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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 m^2 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].

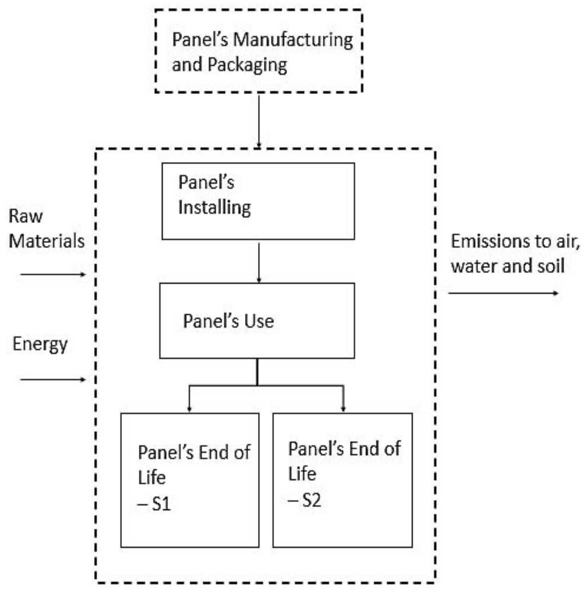

Fig. 1. System boundaries for the product

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 m^2 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 CMLIA 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	[m^3]	0.004
	Cardboard boxes	Corrugated board box {RER}| market for corrugated board box | 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 pPanel	–	[kg]	19.03 (1 m^2)
	Panel waste	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill | APOS, U	[kg]	2.11
	Packaging waste	Packaging waste (waste scenario) {PT}| treatment of packaging waste | APOS, U	[kg]	1.17

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 | APOS, U	-	-
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 | APOS, U	-	-
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 | APOS, U		
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

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 4. LCIA results for the functional unit (1 m^2 of panel) for the S1 scenario

Category	Unit	Total	Manufacturing	Installation	End of life stage
AC	[g SO_2 eq]	357.8	334.8	16.9	6.1
EU	[g PO_4 eq]	216.3	140.9	26.8	48.5
GW	[kg CO_2 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	[m^3 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 m^2 of panel) for the S2 scenario

Category	Unit	Total	Manufacturing stage	Installation	End of life stage
AC	[g SO_2 eq]	353.3	334.8	16.9	1.6
EU	[g PO_4 eq]	182.0	140.9	26.8	14.4
GW	[kg CO_2 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	[m^3 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 SO_2 eq]	357.8	353.3	4.5	1.3
EU	[g PO_4 eq]	216.3	182.0	34.3	15.9
GW	[kg CO_2 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	[m^3 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 SO_2 eq]	45.5	NA	297	324.5	320.2
EU	[g PO_4 eq]	12.2	137	NA	201.3	167.9
GW	[kg CO_2 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	[m^3 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).

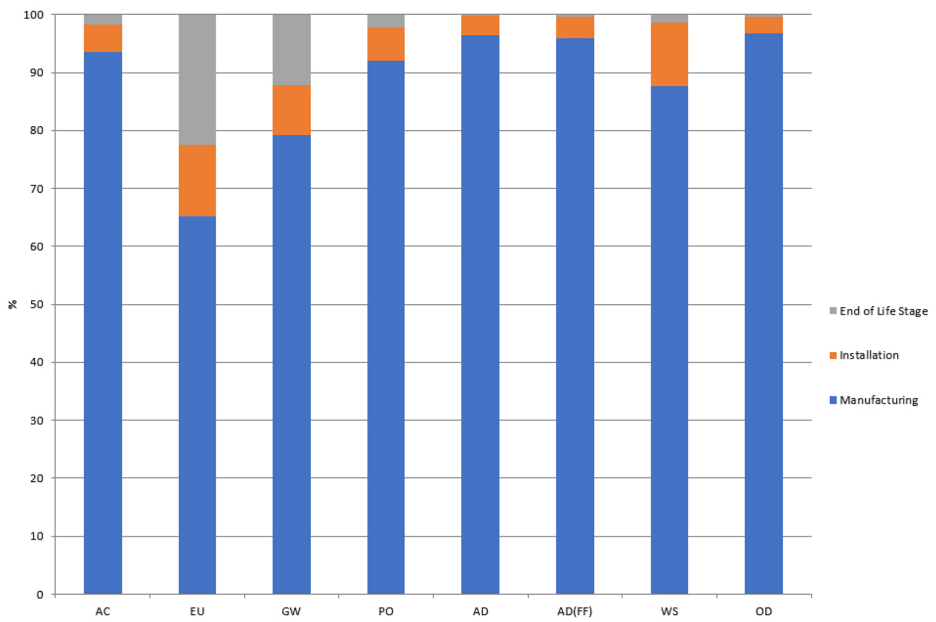

Fig. 2. Environmental profile for the functional unit (1 m^2 of panel) for the S1 scenario

