COMPARATIVE ENVIRONMENTAL ASSESSMENT OF VARIOUS TYPES OF FLOOR COVERINGS

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INTRODUCCIÓN

The construction sector is a major materials consumer. In fact, the European Union deems it a key sector in the attainment of the objectives in the Roadmap to a Resource Efficient Europe (RERM) (COM/2011/0571 final, 2011) and the EU Action Plan for the Circular Economy (COM/2015/0614 final, 2015), as about 50% of materials extraction, 30% of water consumption, and 30% of waste generation are associated with this sector (COM/2014/445 final, 2014), being the cement, wood, and ceramic tiles as the three major energy expensive materials (Asif et al., 2007).

Consequently, in the last years, the design and buildings construction under sustainability criteria has notably increased in the construction sector and therefore, the appropriate selection of construction materials plays a major role in a building's environmental profile (Akadiri, 2015; COM/2014/445 final, 2014; Häfliger et al., 2017; Zabalza et al., 2011).

This situation has pushed for construction materials manufacturers to analyse and communicate the environmental impact of their products, with the clear objective of positioning themselves in the field of "sustainable construction". Life Cycle Analysis (LCA) is unquestionably the most widely used methodology for evaluating product environmental impacts, particularly those of construction products (Basbagill et al., 2013; Iribarren et al., 2015; Zabalza Bribián et al., 2009).

In the particular case of floor covering materials, the application of LCA has consistently drawn attention in the literature. Analysis of this literature review allows important differences to be noted, which prevent direct comparison of the results for conclusions to be drawn.

Causes are methodological differences applied in calculations, impact assessment, differences in scope, temporal or geographical differences, among others. (Ros-Dosdá et al., 2019). Generally speaking, certain coincidences were identified, in which it was concluded that linoleum was the most interesting flooring, followed by vinyl, from an environmental viewpoint, when soft and/or resilient floorings were compared (Jönsson et al., 1997; Minne and Crittenden, 2015; Potting and Blok, 1995).

There have been recent initiatives, such as the SOLCONCER project (https://solconcer.es), which is probably the largest comparative study of surface coatings suitable for different building constructions systems. The comparisons were made from a technical, environmental and economic point of view. For the environmental comparison, EPDs in strict compliance with EN 15804:2012+A1:2013 were used, as these are often the only information architects and planners have to compare and decide on different construction and/or component options (Bovea et al., 2014; IBU-EPD programme). In-depth environmental analysis of the construction solution for floor partitions was carried out by Ros-Dosdá et al., 2019.

The present study enlarges the previous ones with new impact categories to include those referred by EN 15804:2012+A2:2019 such as ecotoxicity, human health and other disaggregated information as for instance the CO_2 biogenic.

GOALS

The goal of the study was to perform an environmental impact and other impact assessment related to health and toxicology of seven different ceramic solutions for flooring systems and to identify the weaknesses and strengths of the product "ceramic tile" compared to a number of selected competing materials.

METHODOLOGY

The methodology applied in this study was built upon ITC's previous work (Ros-Dosdá et al., 2019) and, using a database-driven model, i.e. excluding EPDs and assessing additional environmental impact categories for different flooring solutions.

ITC carried out this study in close collaboration with ©IVL, The Swedish Environmental Research Institute Ltd. ITC oversaw data collection based on the models from the previous study, arrangement of critical review from expert and stakeholder panels. Meanwhile, IVL carried out the modelling using GaBi software (Sphera, 2020), calculation of results and report writing.

To ensure comparability and objectivity, the methodology applied in this study follows the EN 15804:2012+A2:2019 standard as closely as possible and recommendations of the standards ISO 14040-44 (2006). In this sense, sectoral stakeholders and LCA experts provided a critical review, recommendations and, in some cases, specific data for assumptions.

The sectoral stakeholders panel, linked to the value chain of the different covering materials considered, had the function of checking the data and hypotheses assumed. The LCA experts panel had the function of ensuring the objectivity of the work from a methodological point of view and compliance with EN 15804:2012+A2:2019 and ISO 14040-44 (2006).

