SZENT ISTVÁN EGYETEM
Tájépítészeti és Tájökológiai Doktori Iskola

Main findings PhD thesis

ENVIRONMENTAL ASSESSEMENT OF

PACKAGING GLASSES WITH LIFE CYCLE ASSESSMENT

BOGÓNÉ TÓTH ZSUZSÁNNA

Budapest, 2020

Doctoral school:	Szent István University Doctoral School of Landscape Architecture and Landscape Ecology
Research field:	agricultural engineering
Head of Doctoral School:	László Bozó Professor, DSc, MHAS Szent István University Faculty of Horticultural Sciences Department of Soil and Water Management
Supervisor:	Zoltán Lakner Professor, DSc Szent István University Faculty of Food Science Department of Food Economics

....	....
Head of Doctoral School	Supervisor

THE AIM OF THE WORK

Environmental pollution and sustainability are not just a fashionable problem nowdays, but a global problem that needs solution. Climate change, increasing carbon-dioxide and methane emissions, extinction of species and depletion of raw materials are threatening our life.

One of the main reason of pollution is the unreasonably large amounts of waste from packaging materials. The most significant in volume is the one-way packaging, including most wine bottles.

The solution is to collect and refill the bottles. We have to find the optimal solution between economy and environmental impact, and have to make calculations from the design level of the product through production and use, to waste, disposal, and in better case to recycling and reuse.

One possible method and increasingly common tool for calculations is life cycle assessment.

In my dissertation, I examine with life cycle assessment the environmental impacts of glass bottles, which is almost dominant in wine bottling, and how can we influence its scale in different cases of reuse and recycling.

The aim of my research was to quantify the environmental significance of reuse and recycling with life cycle assessment.

I was looking for answers to the following questions:

What are the environmental impacts of bottles with different contents of cullet?

- How does it effect the environmental impacts the increasing the number of refilling and recovery rate?
- What are those impact categories that are clearly affected by glass production and wine bottling?

MATERIAL AND METHOD

Life cycle assessment

Life cycle assessment (LCA) is a complex method wich examines and quantifies the potential or actual impacts of the entire life cycle of a product or service on the environment, from raw material extraction through processing and use, to waste, disposal those the potential and real environmental impacts, and quantify them.

Optimally, the product's life does not end, it is reused or recycled. The life cycle assessment was conducted with te open source openLCA 1.10 software using openLCA EF_secondary_201908 and ecoinvent 3.4. databases.
The environmental impacts are primarily related to the emissions of human activities, and the impact categories are representing classes of environmental issues to which input and output data can be assigned. A common feature of impact categories is that more or less all contribute to global environmental problems.
For each impact category, the authors of impact assessment methods have defined a reference unit. For example, the impact of 1 kg of carbon dioxide on global warming 1, such as the contribution of methane emissions to global warming, is given in kg of CO_2 equivalent.
Impact categories are examined by using impact assessment methods. There are a lot of these methods, I had chosen in my research the Environmental Footprint (Mid-point) method, and the software I used to examine the EF database, only supported the use of this method.
In the first half of the dissertation, I examined the environmental effects of five different glasses with life cycle assessment-.These bottles differ in their recycled glass (cullet) contents, and in their region of manufacture.

In these analysisies, I calculated the environmental impacts of glass manufacturing processes in different impact categories.
To calculate the combined environmental impacts of glass production and technological processes (here: glass collection, washing, filling, use, collecting, disposal of waste), I created a product system in the software that I combined different glass types with basic scenarios, thus examining 21 scenarios for three selected glass types,with 0, 50, 80 and 90% recovery rate and 1, 5 and 6 refill numbers charges,
The necessary so-called inventory dates from a hungarian market-leading winery that fills thousands of wine bottles a day. For their bottled wine they

set a high deposit fee per bottle, thus achieving a collection rate of 80% so that their bottles are refilled five times.

Accordingly, I selected 10 million bottles as the functional unit to calculate the results. The elements of the examined product system are shown in Figure 1.

