The Environmental Performance of Glass and PET Mineral Water Bottles in Italy

Annarita Paiano, Teodoro Gallucci, Andrea Pontrandolfo, Tiziana Crovella, and Giovanni Lagioia

Abstract Worldwide the environmental weight of the packaging has overtaken the threshold, both due to the waste and the emissions generated. This issue stimulated the European Union (EU) to provide for a stringent regulation to tackle this burden. Particularly, the consumption of mineral water packed is very significant, as regards the use of plastic bottles, especially in the small size, which stresses the need for a boosted management of packaging by the governments, industries and consumers (Botto et al. in Environ Sci Policy 14:388–395, 2011). Over the years, the EU has shown an increasing consumption of mineral water packed, and Italy, with 222 L per capita is the first European consumer country and the third worldwide. This chapter investigated the glass and Polyethylene Terephthalate (PET) packaging to analyse their environmental impact and undertake a comparison among them (Vellini and Savioli in Energy 34:2137–2143, 2009). Particularly the research provides a twofold analysis. Firstly, it assesses the impacts of 1 kg of hollow glass through the Life Cycle Assessment methodology (Schmitz et al. in Energy Policy 39:142–155, 2011;Vinci et al. in Trends in beverage packaging 16:105–133, 2019;) and makes a comparison with a 1 kg of PET (Marathe KV, Chavan K, Nakhate P (2017) Lifecycle Assessment (LCA) of Polyethylene Terephthalate (PET) Bottles—Indian Perspective. http://www.in-beverage.org/lca-pet/ICT%20Final%20Report%20on%20LCA%20of%20PET%20Bottles_for%20PACE_01_01_2018.pdf. Accessed 2 March 2021). Secondly, the Greenhouse gas emissions of still water bottled based

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on the current Italian consumption is evaluated using the Carbon Footprint methodology, to highlight which among the glass and PET mineral water bottles have the better environmental performance (Kouloumpis et al. in Sci Total Environ 727, 2020). Finally, according to the European 2030–2050 climate and energy framework, an improved eco-friendly performance scenario based on post-consumption options for both materials, was investigated regarding the Italian mineral water bottles consumption.

Keywords Life cycle assessment · Carbon footprint · Packaging · PET · R-PET · Glass · Bottled water

1 Introduction

Nowadays, bottles play a fundamental role in protecting the integrity of a product and guarantee the quality and safety of drinking water. All containers commonly used in the water industry such as glass, PET and aluminium are recyclable. Furthermore, these materials are safe and comply with the food contact regulations.

PET is the plastic material most used in the food industry, especially for water and soft drinks [86]. In recent years, the PET bottle has been increasingly used as food packaging, because it provides an excellent barrier, preserves the characteristics of the liquid contained, is hygienic, safe, light, impact-resistant, transparent, and economic. Furthermore, from an environmental perspective, the PET bottle is easily recyclable, through a mechanical process.

Mostly, packaging preserves food safety and quality during transportation, distribution and storage along the supply chain.

PET is one of the most diffused thermoplastic polymers available on the plastic market [23] mostly used for the consumption of mineral water.

Bottles, like other rigid plastic packaging in PET, continue to record growth in demand despite the strong environmental pressure in terms of emissions during production and post-consumer waste.

According to [73], by 2025 the global demand for PET will reach 22.65 million tons, with an annual growth rate post pandemic Covid Sars-19 of 3.7% and consumption up to 27.13 million tons. The impact of Covid-19 on PET is not yet clear, probably the overall value could fall by up to 17% compared to 2019.

Nowadays, the global market of PET producers is still fragmented, despite the consolidation of the sector in recent years, in which some of them are acquiring material recycling capabilities to achieve sustainability goals.

The global PET packaging market in 2019 was dominated by bottled water (35%) and carbonated soft drinks (27%), followed by no-food (12%), all other drink (11%), food (8%), thermoforming (7%) as [73] highlighted. Among the most consumer PET, Asia–Pacific (40%) represents the first area, North America (21%) and Western Europe (18%) followed [73].

The analysis of the European market conducted by Nisticò [62] has highlighted that PET packaging covers almost the 16% of European plastic consumption, which, in 2019, was 50.7 million tonnes, of which plastic packaging represents roughly 40%. About 42% of the collected plastic packaging waste, was recycled whereas 58% was sent to energy recovery or landfill [66].

Constantly growth in living standards, urbanization, growth of retail infrastructure (as large-scale-retail) and the replacement of traditional packaging will drive the growth of PET consumption for the next few years, especially in developing countries.