Feedbacks from both panels were collected through workshops, technical meetings and technical reports where the scope, objectives and results of the work were discussed.

SCOPE

The scope of the LCA was defined from cradle to cradle, i.e. product stage, transport to the construction site, installation of all construction elements, use and recovery through recycling, as an end-of-life transition scenario towards a circular economy. At the use stage, three scenarios were analysed according to the intensity of pedestrian traffic, which determined the operations and frequency of maintenance, repair and replacement.

Studied product systems

The study was conducted on seven materials (Figure 1) deemed most representative of those used as indoor floor coverings and, whenever the material requires, it was considered bonding and/or impact sound insulation materials.

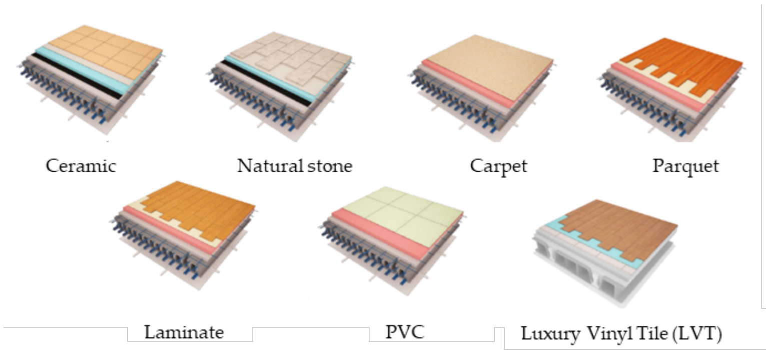

Figure 1. *The different ceramic solutions for flooring considered in present study.*

Functional unit

The **functional unit** was defined as the quantity of construction elements required to build 1 m^2 of indoor flooring system intended to last for 50 years. The study considered the useful life of the floorings and the number of installations needed to cover the reference service life. The study used Spanish-specific data and assumptions wherever available, or country-specific data in case it was assumed that the manufacturing occurred somewhere else, and otherwise used generic European data. The amount of material needed, weight, durability and use phase details all related to being able to perform this function.

System boundaries and scenarios

The **studied construction system** of horizontal partitions was a floating floor screed of cement mortar, as ITC deemed this to be the most generic alternative described in these documents. The system involved a floor made up of a layer of about 5-cm-thick cement mortar installed on a sheet of impact sound insulation material, the screed was covered with a finish (Ros-Dosda et al, 2019) as illustrated in Figure 2 below. As the figure shows, some of the layers were excluded from this study as they were common for all the solutions studied.

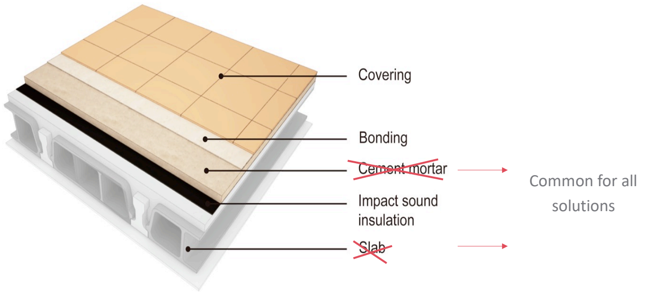

Figure 2. *Detailed of the construction system considered in the present study*

The **life cycle stages included** were: the production stage, transport to the construction site, installation of all construction elements, maintenance and end-of-life. In the last two stages, several scenarios were considered. The data used to model all life cycle stages corresponded to the latest data available, with a maximum threshold of 10 years. Some of the scenarios applied for the end-of-life stage are, however, intended to somewhat represent future practices.

The **scenarios tested** can be seen in Figure 3. Concretely, this paper only shows the results of the $S_TT_ME_C$ scenario.

