International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume –05, Issue – 06, June 2020, PP – 26-33

Environmental Benefits of Glass Recycling

Burçin ATILGAN TÜRKMEN[1]
[1]*(Chemical Engineering, Bilecik Şeyh Edebali University, Turkey)*

Abstract: Glass is produced from a significant amount of raw materials.Glass production is an energy-intensive process since large quantities of material need to be heated to high temperatures. Therefore, it is necessary to improve the environmental sustainability of glass production. Recycled glass (cullet)usage reduces emissions and consumption of energy and raw materials. However, the cullet process requires high quantities of energy.This paper aims to assess and compare the life cycle environmental impacts of two different recycling rates of glass beverage packaging in Turkey. Life cycle assessment has been used to evaluate the environmental sustainability of the glass production following the ISO 14040/14044 standards. The environmental impacts of glass with 44% cullet and glass with 65% cullet are estimated and compared in this study. In total eleven environmental impact categories have been estimated according to the CML 2001 method, using GaBi LCA software.The use of cullet as input in the manufacturing glass process allows a decrease in the consumption of raw materials and a major reduction in energy consumption. The results of this paper show that cullet reduces all the life cycle environmental impacts of glass production up to 31%. Most of the environmental impacts are from the production of glass packaging stage. The environmental impacts can be reduced further by improving the glass cullet process and increasing the cullet utilisation.

Keywords: Environmental sustainability, Glass packaging, Life cycle assessment, Recycling, Turkey

I. INTRODUCTION

Glass is a common part of our daily life. It is commonly used in containers, mirrors, bottles, pots, home glass and artwork. Glass is an inorganic, hard, and fragile material. It has an amorphous structure.It is a widely used group of materials that can be shaped and pass visible wavelengths of light (400 – 700 nm) [1].

Glass has not only one single structure. There are several various styles of glass that all have different functions and applications[2]. The most used glass type classification is based on its chemical composition, resulting in four major groupings: soda-lime glass, lead crystal and crystal glass, borosilicate glass and special glass. The first three of these categories constitute over 95% of all manufactured glass. The remaining 5% accounts for different types of special glass formulations manufactured mainly in small quantities[3, 4].

Glass is made of all-natural raw materials such as silica sand, soda, feldspar, dolomite, limestone, as well as recycled glass (cullet). The raw materials that make up the glass differ depending on the types of glass. Silica sand and cullets are materials that form glass, while soda ash, limestone, dolomite, feldspar, alumina, metal oxides, sulphates, nitrates are intermediate materials modify the glass. For the different colours, chemicals such as iron oxide for green colour and cobalt for blue colour are added [2]. Depending upon the type of glass to be manufactured, suitable raw materials are collected. The collected raw materials and cullet are finely powdered in grinding machines. These materials are accurately weighed, and mixed. This mixture of raw materials which is ready for melting is called batch. The homogeneity of the glass produced is determined by the homogeneity of the batch. Batch is charged into a large furnace to be melted around 1550-1650°C. Melting phase is a combination of chemical and physical transformations. The raw materials are transformed into molten glass, that usually exits the furnace, after refining at around 1200°C. The molten glass is given a suitable shape or form. Specific shaping methods are used to produce various types of containers: blow-and-blow is mainly used for bottles, while press-and-blow is mainly used for jars. After being manufactured and shaped, the glass products are cooled down slowly and gradually to release stress from the glass products. This process of slow and homogeneous cooling of glass products is known as the annealing of glass. This is a very important step. An annealing oven or lehr heats the container to around 500°C, then cools it depending on the thickness of the glass up to 60 minutes [3]. When glass products are allowed to cool down quickly, the superficial layer of the glass cools down first as glass is a bad conductor of heat. The packaging is the last step of glass products manufacturing. Eventually, the completed containers are packed and placed in pallets or boxes ready for delivery. The steps for producing glass containers are the same when they use virgin raw materials or cullet[1, 3].