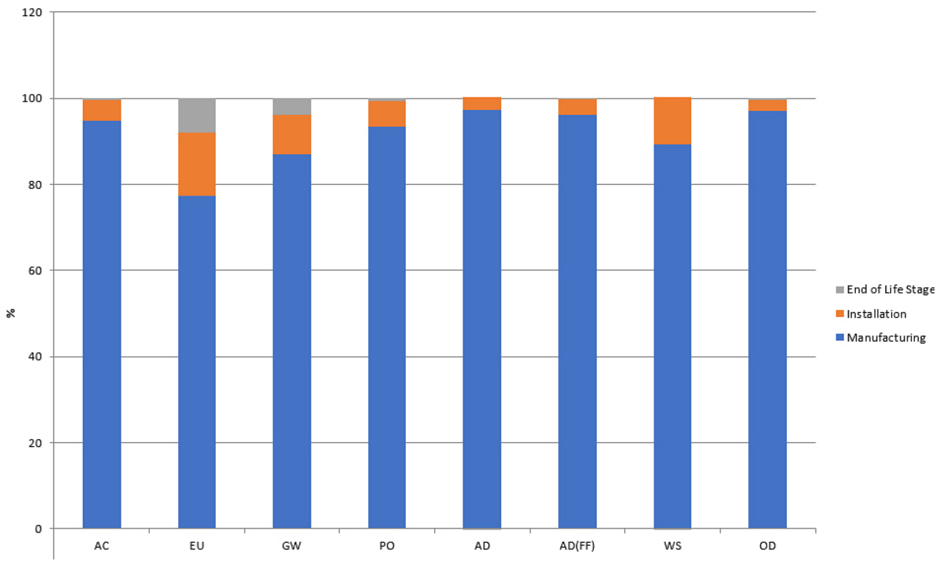

Fig. 3. Environmental profile for the functional unit (1 m^2 of panel) for the S2 scenario

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.

Acknowledgments

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REFERENCES

1. Benson C.H., Barlaz M.A., Lane D.T., Rawe J.M. 2007. Practice review of five bioreactor/recirculation landfills. Waste Management, 27, 13–29.
2. CBI Europe: EPD for SC36V with ceramic tile. Information on https://www.eco-platform.org/epd-data.html
3. Chislock M.F., Doster E., Zitomer R.A., Wilson A.E. 2013. Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems. Nature Education Knowledge, 4(4), 10.
4. Curran A., Williams I.D. 2010. The role of furniture and appliance re-use organizations in England and Wales. Resources, Conservation and Recycling, 54, 692–703.
5. Decree-law no. 102-D/2020
6. DuPont: EPD for Corian Solid Surface. Information on https:// www.corian.com/IMG/pdf/corian-solid-surface-epd.pdf
7. Finnveden G., Hauschild M., Ekvall T., Guineé J., Heijungs R., Hellweg S., Koehler A., Pennington D., Suh S. 2009. Recent developments in Life Cycle Assessment. Journal of Environmental Management, 91, 1–21.
8. Forbo: EPD for Marmoleum Decibel. Information on https://forbo.blob.core.windows.net/forbodocuments/13133/Forbo_Marmoleum_Decibel_EPD.pdf
9. International Standard Organisation, ISO 14040. 2006. Environmental management – Life cycle assessment – principles and framework, International Standard Organisation (Eds), Geneva, Switzerland, 28.
10. International Standard Organisation, ISO 14044. 2006, Environmental management-Life cycle assessment-requirements and guidelines, International Standard Organisation (eds), Geneva, Switzerland, 46.
11. PRé Consultants: SimaPro Database Manual - Methods Library. Information on https://support.simapro.com/articles/Manual/SimaPro-Methods-manual.
12. Shanshan W., Fangli S., Xinfang D. 2005. Recycling Technology of Deserted Wood Material and Our Future Research Focus. Journal of Northwest Forestry Institute, 20(2), 13–18.
13. Silva L., Silva E., Brás I., Domingos I., Wessel D., Ferreira J. 2021. A Life Cycle Assessment Study on a New Countertop Material. Key Engineering Materials, 897, 137.
14. Silva M.J.J. 2008. Avaliação do Consumo Energético no Processo de Demolição de Construções. Relatório de Projecto submetido para satisfação parcial dos requisitos do grau de Mestre Em Engenharia Civil – Especialização Em Construção Civil.
15. Vicente J., Frazão R., Silva F.M. 2018. Sustainable Product Design and the Wood Furniture Sector. Advances in Ergonomics in Design. AHFE 2017. Advances in Intelligent Systems and Computing, 588.
16. Zutshi A., Creed A., Holmes M., Brain J. 2016. Reflections of environmental management implementation in furniture, International Journal of Retail & Distribution Management, 44(8), 840–859.