Regarding glass containers for food and beverage consumption, their market is undergoing significant changes to being more customer focused and to become more customer friendly [26].

Over time, the weight of glass containers has reduced significantly, guarantying decreased logistics costs. However, the success of this material is due to its unique characteristics such as chemical durability, optical properties, transparency and low cost.

In terms of retail and consumer choices, it has to be pointed out that PET is preferred by the commercial consumers, glass remains a product for the luxury segment for e.g. for important brands of restaurants or lounge bars. For example, in 2019, Ardagh Group introduced a sparkling wine bottle for Allure Winery for the luxury edition. Additionally, glass is heavily influenced by the alcoholic beverage industry as most manufacturers sell alcoholic beverages in glass packaging [26].

The global market value of glass packaging in 2019 was 51 billion Euro and for 2025 will reach 65 billion Euro [29].

The leader market of glass packaging is Asia–Pacific, followed by Europe which increases the consumption of alcoholic drinks [54].

The rate of collection for the recycling of glass packaging at the global level varies from 2 to 100%. On the contrary, in the EU it is 74%, ranging from 25% in Romania to 93% in Sweden [70]. At the European level, in 2016, 12 million tonnes of glass containers were recycled, of which 90% glass bottles [24]. Glass packaging contributes to a circular model implementation because glass does not lose its properties either in closed-loop or open-loop reuse/recycling models [70].

In recent years, most beverage producers have identified packaging as a fundamental means of innovation in the sector. Hence, in order to adapt and satisfy jointly the changing needs of consumers in terms of size, design, materials and the role of packaging as a communication tool, many companies have increased their investments in packaging research. This issue has consequently become a place of comparison and competition between the numerous players in the market in terms of sustainability too, directing the research and use of packaging by the lowest environmental impact.

The present chapter provides an evaluation of the sustainability of the most used packaging for mineral still water. Particularly it investigated the glass and Polyethylene Terephthalate (PET) materials to analyse their environmental impact and undertake a comparison among them.

In detail, this chapter is organized into six sections.

Section 2 identifies the methodology adopted, focusing on the Life Cycle Assessment (LCA) and Carbon Footprint (CF) tools;

Section 3 analyses the literary review, split into two subsections regarding the LCA and CF analysis of packaging respectively;

Section 4 displays both the assessment and comparison of PET and glass packaging, based on the LCA methodology;

Section 5 is split into five subsections, the first and the second of which overviewed the European and Italian water bottles sector, whereas the third analyses the CF of water bottles and makes a comparison between glass and PET materials. The last subsections introduce the post-consumption options for glass and PET water bottles, assessing the CF for both materials, and making a comparison of reuse and recycling alternatives. The Italian assessment of water PET bottles is undertaken according to the target of the EU [12]/904. The perspective scenarios are built to underline the reduction of CF by increasing the rate of recycled PET (R-PET).

Finally, Sect. 6 highlights the main findings of the chapter and some recommendations to the stakeholders involved in the packaging sector.

2 Methodology

This study is based on a literature review and a comparative analysis of the most packaging materials of still water (Fig. 1). The literature review investigated the

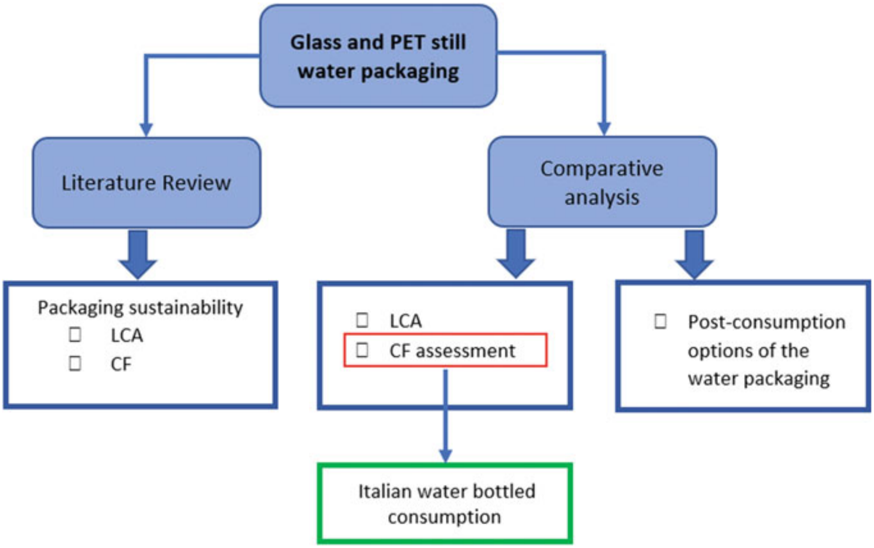

Fig. 1 Overview of methodology

research topic of the sustainability of the packaging sector, focusing on the LCA and CF methods of assessments and analysis.

