A Cradle-to-Grave Life Cycle Assessment Study on a New Countertop Material

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ABSTRACT
The life cycle of furniture products has been decreased in the last years as a consequence of the continuous improvement of people’s housing conditions. This behavior increases the waste amount in an urban area. The focus of this study was developing a Life Cycle Assessment (LCA) (cradle-to-grave) of a new countertop product. Two scenarios for countertop waste management were proposed, one considering landfilling and another considering recycling. The functional unit chosen was 1 m2 of finished panel (countertop) and the boundary system involved the study of raw materials, product packaging, the panel production process, the installation process, the panel use, and its end of life. The chosen method for impact assessment was EPD (2018) available in the SimaPro PhD software. The results showed that recycling has a positive effect on the environmental impacts, with the variation ranging from 0.3% on Abiotic Depletion (FF) to 15.9% on Eutrophication. A comparison between the product studied and products with similar functions was also conducted and although this product was not the worst performer, it has a lot of room for improvement.

Keywords: circular economy, furniture, life cycle assessment, recycling

INTRODUCTION
Furniture is not often emphasized in the policies at the forefront of minimizing the environmental impact. A new awareness is emerging of the centrality of furniture to space, design and broader aesthetic, cultural and physical well-being, in concern with a more harmonious connection with the natural environment. With the rapid development of urban economy and the continuous improvement of people’s housing conditions, the replacement of furniture is also accelerating. The use of wood in furniture manufacturing is generally of lower environmental impact than other materials, such as plastics or metals. Nonetheless, the consumption of wood has impact on the forests, with consumption of important raw materials. Deforestation can be negative if not managed in a sustainable way, with important impacts on climate change, due to the increase of the greenhouse gases in the atmosphere, soil erosion, desertification, crops decrease, flooding and great losses to local population.

Initiatives like the Sustainable Procurement Guidelines for Office Furniture at the United Nations are increasingly emulated by organizations globally [Zutshi, 2016].

The furniture sector in Portugal is an essential element in the country’s industrial landscape. It is a sector that takes advantage, both environmental...
and economic, of one of the greatest riches of the country: the woody material produced in the forests [Vicente, 2018].

The overall usage of wood furniture is generally more than 60 years. However, nowadays, furniture products are usually discarded in 20 years because of the rapid transformation of furniture functions and modeling. According to the statistics of the Association of Waste Materials Recycling, there are 3,000 sets of old furniture that are deserted every day in Shanghai, and more than 1 million sets of old furniture need to be addressed each year [Shanshan, 2005]. Millions of furniture pieces were thrown away in Western developed countries. In the absence of a good recycling system, the increasing discarded furniture is a burden for the community as well as local and national governments, with high risk of developing new city “garbage” sites [Shanshan, 2005]. Curran et al. [2010] stated that collected bulky items, which include furniture, represent less than 5% of total household waste and often contain several different material types that are difficult to separate. They have been largely overlooked to date in favor of “easy win” mass recycling of common materials—paper, glass, metal cans and sometimes plastics. For those reasons, it is important to think about the sustainable solutions for the end of life of furniture pieces, namely their recycling.

Life Cycle Assessment (LCA) is a tool to assess the potential environmental impacts and resources used throughout the lifecycle of a product, i.e., from raw material extraction, through production and use phases, to waste management. The waste management phase includes disposal as well as recycling [Finnveden, 2009].

The main aim of this study was to conduct LCA (cradle-to-grave) to assess the potential life cycle environmental impacts associated with a kitchen furniture countertop manufactured and installed in Portugal. A comparison between these results and results from similar products was also conducted.

MATERIALS AND METHODS

The LCA (cradle-to-grave) study follows the ISO 14040 [ISOa, 2006] and ISO 14044 [ISOb, 2006] standards and two different waste management scenarios for the end of life stage were considered: the deposition in landfill of the countertop that need to be discarded (S1) and the second scenario where 70% of the waste can be recovered by recycling and 30% is sent to landfill (S2). The results were compared to analyze the environmental impacts of all the recycling processes involved.

Functional unit

The functional unit chosen for this study was 1 m² of installed countertop. The countertop panel is constituted by a ceramic sheet on a lamellar panel substrate, formed by glass fiber reinforced polyester and PVC, which is intended to be water, scratch, and impact resistant.

System boundaries

The system boundary for the product under study is represented in Figure 1. The system boundaries include the manufacturing and packaging process, studied by the authors in a previous work [Silva L., 2021], the installation process, the panel use, and its end of life.

For the installation process, the electricity used by the equipment required to install the product was considered. The waste generated by the product installation and its packaging were also considered in this stage. For the end of life stage, two scenarios were modeled: the panel wastes goes to landfill as its final destination (S1), and 70% of the panel wastes are recycled and 30% are sent to landfill (S2), following the recycling goals of the Portuguese Decree-law no. 102-D/2020 [2020].