Air pollution and the use of energy are major environmental threats to the glass sector. Glass processing is a high temperature, an energy-intensive procedure which results in the emission of combustion such as carbon dioxide and sulfur dioxide, and high-temperature oxidation of atmospheric nitrogen. Emissions from furnace also involve dust generated mainly by volatilization and subsequent condensation of volatile batch materials [3, 5].

Container glass is made from a basic soda-lime formulation. It is the glass industry's largest market, accounting for more than 50% of total glass production. The sector covers the manufacture of glass packagings such as bottles and jars used for packaging food, beverages, cosmetics, pharmaceuticals, and technical products. The beverage industry accounts for approximately 75% of the glass containers. The food sector is the second sector accounts for almost 20% of the total amount of containers for glass packaging. The remaining 5% is used within the cosmetics and pharmaceutical sector, mostly in the form of all type of small bottles [2, 3].

Glass is one of the most recycled foods and beverage packaging material. In 2018, the EU28 countries' average recycling rate for glass packaging has increased to 76.2%. Any of the 30 billion glass packaging or containers produced go back to one of the 160 glass facilities in Europe [6]. In the same year, the glass packaging recycling rate was27% in Turkey [7].

Glass is a permanent material that can be unendingly recycled into new packaging. Cullet is the recycled glass, where cullet can be used instead of using raw materials for glass production. Glass processing is a high-volume process that converts vast quantities of substances into consumer goods, requiring significant amounts of fossil fuels and electricity. The use of cullet in the process of glass manufacturing brings considerable environmental benefits. The use of cullet in production requires fewer raw materials and energy resources, both leading to lower carbon footprints [8].

The glass industry is working to support the environment by recycling. This paper addresses the question of whether glass packaging recycling reduced environmental impacts. The aim of the study is to the quantity and compare the environmental impacts for the different cullet usage in glass production. Life cycle assessment method is used to assess the environmental impacts.

II. METHODOLOGY

Life cycle assessment (LCA) has been used as a tool to compare the environmental impacts of glass beverage packaging produced with two different cullet rates. LCA has been carried out in compliance with the ISO 14040 and 14044 standards [9, 10]. The methodology, the goal and scope of the study, inventory data and the assumptions for this assessment are described in more detail in the following sections.

2.1 Aim and Scope

This study aims to evaluate the life cycle environmental impacts of glass beverage packaging produced with different recycling rates. The packaging type was selected as white glass. The facility is in Turkey. The functional unit is defined as 1 kg of formed and finished glass beverage packaging.

Figure 1 shows the product system and system boundaries. The system boundaries are defined according to the goal of the study. The scope of the study is from cradle to gate. As presented in Figure 1, the system boundaries include the following life cycle stages: construction of the facility, raw materials extraction and processing, transportation of the raw materials, glass packaging production and waste management. Since the functional unit is related to the production rather than the use of the bottle, distribution and reuse are outside the system boundary.

