Life cycle assessment of float glass products for the determination of environmental label criteria: the role of cullet usage

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1. Introduction

The glass industry is an energy-intensive sector with significant use of non-renewable sources. A major part of the energy is consumed in furnaces to meet the high-temperature requirements, where raw materials are melted using fossil fuels in the production processes. These fossil fuel-fired combustion processes, together with raw material decomposition, result in various atmospheric emissions such as CO_2, SO_2, NO_x, and particulate matter (IFS, 2007). The environmental aspect of glass manufacturing processes is of great importance in all decisions made during process improvement and the development of emission prevention and minimization approaches. In this regard, the scope of environmental impact assessment studies for glass manufacturing has been extended to adopt the life cycle thinking, including all life cycle stages of products from raw material extraction to the end of life (Guinee, 2011). This approach requires evaluation of environmental impacts, which can be achieved through the Life Cycle Assessment (LCA) methodology defined by the ISO 14040 and ISO 14044 standards. The most widely used and validated holistic approach for the environmental impact assessment of building materials such as float glass is the LCA methodology, and the outputs of LCA applications are considered important data for product and production improvement as well as for decision-making (Santos, 2014). At this point, as a solution for the high emissions, increasing the cullet usage ratio by 10% in the batch process provides a reduction in the use of raw materials while reducing energy consumption by 2-3 % in the furnaces (Scalet et al, 2013). Principally, all internal cullet is recycled to the melting furnaces directly within the production line, which corresponds to approximately 10%. Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control) Best Available Techniques (BAT) Reference Document for the Manufacture of Glass adopted by the European Commission also suggests that the total cullet use in the raw material should be between 10-25% in float glass production (Roudier et al., 2013). Opportunities for using a higher cullet ratio in the process are highly dependent both on the finished product quality requirements and the post-consumer cullet recycling rates. The usage of cullet in float glass production is also crucial for the circular economy approach is one of the pillars of the EU Green Deal's plan.

Environmental labeling is a voluntary award program that aims to promote products with reduced environmental impact throughout their entire lifecycle and to provide consumers with accurate, non-misleading, science-based information about the environmental impact of products. The Environmental Label System in Türkiye has been developed with the Environmental Label Regulation that came into force in 2018. As of December 2022, criteria for 8 product groups (textile, ceramic covering, tissue paper, touristic accommodation, hand dishwashing, personal care cosmetic, glass, laundry and dishwasher detergent products) have been published in the Environmental Label System in Türkiye. Although the glass product group criteria have not been published in the EU Eco-label system yet, the Turkish Environmental Label system has published criteria for float glass, glass container, and glassware as three glass product groups in 2021. In line with the studies on the determination of environmental label criteria of glass products within the Turkish Environmental Label system, this study aims to evaluate the environmental impacts of increased cullet use in float glass production by comparing baseline and alternative scenarios using the LCA approach.

2. Materials and methods

The LCA study, which was carried out according to TS EN ISO 14024, TS EN ISO 14040/44 standards, was based on primary data for the production by Türkiye's float glass manufacturers and secondary data retrieved from the literature. In the LCA studies, the functional unit for float glass was determined as 1 kg of float glass product, and the cradle-to-grave approach was adopted. The life cycle of float glass was structured into five main stages, namely, raw material extraction, raw material acquisition, float glass production, float glass usage, and end of life. The environmental impacts were calculated with the CML-IA Baseline Method using the Ecoinvent v3.7 database and SimaPro v9.2 software.