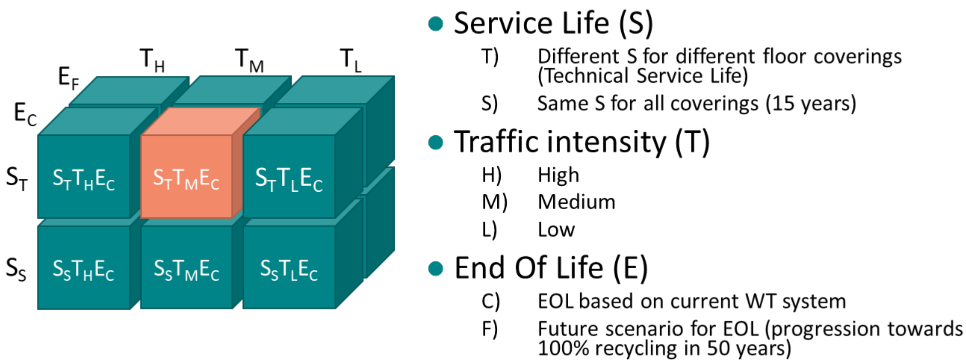

Figure 3 *Outline of the scenarios tested for the sensitivity analysis. Scenario STTMEC (orange box) was chosen as the default scenario for the present study.*

The **geographical context** of the study was Spain, so it was assumed that all the flooring solutions were commonly used in Spanish buildings. Therefore, Spanish-specific data (electricity production, heat generation, etc) and assumptions (transport distances, end-of-life scenarios, etc) were used wherever available, except for specific solutions (e.g. luxury vinyl tile), where a vast majority of the products sold in Spain were manufactured in other countries, meaning that data for such countries were used. Otherwise, generic European data was used.

Data quality requirements and cut-off rules

The study was limited to the data collected in the previous study performed by ITC (Ros-Dosdá et al., 2019), generic data from databases and literature values. Specifically, the production stage (A1-A5) was from the previous study (Ros-Dosdá et al., 2019), while maintenance and end-of-life scenarios were defined in previous work by ITC and was validated by the panel of stakeholders.

A criterion of a 1% maximum cut-off was applied throughout the study, meaning that at least 99% of the known material flows were accounted for in the model and in the scope of each dataset used. Still, no flows are known to have been excluded.

Assumptions and limitations

The most relevant assumptions made for this study were:

- No further data was collected, the whole model used in this study is obtained from generic databases and complemented by literature values. In some cases, published EPDs were applied.
- The manufacturing of the flooring solutions was assumed to take place in Spain, so Spanish specific data was used. The only exception for this assumption was luxury vinyl tile (LVT), which was assumed to be manufactured in The Netherlands, since a Dutch manufacturer dominates the Spanish market. This information was obtained from the stakeholder panel.
- The transport for the distribution to use (A4) follows an assumption of 100km transport for all the solutions, except for the LVT floor where 1700 km was assumed based on the distance between Amsterdam and Madrid.
- The scenarios analysed for the intensity of the use, the maintenance, and the service life of the flooring solutions (Figure 3) were developed using the 2019 base study as a starting point and fine-tuned in collaboration with the stakeholder panel.

The main limitation of the present study was that the involvement of manufacturers and the private sector in this study was limited to their participation in workshops. As valuable as the input from the stakeholders was, the fact that no manufacturers provided site-specific or technology-specific data to model the product system was a limitation of the study, as it was based for the most part in generic data. However, this could be considered a complementary result to that from the first study by Ros-Dosdá et al. (2019), which was built upon producer-specific data from EPDs.

Impact categories

The analysed impact categories are presented in Table 1, these correspond to the new version of the construction products LCA standard EN 15804:2012+A2:2019. The assessment was carried out using the characterisation factors (environmental quantities) available in GaBi for EN 15804 EF 3.0, without modifications.