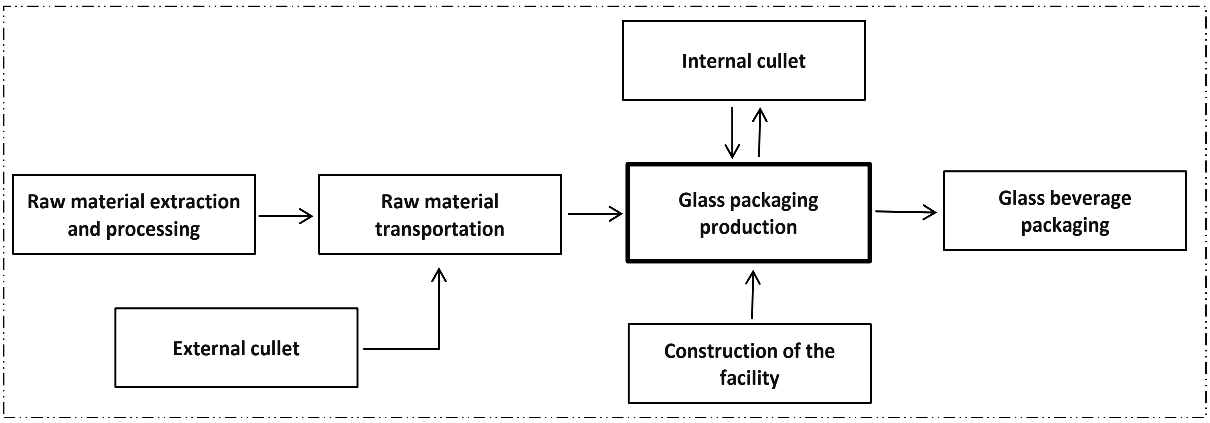


Fig. 1: Life cycle stages of glass bottle production

2.2 Inventory Analysis

Primary data of packaging glass production were collected for the year 2018. Data for the life cycle assessment was obtained from the websites, industry reports, literature, and private communication. Also, the Ecoinvent database, CCalC database and GaBi v9.2 software packages have been used to complete the life cycle inventory of the system[11-13]. The following processes are included in the cradle-to-gate system boundaries.

The selected plant is a typical glass production plant, with natural gas-fired furnaces operating. Glass beverage packaging production stage consists of raw material preparation (blend), preheating, oven, annealing, shaping, and packaging steps. The common glass beverage stages for melting and forming glass were considered in this study. Glass batch, which is a mixture of sand, soda ash, dolomite, feldspar, limestone, cullet, and additional raw materials is melted at approximately 1600°C in the furnace to get the molten glass. The melting process aims to transform the batch materials into a melted glass ready to be used in the forming process. The furnace is heated using natural gas. The molten glass is removed from the furnace, cooled to a uniform temperature, and formed. The forming process has a limited material and energy consumptions compared to the melting processes. This step does not require heat but the only mechanical press and compressed air. Formed glass is reheated and gradually cooled to relieve any stresses and strengthen. The mixture in the molten state is given to the forming part. The shaping of the glass happens with the machine. The glass is reheated and cooled to the ambient temperature, eliminating the internal stresses, and making the glass more durable. The products coming out of the cooling unit collection band come to the packaging part which is the last step of glass production [3, 14].

Facility installation stage includes the construction of the factory and the installation of the systems used in the factory. The data for this stage obtained from the Ecoinvent database [2]. The production facility is assumed as a typical container glass plant with a production amount of 266 kt per year and a total life span of 50 years.

Raw material supply stage includes raw material extraction and pretreatment processes. The main raw materials used in glass beverage packaging production are silica sand, soda ash, dolomite, limestone and additional raw materials. Recycled scrap glass as a raw material in glass manufacturing. The scrap glass produced at the manufacturing site and recycled on-site as an internal loop is called internal cullet. The scrap glass that is produced as post-consumer waste and recycled through external processing, sorting and treatment in the glass industry is called external cullet[14]. Internal cullet is washed and added to the batch while external cullet is transported, stored and then washed before use.

Raw material transportation stage covers the transportation of raw materials to the manufacturing facility and within the facility. Transports of raw materials used for glass bottle production are modelled according to the real transport means and distances. Since the most important raw materials used in glass production are found in Turkey, glass production is largely carried out with domestic raw materials. Soda, dolomite, packaging material and external cullet come from Turkey. As presented in Table 1, the raw materials used in glass packaging transported to the production facility by lorry or ship.

Table 1: Raw material transportation data

Raw material	**Country**	**Lorry (km)**	**Country**	**Lorry (km)**	**Ship (km)**
Silica sand	Turkey	40	Egypt	750	640
Soda	Turkey	785	-	-	-
Dolomite	Turkey	40	-	-	-
Limestone	Turkey	40	Turkey	300	-
Cullet (external)	Turkey	100	-	-	-
Packaging material	Turkey	150	-	-	-

In the glass beverage packaging process, the ingredients such as silica, limestone and soda are first blended with cullet. The composition of the glass packaging modelled in this study is shown in Table *2*. The composition calculated based on the collected data and Ecoinvent database [2] for the usage of 44% and 65% of cullet. Using 100 kg of cullet leads to saving 120 kg of glass raw material[15].