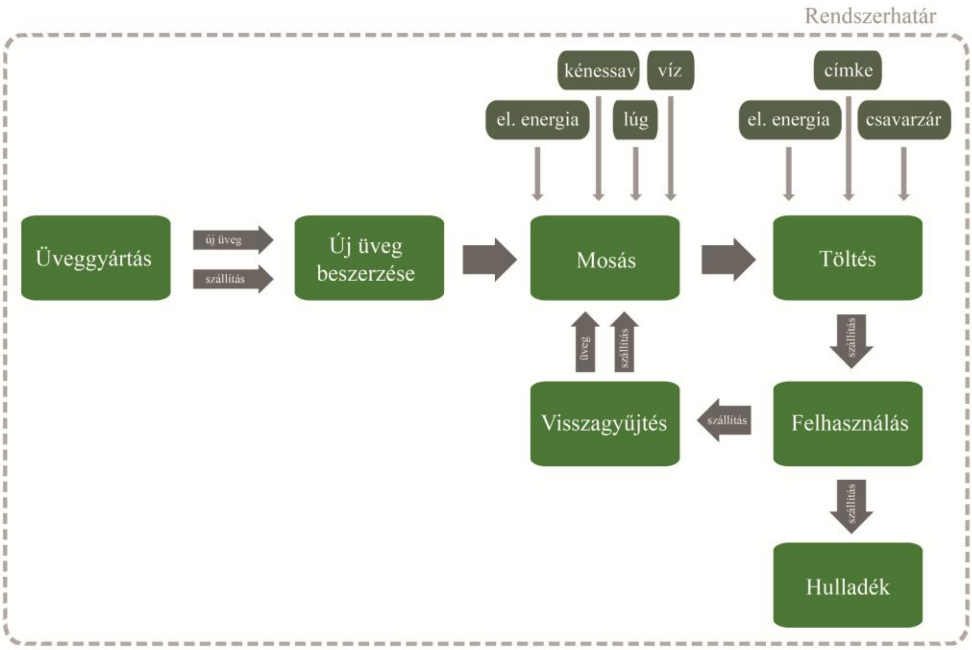

Figure 1. The examined product system

From the 19 impact categories offered by the impact assessment method, I examined 10 impact categories after preliminary calculations. These were climate change, acidification, eutrophication of freshwaters, ecotoxicity, ozone depletion, land use, depletion of mineral and fossil resources, ionizing radiation, and water use.
I separately examined and compared the scenarios modeling the present situation and the best and the worst case.
I examined the proportion of the total environmental impact of the glass production process and the what is the rate between the process and technology.
To compairing the degree of environmental impact, I normalized the calculated raw results. Normalization is an optional element of life cycle assessment. The point is to compare the raw data obtained during the impact assessment with a reference value (belonging to the impact analysis method).

This could be, for example, the average annual environmental impact of a European citizen. Thus, we can express the obtained result in terms of habitant equivalent. I also used another optional element of life cycle assessment, weighting, to clarify the interpretation of the results. Weighting is deciding which environmental effects we consider important, comparing the results, and evaluating the results qualitatively.

RESULTS

In the results of my research, I established the following regarding to the hypotheses.

H1: Those recycled bottles which are produced with more content of cullet has smaller environmental impact.

True. This was confirmed in most of the selected categories. Comparing the cullet-free bottles without cullet content, with 57%, 62.5%, 68.9% and 84.8% (last three German-made) bottles, I found that the environmental impact of German bottles was 26- 54% compared without cullet which is calculated from all average data in the world. In the GWP effect category, which is the most frequently studied effect category in the literature, the environmental impact of German bottles is 50% compared to bottles without cullet. Similar positive result can be seen for the ecotoxicity effect impact category, where the environmental impact is only less than 30% compared to bottles without cullet. The rate of environmental impact in the case of glass with a cullet content of 57% confirms the usage of cullet as much as possible, but here, presumably due to the geographical and atmospheric conditions of the region of production, POCP and AP categories show almost the same environmental impact as without cullet.