Impact category	Category indicator	Reference
Global warming potential (fossil)	kg CO_2 eq.	IPCC baseline, 100 years, 2013
Global warming potential (biogenic)	kg CO_2 eq.	
Global warming potential (LUC)	kg CO_2 eq.	
Eutrophication potential, fraction of nutrients reaching freshwater end compartment, EP-freshwater	kg P eq.	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
Eutrophication potential, fraction of nutrients reaching freshwater end compartment, EP - marine	kg N eq.	
Eutrophication potential (terrestrial)	Mole N eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al. 2008
Acidification potential of soil and water, AP	Mol H^+ eq.	
Photochemical ozone formation	kg NMVOC eq.	LOTOS-EUROS, Van Zelm et al., 2008, as applied in ReCiPe
Potential Human exposure efficiency relative to U235, IRP*	kBq U235 eq.	Human health effect model as developed by Dreicer et al. 1995 update by Frischknecht et al., 2000
Potential Comparative Toxic Unit for ecosystems, ETP-freshwater*	CTUe	USEtox version 2 until the modified USEtox model is available from EC-JRC
Potential Comparative Toxic Unit for humans (cancer effects) , HTP-c*	CTUh	
Potential Comparative Toxic Unit for humans (non-cancer effects, HTP-nc*	CTUh	
Respiratory inorganics*	Disease incidences	SETAC-UNEP, Fantke et al. 2016
Depletion potential of the stratospheric ozone layer, ODP	kg CFC-11 eq.	Steady-state ODPs, WMO 2014
Land use, Potential Soil quality index, SQP*	Pt	Soil quality index based on LANCA
Resource use, mineral and metals	kg Sb eq.	CML 2002, Guinée et al., 2002, and van
Resource use, energy carriers	MJ	
Water (user) deprivation potential, deprivation weighted water consumption, WDP	m^3 world eq. deprived	Available WAter REmaining (AWARE), Boulay et al., 2016

* Impact categories that must be calculated but must not be declared according to the current version of EN 15804:2012+A2:2019

Table 1. *Impact categories considered in the present study.*

Critical review procedure

The panel of experts that carried out the critical review of the LCA was chaired by the University of Cantabria with the participation of Elisava (Barcelona) and the University of Santiago de Compostela. For this study, two critical review periods were proposed in which a panel of interested parties were contacted and a panel of experts were contracted. In the first review period, the objectives and scope of the LCA study were presented to the parties. The second review period was carried out after the LCA study was completed.

INVENTORY ANALYSIS

Product stage (A1-A3)

This stage considers the processes included in the extraction of the raw materials, their transport and the manufacture of the flooring system elements. The flooring systems and their characteristics are presented in Table 2 and was defined on the basis of CYPE ingenieros, 2018, databases. The environmental data associated was taken from commercial LCA databases (the last version of Gabi, Ecoinvent).

FS	Classif.	Covering (1)					Bonding (2)		Impact sound (2)		MSL	Instal. during RSP
		Material	Covering Standard	Product varieties considered	Mean mass (kg/m^2)	Mean thicknes s(mm)	Material	Mean mass (kg/m^2)	Material	Mean mass (kg/m^2)		
PST	Inorganic	Ceramic	ISO 13006, 2012	Mainly Porcelain Stoneware Tiles (water absorption coefficient <0.5%)	24	10.5	Cementitious adhesive	3.5 dry	PE foam sheet (5mm thick)	0.11	>50	1
NS		Natural Stone	EN 12058, 2015	Igneous, Sedimentary and Metamorphic rocks	52	20	Cementitious adhesive	6.4 dry	PE foam sheet (5mm thick)	0.11	>50	1
PVC	Polymer	Polyvinyl chloride	ISO 10581, 2011; ISO 10582, 2017	Luxury, homogeneous and heterogeneous vinyl, with different finish properties, backings and formats (tiles, planks, and rolls),	3.4	2.6	Contact adhesive	0.3	PE foam sheet (5mm thick)	0.11	20	3
LVT		Luxury Vinyl Tile		Vinylic tiles								
TEX		Carpet	EN 1307+A1, 2016	Made of synthetic polyamide fibres of different recycled content, densities, and backings. Class 33 or less	3.9	-	Contact adhesive	0.25	Not needed		15	4
LAM	Wood	Laminate	EN 13329, 2017	Direct Pressure Laminate floor coverings with different finish properties	7.5	8	Not needed (mechanical assembly)		PE foam sheet (3mm thick)	0.07	15	4
WD		Parquet	EN 14342, 2013	Multilayer and solid parquet	9.5	14	Contact adhesive	0.8	PE foam sheet (5mm thick)	0.11	45/ 30/ 15 (3)	2/2/4

(1) Mean values in the selected EPDs
(2) Values taken from CYPE Ingenieros, 2018
(3) Depending on the refurbishing operations
MSL: Material Service Life
RCP: Reference Study Period

Table 2. *Flooring systems and main characteristics considered to perform each LCA and ulterior comparison.*

Distribution and installation (A4-A5)

The same transport distance (1000 km; Truck Euro 6) to customer was assumed for all flooring systems. This assumption was made to avoid that this parameter did not influence the results, since the goal of the present study was to compare the materials and not the suppliers.