Table 2: The glass composition data

Raw materials	44% cullet	65% cullet
Silica Sand	31.0%	20.0%
Soda	10.0%	6.0%
Feldspar	3.3%	2.8%
Dolomite	2.0%	1.9%
Limestone	9.7%	4.3%
Cullet	44.0%	65.0%

Glass packaging manufacturing is a very energy-intensive process. The most intensive process is the melting furnace, that can account up to 80% of the total energy consumption of the plant. The most used carriers in glass packaging are electricity and natural gas. Glass cullet reduces raw materials and energy required to make glass packaging. Generally, a 10% increase of cullet into packaging glass melting mass decreases the energy consumption by about 2-3%[16]. The amount of energy consumed in two types of glass production is calculated based on the literature and Ecoinvent database [2], see Table 3. Regarding the energy for the production of glass packaging, life cycle impacts of Turkey's electricity generation based on Atilgan and Azapagic [17] has been used. Turkey's electricity generation statistics in 2018 [18] has been considered for the LCA modelling of Turkey’s electricity mix. Natural gas production and distribution up to the facility have been modelled using based on Atilgan and Azapagic [17]. Again, the more recent data related to natural gas composition and transportation for Turkey have been used [19, 20].

Table 3: The energy data

Energy	44% cullet	65% cullet
Electricity (MJ/kg)	0.92	0.82
Natural gas (MJ/kg)	3.75	3.47

The types of wastes from glass beverage packaging are classified into three classes, namely hazardous waste, non-hazardous waste and radioactive waste. Hazardous waste is mainly produced during the production phase of glass packaging. Non-hazardous waste is mainly linked to the stage of supply of raw materials and radioactive waste originates from background processes. The waste management phase involves the process of disposal of waste produced within the plant.

III. RESULTS AND DISCUSSION

The glass beverage packaging systems have been modelled using GaBi v9.2 software [12] and the environmental impacts have been estimated according to the CML methodology [21]. The following impacts are considered: abiotic depletion potential elements (ADP), abiotic depletion potential fossil (ADP fossil), acidification potential (AP), eutrophication potential (EP), freshwater aquatic ecotoxicity potential (FAETP), global warming potential (GWP), human toxicity potential (HTP), marine aquatic ecotoxicity potential (MAETP), ozone layer depletion potential (ODP), photochemical ozone creation potential (POCP), and terrestrial ecotoxicity potential (TETP).

The impacts are estimated at the product level per kg of glass packaging with two different recycling rates. The modelling results indicate a reduction in the life cycle environmental impacts of packaging glass production with an increase in recycling of glass. Most of the environmental impacts are from glass production stage followed by raw material extraction and processing, transportation, and waste management. The results in Fig.2 suggest that using cullet in the batch reduces all the environmental impacts of glass beverage packaging production up to 31%. These results are discussed in more detail below.