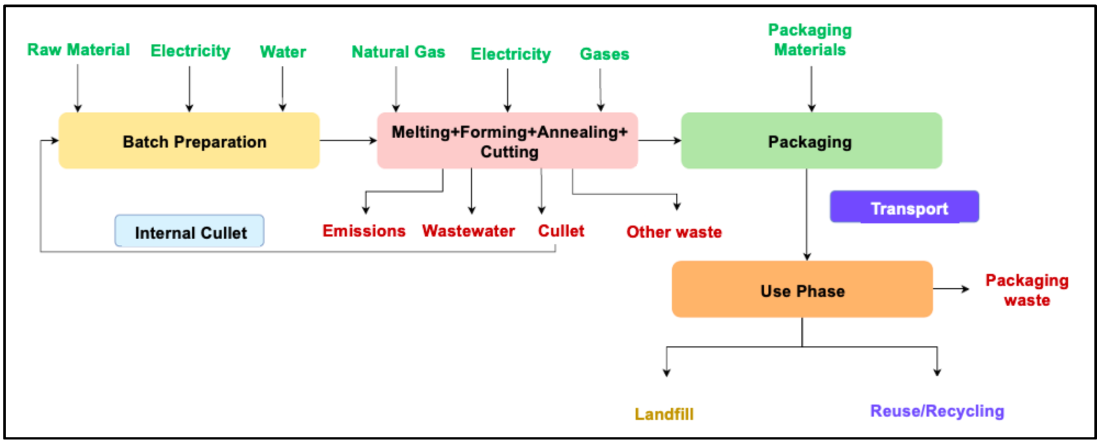

Figure 1. The system boundaries of float glass production used in LCA studies

3. Results and discussion

A cradle-to-grave LCA of float glass products was made based on the CML-IA baseline method. The distribution of environmental impacts of float glass products among different life-cycle stages is illustrated in Figure 2. As can be seen, most of the environmental impacts occur during the batch preparation (28-76%) and melting, forming, annealing, and cutting (12-67%) processes of the entire life cycle of float glass products. The use phase has negligible environmental impacts (less than 1%). In addition, LCA analysis showed that the main contributor to the batch preparation process is the consumption of soda ash and fossil-based energy for the melting process. Among the fossil-based energy sources, natural gas, mostly used for melting in furnaces, has the highest impact on the melting process. Electricity exerts the second most significant impact on the melting process. Considering the direct relation between the cullet usage in batch preparation and energy usage in melting processes, different scenarios were assessed to reveal the effect of external cullet usage on the environmental performance of float glass.