The comparative analysis between the PET and glass packaging has been split into twofold. Firstly, through the LCA was assessed the environmental impacts of water packaging, comparing mass (1kg) and volume (single bottle) units. Then, the evaluation of the CF of the still water bottles, based on the current Italian consumption, has been undertaken. Further analysis of the improvements according to the end-of-life systems of the water packaging has been carried out with reference to reuse for glass and recycling for PET. The goal is to highlights which among the glass and PET still water bottles have the better environmental performance.

2.1 Environmental Impact Assessment Methodologies. An Overview of Life Cycle Assessment and Carbon Footprint

The LCA is based on the international technical standards of ISO 14040:2006 (environmental management—life cycle assessment—principles and framework) [41] and ISO 14044:2006 (environmental management e life cycle assessment e requirements and guidelines) [42], which allow to evaluate and measure the environmental impacts of products along their entire life cycle, within the system boundary defined as well.

It is a "cradle to the grave" method, which has acquired an important role since representing the most efficient approach to provide the data and information required to implement eco-sustainable strategies.

The definition of the functional unit (FU) gain significance to set up comparative analyses within alternative scenarios. The FU is indented to indicate the reference object of the study to which all input and output data have to be normalized. As the Fig. 2. displays, the LCA procedure involves four phases: (1) Goal and Scope Definition, which identifies the goal, scope, functional unit and system boundary, inter alia; (2) Life Cycle Inventory (LCI) involves the inventory analysis, containing the main issues of data collection and validation, and the allocation too; (3) Life Cycle Impact Assessment (LCIA), which defines the category, characterization and

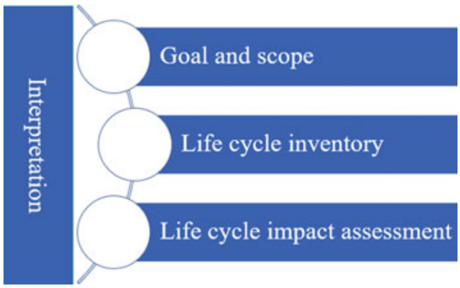

Fig. 2 Phases of LCA according to the ISO standards

weighting of the environmental impacts; (4) Life Cycle Interpretation identifies the main environmental issues and evaluates the results.

As regards the CF, it is a subset of LCA and quantifies the Greenhouse Gas (GHG) emissions, expressed in the unit of CO_2eq, generated by a product, service, activity or organization. LCA encompasses multiple "impact categories" along the life cycle, such as e.g. acid rain, summer smog, cancer effects and land use, if the end-point approach is considered, whereas CF, a more flexible and suitable tool for benchmarking different products or services, is a mono-criterion analysis focused on the emissions which affected the climate change.

To assess the CF there are some voluntary reference standards, such as the Public Available Specification 2050 based on BSI (British Standards Institution guideline for the assessment of the life cycle GHG emissions of goods and services), or on the GWP protocol corporate standard ISO 14067:2018 "Greenhouse gases—Carbon footprint of products—Requirements and guidelines for quantification", based on LCA methodology. The methodology commonly used in calculating CF, follows the ISO standards (14067: 2018), which is based on the LCA methodology and provides more specific guidelines for calculating the value of this indicator. This standard provides the guidance to the quantification and reporting of the CF of products along the supply chain [92].

In our case study the CF has been calculated according to this standard ISO.

3 Literature Review

In the last years, scientific literature focused on the analysis of waste minimization in the food and drink industry and of innovation in packaging design. The main goal has been the reduction in food losses and, at the same time, in the environmental impact of the food-packaging system.

In the early'90, certain sustainability criteria embedding in the packaging production began to be highlighted. Due to the first EU directive on packaging and packaging waste in 1994, the EU member countries have adjusted the national legislation to regulate the production, recovery and recycling of packaging waste, providing for policies and measures too for the allocation of the packaging costs. Today, the product design for recycling is promoted by governments as one of the most important practices to achieve sustainability. However, it must be stressed that the success of design for the environment largely depends on financial incentives for companies to design products with more content of recycled or recyclable material.