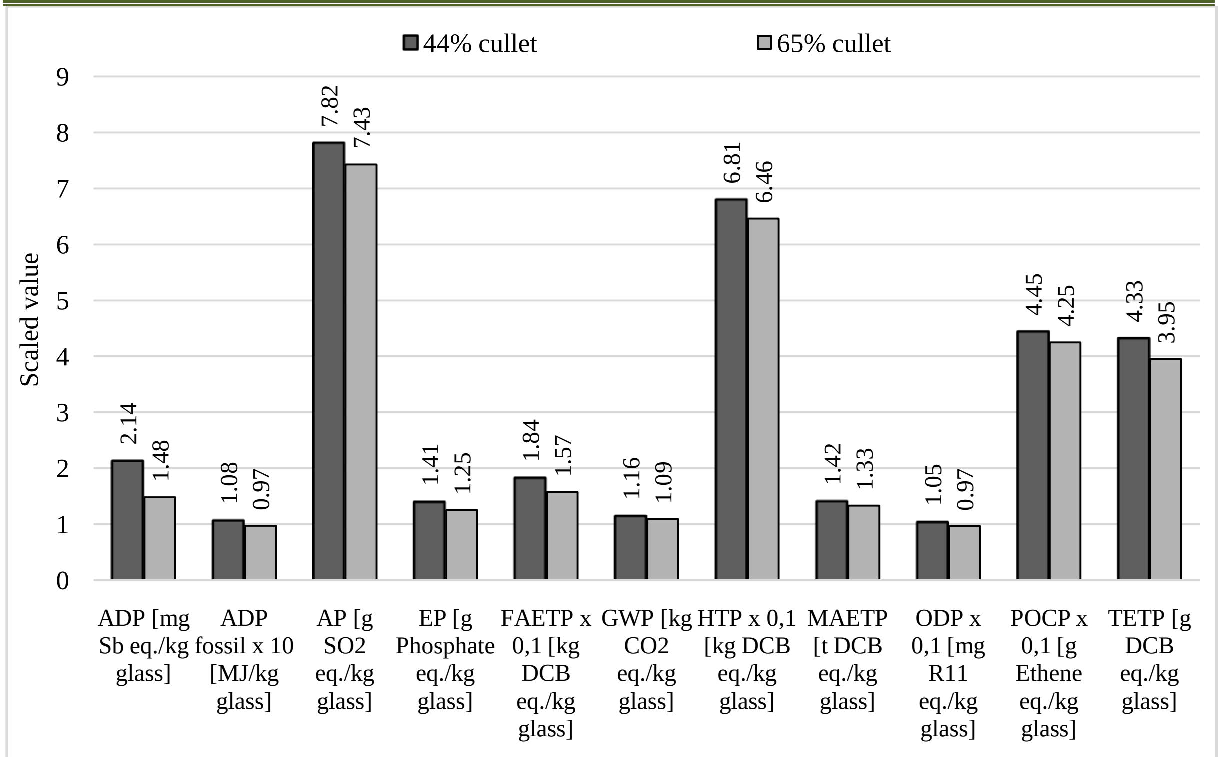
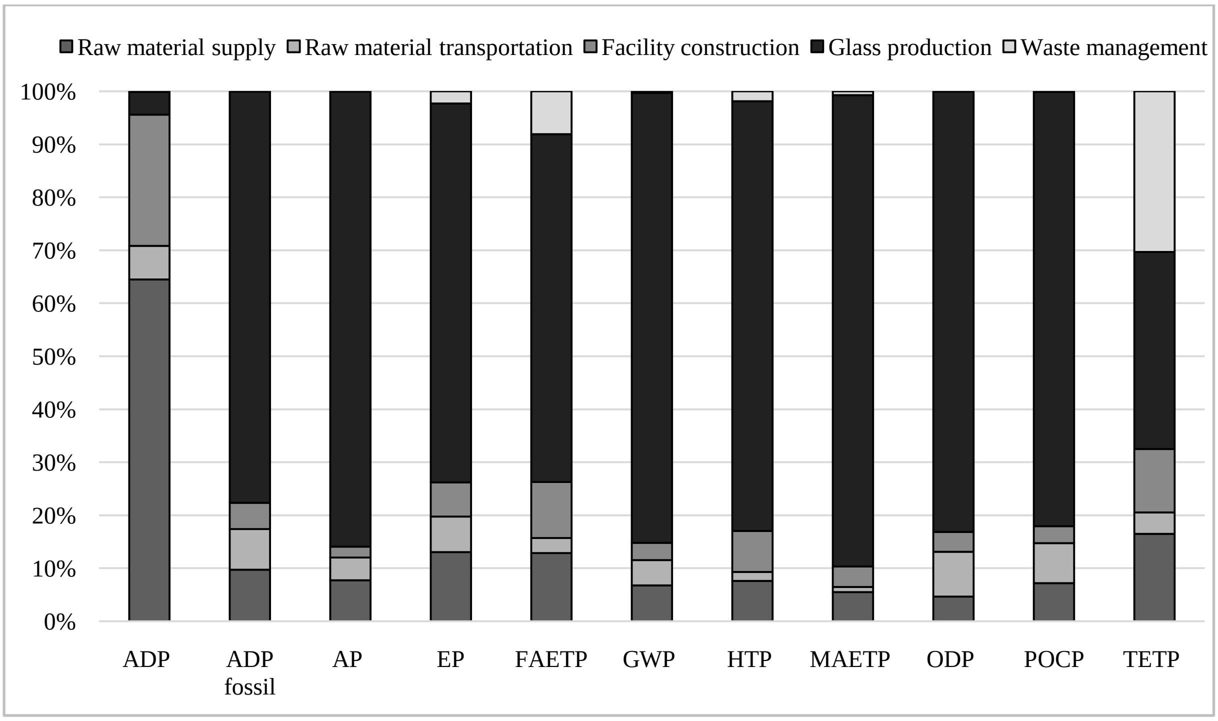
