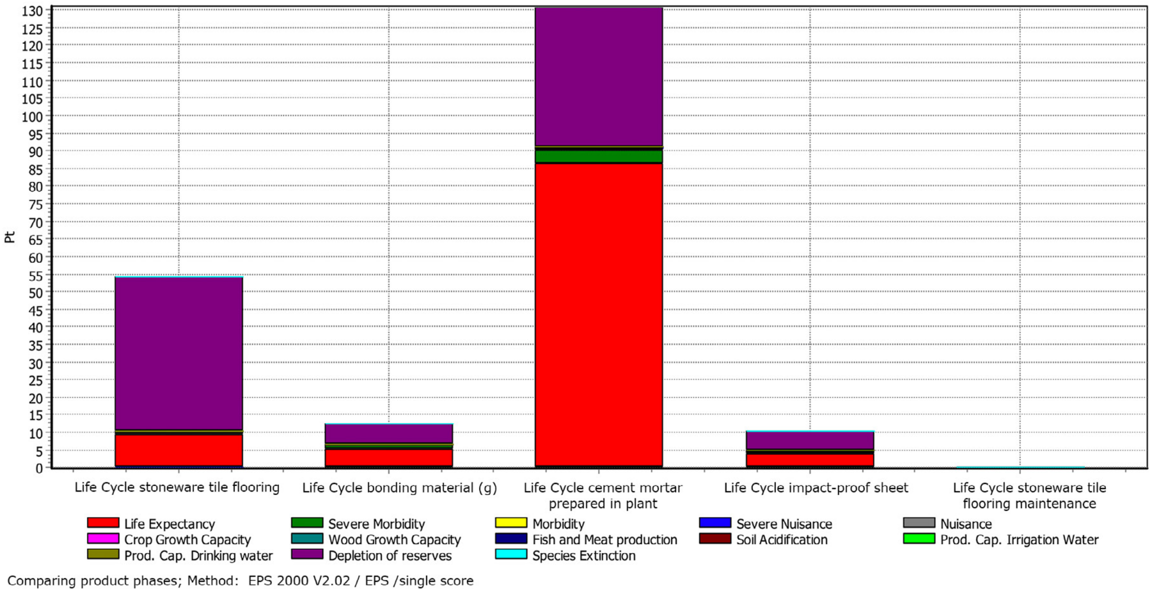

Figure 12. *Results of the weighting by layers s.c. stoneware tile with the EPS 2000 methodology*

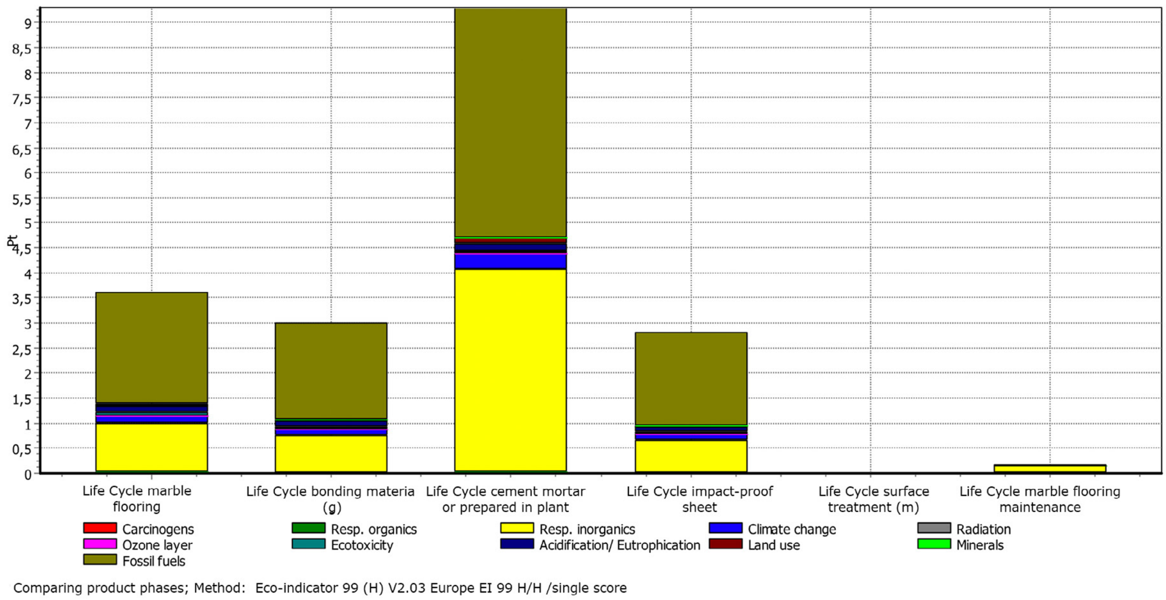

Figure 13. *Results of the weighting by layers s.c. marble with the ECO INDICATOR 99 methodology*