Nowadays, the packaging is ubiquitous in our daily lives and plastic continues to be the most used material, mainly in food packaging. As consequence, a steady increase in plastic waste outpacing the global growth rates and waste-collection systems has occurred [65]. This is especially true for multi-material packaging, which poses a significant challenge in the recycling process. Traditionally, the primary function of the package is to contain and protect the product, but its role has evolved over time becoming more complex and articulated. The growing issues of climate change and the issue of plastic waste disposal are pushing industries and researchers in studying solution to redesigning packaging, proposing new materials (as biodegradable) or substituting it with glass or paper. The challenge is to reverse the trend of plastic packaging and find materials by lower environmental impacts. The main question is whether glass or unconventional materials are better than plastic from an environmental point of view. To address this issue, we have analysed the scientific literature with the goal to benchmark the main environmental impacts of packaging from the extraction of raw materials, manufacturing phase until post-consumption disposal.

Particularly, to decrease the environmental impact of food packaging, the Life Cycle Assessment and Carbon Footprint are the most used analytical tools. These are based on the international standards ISO 14040-14044-14067 [41–43] and provide guidance for performing transparent and robust environmental calculations.

For this reason, the following literature review has been organized into two subsections related to (a) LCA analysis of packaging and (b) CF analysis of packaging.

3.1 LCA Analysis of Packaging

The Life Cycle Assessment, which is a methodology for calculating the environmental impacts of a product over its life cycle and based on ISO 14040 and ISO 14044, has been the most used for these comparative analyses.

Lee and Xu [51] reviewed different sustainable product packaging through LCA emphasizing the importance of eco-design and light weighting in minimizing environmental performance. Furthermore, they underlined how the environmental burdens are affected both by packaging materials and the impact of legislation on the disposal of used packaging.

Also, Dominic et al. [13] recommended eco-design in practice as a key factor to leverage sustainability gains. Differently, Del Monte et al. [11] studied the environmental performances of alternative packaging systems for retail sales of coffee showing how the replacement of plastic components can reduce the packaging weight enhancing the energy efficiency of production lines. The paper of [3], comparing the environmental burdens associated with drink packaging, underlined how “packaging is the main hotspot for most environmental impacts, contributing between 59 and 77%”. Another study focused on the evaluation of the environmental impacts of packaging systems for milk and dairy products always through LCA analysis [31]. The findings show which the most impacting phase of the milk life cycle in the packaging, underlying the importance of the selection of the post-consumption materials.

Del Borghi et al. [10], have benchmarked the differences in the environmental performance between glass bottles and steel tin cans, emphasising that the impact of packaging production accounting for over 70% of the total environmental impact indicators. The LCA assessment has been used also in an exploratory study to correlate the environmental impact of food across the whole supply chain [89]. In this study, the authors benchmarked food packaging, pointing out that the use of appropriate packaging can reduce the percentage of food waste and ensure better preservation of food quality.

Manfredi and Vignali [57] studied the life cycle of tomato puree production including packaging and transport to suggest potential improvements. Also, in this study the analysis shows that lightweight glass packaging could reduce the environmental impact. Guiso et al. [33] assessed the impacts of extra virgin olive oil packaging concluding that the largest environmental benefit for environmental sustainability is represented by the glass while tin-plated steel cans are preferable for long-distance transport. Accorsi et al. [1] compared, through LCA methodology, glass versus plastic packaging associated with the bottled extra-virgin olive oil (EVOO) and underlined the potential of PET packaging in reducing the environmental impact of EVOO supply chains.

Garfí et al. [28] compared the environmental impacts between tap water consumption through different treatment scenarios (conventional drinking water treatment and domestic reverse osmosis treatment) and bottled mineral water in Spain. The results showed how the packaging of bottled water had the worst results mainly due "to the high consumption of raw materials and energy for bottle manufacturing, and to the higher weight of glass bottles per volume of water". Similar findings have been obtained by [49] emphasizing that bottled water has higher environmental impacts than tap water because it requires much higher material inputs than tap water and generates more waste.

Horowitz et al. [34] analysed the environmental impacts of bottled water with different bottle materials, such as Polylactic acid (PLA), corn based, R-PET, and regular (petroleum based) PET showing that the recycled PET is the more environmentally friendly for bottled water production, whereas the regular PET and PLA bottle are less environmentally favorable.

In terms of sustainability in the drinking water sector, [78] highlighted that PET bottles if, properly recycled, can assure an environmental benefit due to virgin material usage causing lower burdening on natural resources depletion.

Other papers investigated the environmental advantages of the recycling process of packaging.