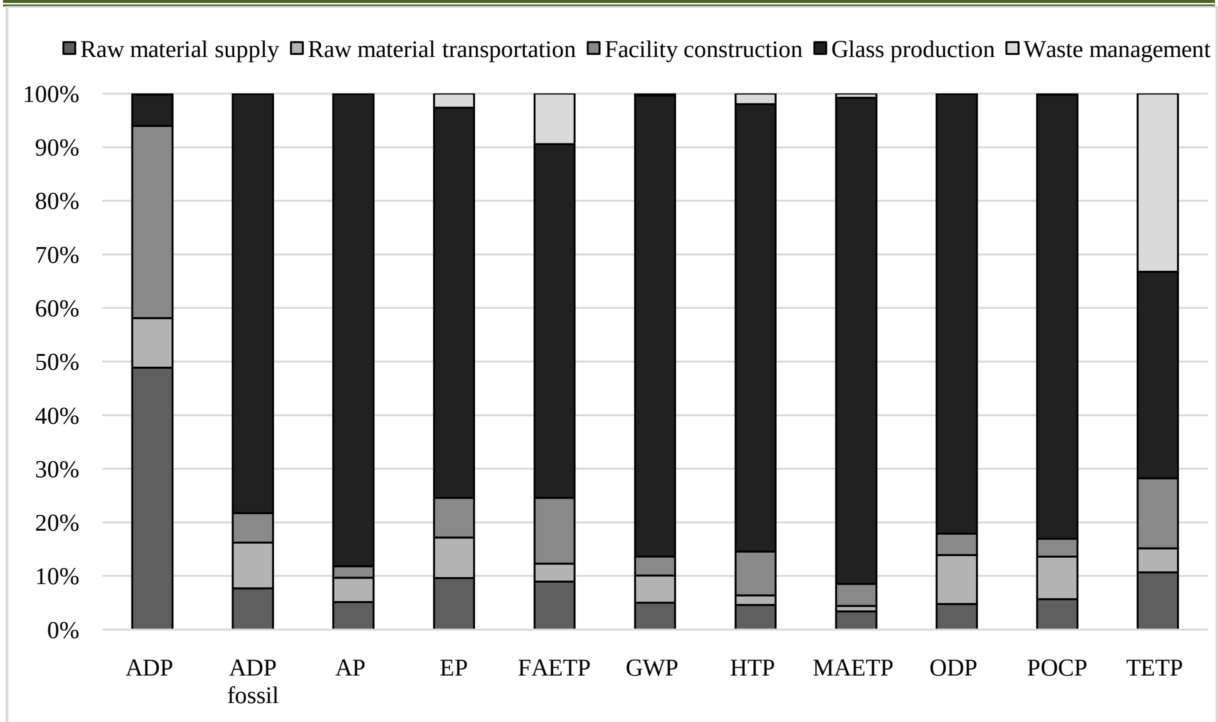