For the installation of flooring, the impacts accounted for were the production and transport of additional material for construction, the waste management generated from this activity and the packaging of the products (70% to incineration and 30% to landfill).

Use

The technical material service life considered for each covering in this default scenario is presented in Table 2. These values were obtained originally from the previous study and validated or modified accordingly during the stakeholder workshops. Since the Reference Study Period was 50 years, coverings with shorter service lives need to be replaced. The number of replacements is also presented in Table 2.

Maintenance (B2)

The impact considered during the maintenance stage was those due to cleaning activities, which depended on the assumed pedestrian traffic intensity of the building. Three levels of traffic intensity were defined for this study: low, medium and high. But only medium traffic will be presented in this paper for a sake of simplicity. The traffic intensity influences primarily the type of cleaning activities that are required for each flooring and their frequency. Data regarding the maintenance activities were collected from Ros-Dosda et al., 2019 and represents cleaning activities in a Spanish context. The values assumed for each flooring solution and traffic intensity level in terms of cleaning activities can be found in Table 3.

Flooring solution	Cleaning activities	Operations per year (no.)
Ceramic tile	Wet mop Wet mop + cleaner	365 182
PVC	Wet mop + cleaner / Household vacuum	365 260
Laminate	Wet mop + cleaner Household vacuum	365 260
Carpet	Wet mop + cleaner Household vacuum	2 365
Natural stone	Wet mop Wet mop + cleaner	365 182
Parquet	Wet mop Wet mop + cleaner Household vacuum	24 12 365
LVT	Wet mop + cleaner Household vacuum	365 260

Table 3. *Cleaning activities assumed for each flooring solution under a medium traffic intensity*

Repairing (B3)

Repairing activities were only considered for parquet and natural stone covering, and they were dependent on the assumed traffic intensity. The number of repairs for each floor covering associated to medium traffic intensity are outlined in Table 4.

Floor coverings	Traffic intensity	Number of repairs
Parquet	M	10
Natural Stone	M	3

Table 4 *Number of repairs under the reference study period (50 years) assumed for each flooring covering in medium traffic intensity*

Replacement (B4)

Replacement of the flooring materials was only considered for those scenarios where the service life of the flooring was lower than the studied period of 50 years. In replacement, deconstruction, management of demolition waste and manufacture of the new material were considered.

End-of-life stage (C1-C4)

For the deconstruction activities, the impact considered corresponded to the use of diesel-powered pneumatic compressor and hammer, except for laminate, which was assumed to be removed manually and therefore had zero impacts for deconstruction.

The default end-of-life scenario applied in this study was based on waste statistics, a 30% recycling rate for the mineral based floors (ceramics and natural stone) (INE, 2019) and 84% recycling for the parquet floor (INE, 2019). The PVC floor covering (PVC and LVT) were assumed to have a 100% landfilling rate. This assumption was grounded in statistics from Anarpla, 2018, which shows that only 1% of the plastic waste from construction is recycled. Laminate was also assumed to have a 100% landfilling rate, because of the multicomponent nature of the material and the low level of incineration in Spain (Ros Dosda et al., 2019).

Other end-of-life scenarios were assumed but for a shake of simplicity only the current waste treatment scenario is shown.

Benefits and drawbacks beyond the life cycle (D)

The benefits beyond the life cycle, also known as module D, according to the EN 15804:2012+A2:2019 standard, were included in this study.

RESULTS AND DISCUSSION

The study carried out provided very valuable information, as it identified both the strengths and weaknesses of ceramic tiles compared to alternative products and it could be considered therefore as a starting point for establishing actions to improve environmental performance and commercial arguments compared to those offered by other alternative solutions.