H2: Increasing the recovery rate by 10% significantly reduces the specific environmental impact.

True. Compared to one-way bottles, a reduction in environmental impact of up to 80% can be achieved in some categories. For the three highlighted scenarios, which are the current situation, the best and worst case, I found that in the AP category, the environmental impact drops to 12% when the best case is compared to the worst case scenario. This study also showed positive changes in the other impact categories without exception, which ranged from 6% to 94% based on the former comparison.

I examined separately the results of the 80% and 90% recovery rates for the 5 charges. I found that by increasing the collection load by 10%, the rate of environmental impact shows a 1% decrease in the WU impact category. Significantly better results were detected in the other impact categories. In ADP mineral there was a 4% reduction of environmental impact and in other impact categories 19-22%.

H3: Increasing the number of refill during re-use clearly has a positive effect on the environmental impact.
True. Compared to one-way bottles, increasing the number of refill and the collection rate can reduce the environmental impact up to 75%. I examined the cases when the same number of refills was 5 and the collection rate was 80% and 90%. The importance of this scenarios is because in the current situation, a bottle is filled 5 times and the collection rate is 80%. It is proved here again, depending on the impact categories there was a 4% and 22% improvement. The vast majority of cases were 20-22%. Improvements were observed in the following environmental impact categories: GWP, ETP, EP, AP, POCP, ADP (fossil), LU, and IR. In category of ADP (mineral) I could prove only 4% difference.
By increasing the number of refill from 5 to 6, assuming a recovery rate of 90%, a reduction in the environmental impact between 5% and 11% can be observed in the different impact categories. In most categories, this value

was 11%. An exception is the WU impact category, where this refill number increase does not change the results.

H4: There are environmental impact categories in which the environmental impact of glass production is not significant.
Partly true. With regard to the examined effect categories, I obtained an evaluable raw result in all impact categories during the comparison of the glasses. These, as expected, have demonstrated that higher cullet content in all categories has a beneficial effect on reducing environmental impact. If we look only at the numerical values, there is an impact category where the amount emitted seems to be negligible. Therefore, in order to support the importance of each category of impacts, they should be examined with weights, because the effect of the substances released can cause damage to health even at low doses.
Therefore, to further interpret the results, I normalized and weighted the raw environmental impact results.
Analyzing the weighted results, it was seen that there are categories that are negligible, while some effect categories such as ecotoxicity did not receive a weighting factor. The EF (Mid-point) impact assessment method also does not have a weighting factor, such as the human toxicity effect categories.
I examined the extent to which each impact category contributes to the overall environmental impact of my product system.
I selected the categories with a contribution below 5%. It was my subjective choice, I declare it to prove this hypothesis.
I calculated that the values of the POCP impact category are the same for all type of glasses (5%), the content of the glass did not affect the result.
ADP mineral value is 4-5%, EP freshwater 2-5%, EP terrestial 3-4%, WU 2-3% and EP marine 1-2%.
I proved that the rate in environmental impacts of the ODP, IR and LU

impact categories is below 1% for all glass types.
In regard to the glasses I have examined, they play a negligible role in the environmental impact of glass production.

H5: Impact categories can be identified in which the environmental impact of glass production is clearly significant.
True. By comparing the normalized and weighted results, I investigated what these effect categories might be. Based on the results calculated here, I concluded that in the life cycle assessment, the most significant result categories were AP, ADP fossil and ADP mineral, GWP, LU, RI and POCP. My calculations have shown that the most significant impact category is GWP, which is 31-36% of the total environmental impact of glass production. This high rate is due to CO2 emissions from transport and glass manufacturing technology.
The contribution of the ADP fossil impact category to the total environmental impact by 18-24% is also significant. This high value is due to the processes of energy production and transportation.
Non-European glass has a higher RI (17-18%) than European products (7-8%). Thus, the importance of this impact category can differ from region to region. This probably indicates the state of the glass production technology, whether it is up to date or not.
Also for the AP impact category, the contribution is relatively significant between 9-12%, which can be attributed to the emissions from glass production.