Fig.2: Comparison of life cycle environmental impacts from 1 kg glass beverage packaging with different cullet percentage
[Some impacts have been scaled to fit.]



(a) 44% cullet



(b) 65% cullet

Fig.3: Life cycle impacts of the glass production showing the contributions of the life cycle stages

3.1 Global warming potential (GWP)

As presented in Fig.2, the total GWP is estimated at 1.16 and 1.09kg CO_2-eq. per kg beverage packaging glass for the cullet amount of 44% and 65%, respectively. The impacts from the 65% cullet used composition is around 6% lower than from the 44% cullet used composition. This impact is largely due to the impacts of glass production, see Fig.3. This stage is a significant emitter of greenhouse gases, especially CO_2.

3.2 Other environmental impacts

The depletion of elements for 44% cullet used glass is 2.14 mg Sb-eq./kg glass, approximately 31% higher than for 65% cullet used glass. Sodium chloride, gold and copper are the main elements depleted. For all two types of glass type, raw material supply stage is the main source of this impact (Fig.3).

As shown in Figure 2, the total abiotic depletion potential (fossil) is estimated at 10.8 MJ per functional unit for 44% cullet used packaging glass. The ADP fossil from 65% cullet used glass is around 10% lower than from 44% cullet used glass.

Glass with 44% cullet has the acidification potential of 7.8 g SO_2-eq./1 kg beverage glass packaging. Calculated at 7.4 g SO_2-eq./1 kg beverage glass packaging, the impact glass with 65% cullet is 5% is lower than the 44% cullet one, see Fig.2. For both, this impact is mainly due to the emissions of sulphur dioxide and nitrogen oxides to the air.

The EP for 44% cullet glass is equal to 1.4 g PO_4-eq./per kg glass. The EP for 65% cullet one is approximately 11% lower (1.25 g PO_4-eq./kWh) than from 44%cullet mixed glass packaging. For both types of glass, most of the impact comes from glass production step.

The value for FAETP for 65% cullet used glass beverage packaging is 0.16 kg DCB-eq./kWh, around 24% lower than for the glass with 44% cullet.

The HTP for glass with 44% cullet is estimated at 0.6 kg DCB-eq./1 kg glass, around 5% higher than for glass with 65% cullet, see Fig.2. This impact is mainly due to the glass production stage.

Glass with 44% cullet emits 1.42 t DCB-eq./kg glass, nearly 6% more than glass with 65% cullet (1.33 t DCB-eq./kg glass). For all two types of glasses, the production stage is the main source of MAETP (Fig.3), mainly due to the heavy metal emissions to water.

The ODP of 44% cullet used glass is estimated at 105µg R11-eq. per kg glass. ODP from 65% cullet used glass is nearly 8% higher (97 µg R11-eq. per kg glass). As illustrated in Fig.3, the large majority of this impact is due to glass production.

As indicated in Fig.2, glass with 44% cullet and 65% cullet have the POCP of 0.46 g C_2H_4-eq./kg glass and 0.43 g C_2H_4-eq./kg glass, respectively.

The TETP of the 44% cullet used packaging glass is equivalent to 4.33 g DCB-eq. per kg glass and that of 65% cullet used packaging glass to 3.95 g DCB-eq. per kg glass.

IV. CONCLUSION

This paper presents an environmental comparison of two different cullet ratio used for packaging glass production. This study used the LCA method to assess the life cycle environmental impacts of glass production in Turkey. The LCA software tool GaBi v9.2 has been used for LCA modelling. The environmental impacts have been estimated according to the CML 2001 method.

The results obtained from the assessment of the glass packaging life cycle environmental impacts confirmthat reductions of environmental impacts up to 31% can be achieved with increase cullet from 44% to 65%. Most of the environmental impact correlates directly to the raw material and energy used in the process. The use of cullet in the process of glass manufacturing allows a reduction in raw material uses and energy consumption. As a result of this, the environmental impacts reduced by increasing the cullet ratio in the glass composition. For example, displacing raw materials by cullet saves 70 kg of CO_2-eq. per tonne of glass. The environmental impacts can be reduced further by increasing the cullet utilisation and improving the glass cullet process.