In general, the lifecycle stages that most consistently caused large impacts among the impact categories and products analysed were product stage (A1-A3), maintenance (B2) and replacement (B4), this last case only for those coverings with a short technical service life.

The results showed that in the baseline scenario, the carpet covering had the highest environmental impacts. The results for the other coverings varied for the different impact categories. On the other hand, the covering with the lowest climate impact in the baseline scenario were the ceramic tiles. The results also showed that the assumed values for the key parameters of the use phase had a significant influence on the outcome of the analysis in almost all analysed categories; especially with regard to cleaning activities and service life.

For the sake of simplicity, in the next paragraphs results and discussions will be focused on the following topics: i) only the **Global Warming Potential** for the different flooring are discussed and, ii) the influence of the **covering service life.**

Global Warming Potential

Table 5 shows the results associated with Global Warming Potential (GWP). Global Warming Potential (GWP) is an indicator to measure climate change. Climate change is the global warming effect of greenhouse gas emissions caused by human activity. When emitted to the atmosphere, these greenhouse gases increase the temperature at the earth's surface by absorbing energy and slowing the release of energy back to space, causing a greenhouse effect. Different greenhouse gases have different effects on earth's warming, and the effect caused by carbon dioxide is used as a reference unit referred to as CO_2 equivalents. This is the indicator includes GWP from fossil, biogenic and land-use change emissions.

Stages		Ceramic	Natural stone	PVC	LVT	Carpet	Laminate	Parquet
Product	A1-A3	18.7	30.8	8.8	12.9	18.8	-7.7	-7.9
Distribution and Installation	A4+A5	2.1	2.7	1.7	1.5	1.6	1.4	2.0
Maintenance	B2	7.9	7.9	15.3	15.3	99.3	19.3	14.5
Repairing	B3	0	0.02	0	0	0	0	9.1
Replacement	B4	0	0	24.3	32.5	83.3	32.0	13.8
End of life	C1-C4	2,5	2,9	1,6	1,9	7,4	17,0	17,7
Benefits and drawbacks	D	-0.7	-0.09	-0.6	-0.24	-1.5	0	-2.0

Table 5. *Climate impact per functional unit assessed with Global Warming Potential (GWP-Total) over 100 years for fossil, biogenic and land use change emissions*

The floor system resulting in the largest impact from fossil sources was the carpet. The life-cycle stages causing the largest impact were the replacement and manufacturing. In addition, the carpet floor system showed large impact from the maintenance stage due to the large use of household vacuum. The floor system with lowest fossil climate impact was the ceramic tiles.

For the systems with shorter service life (PVC, Laminate, Carpet and LVT), the largest climate impact was assessed for the replacement phase. Meanwhile, for the floor coverings with longer service life (ceramic and natural stone) the largest climate impact was from product manufacturing (A1-A3). The parquet floor displayed low climate impact during the production stage but makes the greatest contribution at the end of life due to biogenic CO_2, which is absorbed during the growth of the wood but is re-emitted again at the end of life when the material left the system boundary, in addition to replacement and repair operations. In the case of laminate flooring, although it was based on wood, recyclability was not viable because it is multi-component and incineration was not a common practice in Spain, so its deposit in landfill and consequent emission of methane, considerably increased its contribution to global warming, without providing any benefit and drawbacks beyond the study system.

Service Life

The assumed service life showed to have great influence over the results. A lower service life in S_S (non-technical scenario: 15 years for all flooring systems), typically increased the climate impact considerably, most dramatically in the case of the ceramic and the natural stone floor system (see Figure 4). This confirms that service life is a key assumption when assessing the environmental impact of floor systems. In this study, the technical service life was used as the default scenario, which is considered the best option available.