New results
I consider it a new scientific result the following:
1. This is the first Hungarian-language study based on manufacturer data in this field.

2. I was the first to make a life cycle assessment for a wine bottle in Hungary.

3. In my dissertation I prove quantitatively that the refilling of wine bottles several times and / or the increase of the collection rate has a positive effect on reducing the environmental impact.

4. I have identified the impact categories where glass production and bottling have a significant environmental impact.

CONCLUSIONS, SUGGESTIONS

In my research, building different scenarios, I examined different glass types, filling numbers, and collection rates in terms of how and how much it changes the environmental impact calculated in different impact categories.

Overall, I found that each of the examined factors - glass types, filling numbers, collection rate - has a smaller to a greater effect on the expected environmental impact in the impact category.

Increasing the number of refilling of the bottles by even just one causes a significant improvement, especially in high-volume production. Of course, the physical and aesthetic condition of the glass must be examined aswell. While some literature reports up to ten refills - and even more on a theoretical level - when reusing a wine bottle, the experience shows that the approx a recycled glass bottle with a cullet content of 50-60% can be refilled five times without damage of quality and aesthetics.

There is a similarly positive effect on the environmental impact values increasing the collection rate by 10%.

Currently, the collection rate in Hungary is around 50%, so this was one of the collection values during the creating of the scenarios. In the case of the company, a collection rate of 80% has been achieved, which exemplifies the current situation (scenario S3). In order to achieve even better results,- as has already been the case in some Nordic countries and Germany-, I also

expected 90% collection and reuse. As I expected, a significant reduction in pollutant emissions can also be achieved by increasing the collection rate, thereby also achieving a reduction in environmental impact.
I found that among the processes studied in the product system, the production of glass represents the largest volume in the environmental impact in the impact categories GWP, AP, EP, ET, WU.
The use of sodium hydroxide for washing and the use of low-concentration sulfuric acid for disinfection also does not have a serious impact on the environment, just as energy consumption is not decisive. However, it should be noted that wastewater treatment fell outside the boundaries of the system. The availability of data within the region also greatly influences the results obtained.
During the analysis of the glass types, I found that the region of glass production, the technical development of glass production, has a decisive influence on the environmental impact.

Overall, I have found that, since the glass bottle is expected to be the most accepted and most widely used packaging for wine in the long run, there is a need to encourage a reduction in one-way packaging and, at the same time, an increase in reuse and recovery rates.

PUBLICATIONS

BOGÓ-TÓTH, Zs., LAKNER, Z. (2013): System-based analysis of environmental effects of liquid food packaging Taylor & Francis (ISBN: 978-1-138-00046-9). Green Design, Materials and Manufacturing Processes

Edited by Telma Ferreira 2nd Sustainable Intelligent Manufacturing 26_29 June 2013 Lisbon CRC Press 2013 Pages 257–259 Print ISBN: 978-1-138-00046-9
eBook ISBN: 978-1-315-87948-2 DOI: 10.1201 / b15002-49

BOGÓ-TÓTH Zs, LAKNER Z (2014) Multicriterial optimization of liquid food packaging systems. Acta Alimentaria 43: 29–35. https://doi.org/10.1556/AAlim.43.2014.Suppl.5

BOGÓ-TÓTH, Zs., LAKNER, Z. (2014): Strategic problems of agribusiness development and environmental burden in light of life cycle analysis in Hungary, Procedia - Social and Behavioral Sciences Vol. 143 (2014) pp. 1025-1030

BOGÓNÉ TÓTH, Zs, SZILÁGYI, A: Environmental impact assessment of packaging bottles. Eco-Matrix 8 (2020) 22-30. ECO-MATRIX: ONLINE JOURNAL OF THE LCA CENTER ASSOCIATION, LCA Center Association, Miskolc, 2020, ISSN: 2061-344X