The amount of raw material is also important to reduce environmental impacts. Product lightweight in glass containers and packaging should be considered to improve the environmental sustainability of the sector.

The environmental sustainability of glass with different cullet ratio should be assessed in future studies. However, the cullet process requires high quantities of energy. The reuse alternative for glass packaging, which needs less energy-intensive processes, maybe another scenario that possibly contributes to further the impact.

REFERENCES

[1]. Bansal, N.P. and Doremus, R.H., *Handbook of glass properties*. 2013: Elsevier.

[2]. Hischier, R., *Life Cycle Inventories of Packaging and Graphical Paper. Final report Ecoinvent data v2.0 No. 11*. 2007: Swiss Centre for Life Cycle Inventories, EMPA- TSL, Dübendorf, CH, Online-Version under www.ecoinvent.ch.

[3]. Sissa, A.Q., et al., *Best Available Techniques (BAT) Reference Document for the Manufacture of Glass Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)*. 2013, European Commission, Institute for Prospective Technological Studies (Joint Research Centre).

[4]. Nilsson, L., *Cleaner production: technologies and tools for resource-efficient production*. Vol. 2. 2007: Baltic University Press.

[5]. Bank, W., *Environmental, Health, and Safety Guidelines for Glass Manufacturing*, World Bank Group, Editor. 2007: Washington, D.C.

[6]. FEVE, *Recycling Statistics 2017*, FEVE - The European Container Glass Federation, Editor. 2018.

[7]. PAGÇEV, *Atık İstatistikleri*. 2019, Türk Plastik Sanayicileri Araştırma Geliştirme ve Eğitim Vakfı Geri Dönüşüm İktisadi İşletmesi: Ankara.

[8]. Testa, M., et al., *Long-Term Sustainability from the Perspective of Cullet Recycling in the Container Glass Industry: Evidence from Italy*. Sustainability, 2017. **9**: p. 1752.

[9]. ISO, *Life Cycle Assessment - Principles and Framework*. 2006, International Standard Organization: Geneva, Switzerland.

[10]. ISO, *Life Cycle Assessment - Requirements and Guidelines*. 2006, International Standard Organization: Geneva, Switzerland.

[11]. Ecoinvent, *Ecoinvent Database v2.2*. 2010, Swiss Centre for Life Cycle Inventories: St Gallen, Switzerland.

[12]. Sphera, *GaBi LCA Software and Database*, Sphera, Editor. 2020: Stuttgart, Echterdingen.

[13]. CCaLC2, *CCaLC2 Carbon Footprinting Tool*. 2011, University of Manchester, Sustainable Industrial Systems: Manchester.

[14]. Bettens, F. and Bagard, R., *Life Cycle Assessment of Container Glass in Europe, Methodological report*, FEVE - The European Container Glass Federation, Editor. 2016.

[15]. Vieitez, E.R., Villanueva, A., and Saveyn, H., *End-of-Waste Criteria for Glass Cullet: Technical Proposals*. 2011, European Commission Joint Research Centre Institute for Prospective Technological Studies.

[16]. Testa, M., et al., *Long-term sustainability from the perspective of cullet recycling in the container glass industry: Evidence from Italy*. 2017. **9**(10): p. 1752.

[17]. Atilgan, B. and AzapagicA., *Assessing the Environmental Sustainability of Electricity Generation in Turkey on a Life Cycle Basis.* Energies, 2016. **9**(1): p. 31.

[18]. TEIAS. *Electricity Generation and Transmission Statistics of Turkey*. 2019; Available from http://www.teias.gov.tr/TurkiyeElektrikIstatistikleri.aspx.

[19]. EMRA, *Natural Gas Sector Report*. 2020, Republic of Turkey Energy Market Regulatory Authority: Ankara.

[20]. BOTAS, *Natural Gas / Crude Oil Report*. 2019, Petroleum Pipeline Corporation: Ankara.

[21]. CML. *CML-IA Characterisation Factors. [November 2010]*. 2010; Available from: http://cml.leiden.edu/software/data-cmlia.html.