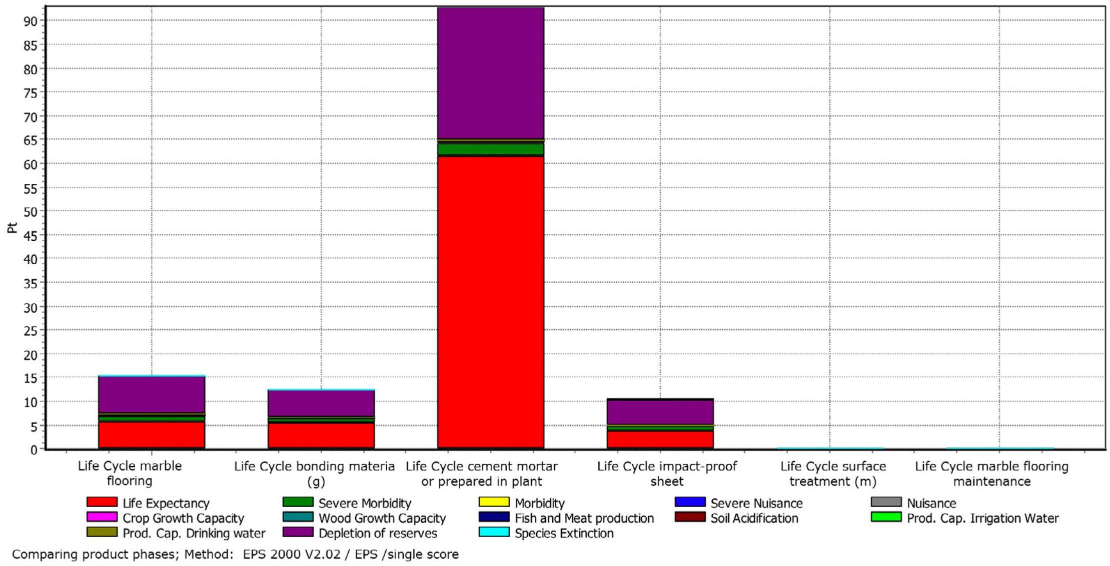

Figure 14. *Results of the weighting by layers s.c. marble with the EPS 2000 methodology*

5. DISCUSSION AND CONCLUSIONS

Analysis of the results obtained enables the following conclusions to be drawn:

- The marble flooring construction solution is, from an environmental viewpoint, better than the stoneware tile flooring solution, the environmental impact of the marble construction solution having about one third of the impact of the stoneware tile flooring solution.
- If the finish layer is considered just by itself, i.e. stoneware tile and marble, the differences are greater.
- In the stoneware tile production process a greater amount of fossil fuel is used than in the extraction and treatment of marble. In the former case, the fuel used is mainly natural gas, whereas in the case of marble diesel fuel is used, its extraction and combustion producing a greater impact than those of natural gas.
- The production of ceramic tiles, in addition to the raw materials extraction process, includes a product transformation that requires large amounts of energy (mainly for firing and drying). However, natural marble requires no transformation, it just needs to be extracted, cut, and a surface treatment to be applied.
- The layer with the greatest impact in the entire service life cycle of the two flooring construction solutions is the self-levelling cement mortar. Therefore, to improve the construction solution as a whole, this layer needs to be improved, this being a good research line.
- In the case of the flooring construction solution with stoneware tile, the stoneware tile layer also has a significant impact. The solution could be environmentally ameliorated by using thin ceramics because, on containing less material, fewer raw materials would be used, with the ensuing impact reduction owing to raw materials extraction. This reduction in thickness would also affect transportation, reducing its impact.

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