Fig. 1. System boundaries for the product
Assumptions

During the use phase, only product maintenance is included – typically cleaning with tap water and soap – over its life cycle. For this reason, a negligible or null impact (0) was considered for this stage. It was considered that the life cycle of a panel is the same as the building where it is installed.

Since the panel is used for more than one type of kitchen countertop, a 10% scrap rate in the installation phase is assumed. To model the cycling scenario, it was considered that the material is ground and incorporated into concrete making, as a substitute for gravel.

Data gathering

The data on the product manufacturing was provided by the authors’ previous work and relates to the year 2020. The data for the background processes were obtained from the Ecoinvent 3 databases. All the materials and energy used to produce 1 m² of panel were accounted for [Silva L., 2021]

For the end of life stage, the data was modeled according to the results from previous studies on construction and demolition waste disposal, mainly regarding the equipment used for demolition and their energy consumption. The study provided the energy consumption per Kg of demolished material. This energy consumption is registered in Tables 2 and 3 [Silva M., 2008]. The data for scenarios S1 and S2 are also described in these tables. For the background processes, the data were provided by the equivalent processes in the Ecoinvent 3 database according to Table 1, Table 2 and Table 3.

Life cycle impact assessment (LCIA)

The method chosen for impact assessment was EPD (2018) ready to use in the SimaPro PhD software [PRé Consultants, 2021]. All impact categories are taken directly from the CML-IA baseline method (eutrophication, global warming, photochemical oxidation, ozone layer depletion and abiotic depletion) and the CML-IA non-baseline method (acidification).

RESULTS AND DISCUSSION

Tables 4 and 5 present the quantitative results for each process within the system boundaries, for scenarios S1 and S2, respectively. Figures 2 and 3 show the environmental profile for the functional unit related with scenarios S1 and S2, respectively.

Table 1. Input and output data for the panel installation process for both scenarios

| Data       | Material/Resource                                      | Equivalent process in the Ecoinvent 3 database                     | Unit     | Quantity |
|------------|-------------------------------------------------------|--------------------------------------------------------------------|----------|----------|
| Input      | Panel                                                 | –                                                                  | [kg]     | 21.1     |
|            | Electricity                                           | Electricity, high voltage (PT) market for | APOS, U | [kWh]   | 0.7     |
|            | Glue                                                 | Silicone product (RER) market for silicone product | APOS, U | [kg]     | 0.4     |
|            | Panel packaging:                                     | –                                                                  |          |          |
|            | Pallets                                              | Sawnwood, softwood, dried (u=10%), planed (RER) market for | APOS, U | [m³]    | 0.004   |
|            | Cardboard boxes                                      | Corrugated board box (RER) market for | APOS, U | [kg]     | 0.5     |
|            | Plastic ties                                         | Polyethylene terephthalate, granulate, amorphous (GLO) market for | APOS, U | [kg]     | 0.02    |
|            | Polyethylene foam                                    | Polyethylene, low density, granulate (GLO) market for | APOS, U | [kg]     | 0.3     |
|            | Steel hardware                                       | Steel, unalloyed (GLO) market for | APOS, U | [kg]     | 0.013   |
|            | Plastic ties                                         | Extrusion of plastic sheets and thermoforming, inline (GLO) market for | APOS, U | [kg]     | 0.02    |
|            | Polyethylene foam                                    | Polymer foaming (GLO) market for | APOS, U | [kg]     | 0.3     |
|            | Steel hardware                                       | Metal working, average for metal product manufacturing (GLO) market for | APOS, U | [kg]     | 0.013   |
| Output     | Installed panel                                      | –                                                                  | [kg]     | 19.03 (1 m²) |
|            | Panel waste                                          | Municipal solid waste (waste scenario) (RoW) | Treatment of | APOS, U | [kg]     | 2.11 |
|            | Packaging waste                                      | Packaging waste (waste scenario) (PT) | treatment of | APOS, U | [kg]     | 1.17   |
Is noticeable that the manufacturing process is the main contributor (more than 60%) to the impact for the two scenarios. Previous study by the authors [Silva L., 2021] showed that this process is largely affected by two plastic components present in the panel composition, which have large environmental impact. Therefore, it is possible that these components play an important part in the influence of the manufacturing process contribution to the environmental profile of this product.

The installation contributes negatively to all categories. The end of life stage has no influence in 3 categories for S1 and 4 for S2. The LCIA results comparison of the two scenarios are registered in Table 6.

Comparing the two scenarios, the one where the waste is recycled has lesser impact in every category, as expected. The difference ranges from 0.3% on the Abiotic Depletion (FF) category to 15.9% on the Eutrophication category, which stands out.