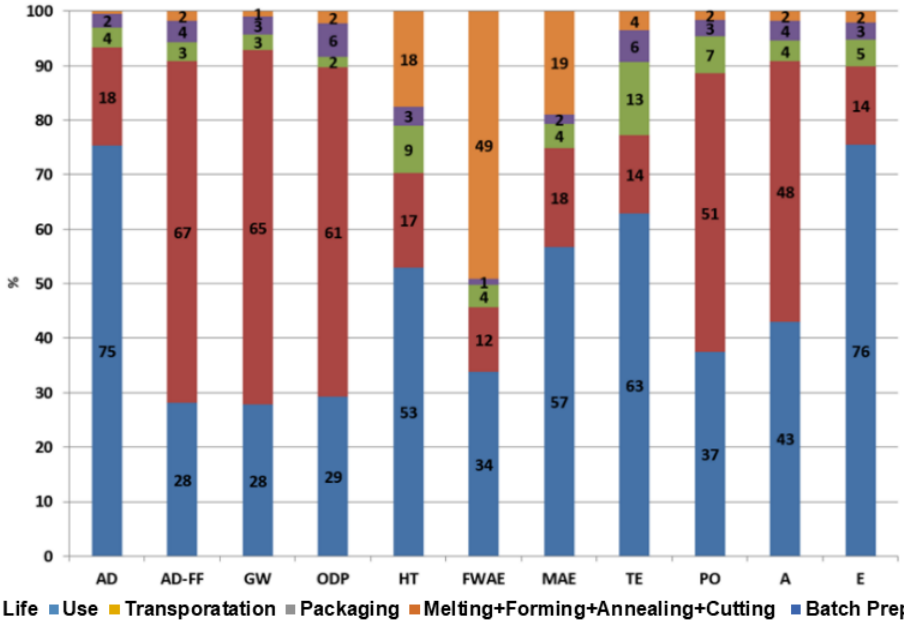

Figure 2. The distribution of the environmental impacts for 1 kg float glass product based on CML-IA baseline method: CML-IA baseline V3.04/EU25/characterisation. AD, abiotic depletion; AD-FF, abiotic depletion (fossil fuels); GW, global warming; ODP, ozone layer depletion; HT, human toxicity; FWAE, freshwater aquatic ecotoxicity; MAE, Marine aquatic ecotoxicity; TE, terrestrial ecotoxicity; PO, photochemical oxidation; A, acidification; E, eutrophication

The baseline scenario is the current production cycle in which internal glass cullet use is 0%. The Three alternative scenarios were identified with 5, 10 and 15% external cullet usages in the float glass production. Taking the baseline scenario as a reference, a relative comparison of alternative scenarios in terms of the magnitude of impacts at different impact categories was performed, and the results given in Table 1 were obtained. As expected, the results revealed that Scenario 3 (15% external cullet usage) shows the best environmental performance in all environmental impact categories. With 15% external glass cullet usage, the reductions in impacts in all categories are considerable, ranging between 4.5% and 11.3%. When the decrease in impacts at different categories was assessed, it was seen that the decrease from the baseline scenario to Scenario 3 is the largest in eutrophication and abiotic depletion categories due to the largest reduction of soda ash usage as a raw material. Thus, it could safely be inferred that the use of glass cullet significantly reduces the environmental impacts of float glass production.

Table 1. The environmental impact results of the external cullet use scenarios

Percentage of External Cullet Use (%)	AD	AD-FF	GW	OLD	HT	FWAE	MAE	TE	PO	A	E
Baseline (0%)	100	100	100	100	100	100	100	100	100	100	100
Scenario 1 (5%)	96.3	97.9	98.5	97.8	96.7	97.5	97.6	96.7	97.6	97.3	96.2
Scenario 2 (10%)	92.0	95.7	97.0	95.6	93.5	95.0	95.3	93.4	95.1	94.7	92.4
Scenario 3 (15%)	88.8	93.6	95.5	93.4	90.2	92.5	92.9	90.2	92.7	92.0	88.7

4. Conclusions

In conclusion, the obtained results showed that batch preparation and melting stages are the main contributors to the environmental impacts of float glass production. Besides, the use of cullet to replace the raw materials in batch preparation notably reduces all environmental impacts, particularly eutrophication and abiotic depletion impacts, due to the corresponding large reduction in the use of soda ash as a raw material. Thus, the usage of cullet in float glass production should be promoted to reduce the environmental impacts of float glass production.

5. References

International Finance Corporation. 2007. Environmental, Health, and Safety Guidelines for Glass Manufacturing. Washington (WA), USA: World Bank Group.

Santos CG. 2014. Using life cycle assessment (LCA) methodology to develop eco-labels for construction and building materials. In: Eco-efficient construction and building materials-Life cycle assessment (LCA), eco-labelling and case studies. Cambridge (CB), UK: Woodhead Publishing. p 103-104.

Scalet BM, Garcia Muñoz M, Sissa AQ, Roudier S, Delgado Sancho L. 2013. Best Available Techniques (BAT) Reference Document for the Manufacture of Glass. Seville (SVQ), Spain: European Commission.

Guinee JB, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonamici R, Ekvall T, Rydberg T. 2011. Life Cycle Assessment: Past, Present, and Future. Environ. Sci. Technol. 45, 90–96.

Roudier, S., Sancho, L. D., Scalet, B., & Muñoz, M. G. (2013). Best Available Techniques (BAT) Reference Document for the Manufacture of Glass: Industrial Emissions Directive 2010/75/EU:(Integrated Pollution Prevention and Control) (No. JRC78091). Joint Research Centre.

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