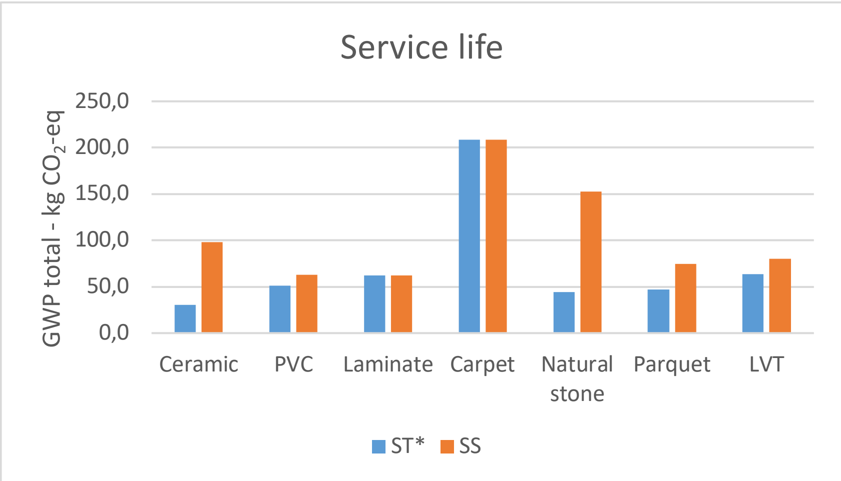

Figure 4. *Lifecycle climate impact (GWP total) of the assessed floor systems. Comparison between the two scenarios for service life where ST represents the technical service life (see Table 2; column MSL) and SS the scenario where all floor systems were assessed with the same service life (15 years). The default scenario is indicated with *.*

However, it can be argued that a more realistic situation might be to use a service life where the floor systems are replaced for other reasons than technical performance; namely aesthetics or change in the use of the building are. This scenario analysis shows that in situations where floors are expected to be replaced with high frequency, the best option from a global warming point of view would be to use floor systems with low impact in this category during the manufacturing phase such as laminate or PVC.

On the other hand, for situations where floors were intended to have a more stable use, the longest-lasting coverings such as ceramics, natural stone and parquet, were preferable from an environmental perspective.

HOT SPOTS FOR MITIGATION STRATEGIES

This section summarizes the findings from this study about environmental hotspots for each flooring system and the impact categories analysed. This information may prove useful for stakeholders, as it hints towards the processes and activities that have the highest contribution to the environmental impacts and therefore, those with a higher potential for mitigation strategies:

- For the carpet system, the identified hotspots were the vacuuming and cleaning agents for maintenance, as well as, the manufacturing and replacement stage.
- For the PVC and LVT systems, the main hotspots were the manufacturing of the plastic raw materials both for the production and replacement stages, especially with respect to toxic substances where the score was relatively high.
- For the laminate system, the manufacturing of new products for the replacement were identified as hotspots, more specifically the production of particle board and melamine.
- For the ceramic tiles and natural stone systems, the main contribution comes from the product manufacturing, mainly the energy consumption and mining of mineral raw materials.
- Finally, in the case of the parquet, the process with the largest contribution was the manufacturing of new products, mostly for the replacement.

RECOMMENDATIONS FOR FUTURE WORK

The following are recommendations for future work, as ways to improve the robustness of the model and the reliability of the results:

- To obtain manufacturer-specific data for material composition, which would represent Spanish conditions better than the model used, partly based on data from LCA databases. Examples of these improvements could be specific types of materials used, more accurate amounts of raw material and energy inputs or even transport data.
- To obtain and apply data that represents real life practices for the use phase; more specifically frequency of cleaning activities, replacement and repair. Aware that these are highly subjective practices, the assumptions applied in this study were based on manufacturer's recommendations, which may tend to be on the safe side and therefore overestimating the magnitude and impacts of these activities. This type of information may be obtained from sector-specific statistics.
- To research more deeply which is the most adequate service life assumption for the service life of flooring systems; the technical service life or a more realistic service life assumption based on the probability of earlier replacement depending on the intended use.
- Investigating more end-of-life scenarios, for example based on more specific sector-based statistics of recycling or incineration rates.
- Given the extensive assessment period for most building products, the quality of the model could be improved by more accurate modelling of future scenarios. What is more, many things can change under these extensive time periods, and dynamic modelling of future processes that represent the expected changes in technology could be implemented, e.g. dynamic electricity mixes, or manufacturing processes of key future input materials such as cleaning agents.

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