Trying to understand the reason for that, the results on this category for both scenarios were further analyzed. It could be observed that the levels of Phosphates, Chemical Oxygen Demands, Nitrogen Oxides and Nitrates emissions were larger in the S1 Scenario. According to Chislock et al. [2013], the presence of Nitrogen and Phosphorus, along with Nitrates and Phosphates are known causes of Eutrophication and according to Benson et al [2007] these elements are found as components of landfills leachate.

In an attempt to better understand the impacts of this product’s life cycle on the environment, a comparison was made between the results found on this study and the results from products with a similar function, found on their products’ Environmental Product Declarations (EPDs). These EPDs show the results for the cradle-to-grave LCA studies, although it is not clear if the stages studies were similar to the ones considered on this paper. The products selected were: Marmoleum Decibel, by Forbo, which consists of decorative linoleum on a foam backing [Forbo, 2018]; SC36V with ceramic tile by CBI Europe, which is a factory finished panel with calcium sulfate panel and galvanized steel dish covered in ceramic tiles [CBI Europe, 2021] and Corian by DuPont, which consists of a composite (acrylic resin and natural minerals) [DuPont, 2017]. The functional unit for all the products was 1 m$^2$. The waste average from the installation for the products, as stated on their

| Table 2. Data and equivalent process for the panel end of life – S1 scenario |
|-----------------------------------------------|------------------------|-----------------|-----------------|
| **Process** | **Equivalent process in the Ecoinvent 3 database** | **Unit** | **Quantity** |
| Disposal in landfill (100%) | Municipal solid waste (waste scenario) [RoW], treatment of municipal solid waste, landfill | - | - |
| Inputs: | | | |
| Panel | - | [kg] | 19.03 |
| Electricity | Electricity, high voltage [PT] market for | APOS, U | [kWh] | 0.031 |
| Transport | Transport, freight, lorry >32 metric ton, euro5 [RoW] market for transport, freight, lorry >32 metric ton, EURO5 | APOS, U | [tKm] | 0.93 |

| Table 3. Data and equivalent process for the panel end of life – S2 scenario |
|-----------------------------------------------|------------------------|-----------------|-----------------|
| **Process** | **Equivalent process in the Ecoinvent 3 database** | **Unit** | **Quantity** |
| Disposal in landfill (30%) | Municipal solid waste (waste scenario) [RoW], treatment of municipal solid waste, landfill | - | - |
| Inputs | | | |
| Panel | - | [kg] | 5.71 |
| Electricity | Electricity, high voltage [PT] market for | APOS, U | [kWh] | 0.031 |
| Transport | Transport, freight, lorry >32 metric ton, euro5 [RoW] market for transport, freight, lorry >32 metric ton, EURO5 | APOS, U | [tKm] | 0.93 |
| Recycling (70%) | Municipal solid waste (waste scenario) [RoW] Treatment of municipal solid waste, landfill | - | - |
| Panels’ grinding | - | | |
| Inputs | | | |
| Panel | - | [kg] | 13.32 |
| Gravel avoided | Gravel, crushed [RoW] production | APOS, U (evitado) | [kg] | 13.02 |
| Diesel (for grinding) | Diesel, burned in building machine [GLO] market for | APOS, U | [MJ] | 0.51 |
### Table 4. LCIA results for the functional unit (1 m² of panel) for the S1 scenario

| Category | Unit | Total | Manufacturing | Installation | End of life stage |
|----------|------|-------|--------------|-------------|------------------|
| AC       | [g SO₂ eq] | 357.8 | 334.8 | 16.9 | 6.1 |
| EU       | [g PO₄ eq] | 216.3 | 140.9 | 26.8 | 48.5 |
| GW       | [kg CO₂ eq] | 97.4 | 77.2 | 8.2 | 11.9 |
| PO       | [g NMVOC] | 311.9 | 286.9 | 18.2 | 6.7 |
| AD       | [g Sb eq] | 1.9 | 1.9 | 0.06 | 0.003 |
| AD(FF)   | [MJ] | 1397.3 | 1339.3 | 51.9 | 6.05 |
| WS       | [m³ eq] | 17.5 | 15.4 | 1.9 | 0.2 |
| OD       | [mg CFC-11 eq] | 19.4 | 18.8 | 0.5 | 0.05 |

AC (acidification-fate not incl.); EU (eutrophication); GW (global warming - GWP100a); PO (photochemical oxidation); AD (abiotic depletion); AD(FF) (abiotic depletion - fossil fuels); WS (water scarcity); OD (ozone layer depletion).

### Table 5. LCIA results for the functional unit (1 m² of panel) for the S2 scenario

| Category | Unit | Total | Manufacturing | Installation | End of life stage |
|----------|------|-------|--------------|-------------|------------------|
| AC       | [g SO₂ eq] | 353.3 | 334.8 | 16.9 | 1.6 |
| EU       | [g PO₄ eq] | 182.0 | 140.9 | 26.8 | 14.4 |
| GW       | [kg CO₂ eq] | 88.9 | 77.2 | 8.2 | 3.5 |
| PO       | [g NMVOC] | 307.1 | 286.9 | 18.2 | 2.4 |
| AD       | [g Sb eq] | 1.95 | 1.9 | 0.06 | -0.007 |
| AD(FF)   | [MJ] | 1392.6 | 1339.3 | 51.9 | 1.3 |
| WS       | [m³ eq] | 17.2 | 15.3 | 1.9 | -0.06 |
| OD       | [mg CFC-11 eq] | 19.3 | 18.8 | 0.5 | 0.08 |

AC (acidification-fate not incl.); EU (eutrophication); GW (global warming - GWP100a); PO (photochemical oxidation); AD (abiotic depletion); AD(FF) (abiotic depletion - fossil fuels); WS (water scarcity); OD (ozone layer depletion).

### Table 6. Comparison of LCIA results for two waste scenarios

| Category | Unit | S1 | S2 | Difference | % |
|----------|------|----|----|-----------|---|
| AC       | [g SO₂ eq] | 357.8 | 353.3 | 4.5 | 1.3 |
| EU       | [g PO₄ eq] | 216.3 | 182.0 | 34.3 | 15.9 |
| GW       | [kg CO₂ eq] | 97.4 | 88.9 | 8.5 | 8.7 |
| PO       | [g NMVOC] | 311.9 | 307.1 | 4.8 | 1.6 |
| AD       | [g Sb eq] | 1.9 | 1.89 | 0.01 | 0.5 |
| AD(FF)   | [MJ] | 1397.3 | 1392.6 | 4.7 | 0.3 |
| WS       | [m³ eq] | 17.5 | 17.2 | 0.3 | 1.7 |
| OD       | [mg CFC-11 eq] | 19.4 | 19.3 | 0.1 | 0.5 |

AC (acidification-fate not incl.); EU (eutrophication); GW (global warming - GWP100a); PO (photochemical oxidation); AD (abiotic depletion); AD(FF) (abiotic depletion - fossil fuels); WS (water scarcity); OD (ozone layer depletion).

### Table 7. LCIA results for various countertop materials

| Category | Unit | Marmoleum decibel | SC36V with ceramic tile | Corian | Studied product S1 | Studied product S2 |
|----------|------|-------------------|-------------------------|-------|-------------------|-------------------|
| AC       | [g SO₂ eq] | 45.5 | NA | 297 | 324.5 | 320.2 |
| EU       | [g PO₄ eq] | 12.2 | 137 | NA | 201.3 | 167.9 |
| GW       | [kg CO₂ eq] | 7.9 | 86.3 | 94.2 | 89.5 | 81.3 |
| PO       | [g NMVOC] | NA | 431 | NA | 283.3 | 278.8 |
| AD       | [g Sb eq] | 0.004 | 64 | 0.07 | 1.78 | 1.77 |
| AD(FF)   | [MJ] | 88.2 | 1150 | 1680 | 1264.5 | 1259.9 |
| WS       | [m³ eq] | NA | 27.7 | NA | 16.0 | 15.7 |
| OD       | [mg CFC-11 eq] | 0.0208 | 11.4 | 0.01 | 17.5 | 17.5 |

AC (acidification-fate not incl.); EU (eutrophication); GW (global warming - GWP100a); PO (photochemical oxidation); AD (abiotic depletion); AD(FF) (abiotic depletion - fossil fuels); WS (water scarcity); OD (ozone layer depletion).
EPDs is 5% for the Marmoleum product [Forbo, 2018], 0% for the SC36V product [CBI Europe, 2021] and 10% for the Corian product [DuPont, 2017]. The final results are registered in Table 7.

The product under evaluation must improve its environmental performance comparing with the other products with similar function. Although only better than the Corian product, it had the best performance in two categories. However, is worth noticing that on those two categories, the Marmoleum Decibel product (which was the best performer in all other categories) did not present comparable results. It is interesting to observe that the difference between the results for the two scenarios is not significative enough to affect the “ranking” of the product in this comparison except for the Global Warming category. Therefore, it would be important to search for other alternatives to further improve the environmental profile of this product.

CONCLUSIONS

In this paper, an LCA study on a countertop material was conducted and the results obtained were presented. Two different scenarios for the end of life stage of the product were analyzed.
It was observed that the manufacturing process is the main contributor to the impact generation. It was also shown that recycling the waste at the end of panel life decreases the environmental impacts in every category, as it was expected, with the variation ranging from 0.2% in ozone layer depletion to 16.6% in eutrophication. A comparison between the product studied and products with similar functions was also conducted and although this product was not the worst performer, it has a lot of room for improvement, and it would be interesting to find better solutions for improvement of its environmental profile.

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