Toniolo et al. [80] underlined the environmental benefits of assessing the convenience of an innovative recyclable package compared to an alternative package that is not recyclable. Furthermore, the study of [72], allowed to highlight the main environmental loads of a multilayer polymer bag for food packaging showing that the most impacting phase is the production of the polymer granules and can be reduced by thinning the thickness of the polymer.

Landi et al. [50] investigated the reuse of glass bottles to quantify the potential environmental performance highlighting how the glass recycling phase can reduce the environmental load whereas.

It is important to underline that literature focused too on studies concerning influence of green packaging on the consumer choices. For example, a recent study has highlighted how consumer before their purchases, gather information on the internet about the sustainability of packaging, changing their preferences to pro-environmental ones [32]. Other researchers have analysed the increasing influence on consumer decisions of sustainable product solutions [91]. Despite the slowness towards sustainable business practices, in conjunction with the environmental issue for the growing rate of packaging waste, nowadays, consumer's material needs-oriented towards more natural, high-quality materials and presents a growing demand for food packaging that does not do increase pollution. Globally, consumer demands driving the research and development of new materials in order to find alternatives to conventional materials made from fossil resources [81].

According to [5, 60], given the impact on different ecosystems, there is a potential role of the packaging within the Circular Economy with the aim of designing a sustainable pattern, extracting as much value as possible from products, components and long-term materials.

Conversely, it is important to underline that consumers are suspicious about the health risk of recycled or unknown materials composing the packaging [6, 8].

3.2 Carbon Footprint of Packaging

The CF indicator, spread in recent decades, is presented as an intuitive and easily understandable indicator even for non-expert users. However, [25] has supported that CF is not a new concept, existing for decades but differently named, e.g. as the result of the GWP impact indicator, LCA based. In the same line, [45] suggested that "The carbon footprint is quantified using indicators such as the Global Warming Potential (GWP)", which defined by the Intergovernmental Panel on Climate Change (IPCC), as "GWP is an indicator that reflects the relative effect of a greenhouse gas in terms of climate change considering a fixed time period, such as 100 years (GWP100)". Moreover, [45] explained as CF is one of the main impact categories in the LCA methodology, which typically uses IPCC characterization factors for CO_2 equivalents. Particularly, the CF comprehends a life cycle assessment limited to the emissions affecting climate change.

Matthews et al. [59] underlined that CF is one of the most important conceptual extensions of the Ecological Footprint, although a univocal definition was still missing.

However, until more than ten years ago, there is no unanimous consensus on the CF methodology. The spectrum of definitions varied from direct CO_2 emissions to GHG over the entire life cycle and the units of measurement were not even clear [88].

Among the most recent definitions of CF, [67] have defined the CF as an indicator of the total Greenhouse Gas emissions of a product expressed as CO_2equivalents.

The methodology commonly used in calculating CF follows the ISO standard (14067: 2018) based on the LCA methodology, as mentioned above, and provides more specific guidelines for calculating the value of this indicator.

According to Navarro et al. [61], CF represents today one of the most used environmental and sustainability indicators at the company or product level.

Within the plastic packaging industry, the CF indicator has been applied to various food-grade plastic packaging products [14, 55], using a cradle-to-cradle LCA methodology, compared PET containers for strawberries with PLA and Polystyrene (PS) ones and argued that “PET showed the highest overall values for all the impact categories, mainly due to the higher weight of the containers”. Furthermore, to minimize the ecological footprint of a packaging system, the authors stressed that the production and procurement of inputs have to take place locally, reducing the high impacts of the transport.

In the same year, [35] compared the glass and the polypropylene (PP) plastic used to produce the baby food cups. The authors highlighted that the end-of-life impact of plastic packaging was lower than glass. Moreover, plastic packaging having a lighter mass than glass, is responsible for the reduction of CF.

A few years earlier, [46] examined the CF of PP yogurt cups and highlighted that, thought an LCA analysis, a 32 oz (0.9 L) instead of one by 6 oz (0.17 L) container can save energy, waste and reduce the impacts. Instead, [64] quantified the CF of mineral water in PET and glass bottles of various sizes: they recommended to recycling all beverage packaging materials more as they have less impact on the environment. Also, larger packs should be preferred which always have a lower environmental impact than smaller packs. However, when choosing the packaging material for a less impactful beverage, transport and secondary materials must be considered. Maga et al. [56] benchmarked environmental burdens for different meat packaging. The result pointed out the importance of recycling materials to reducing the negative effects on the environment highlighting how the use of “recycled PET instead of virgin PET allows reducing the carbon footprint by approximately 40%”. Another study carried out by [48] analysed the substitution of Polyethylene Terephthalate (PET) with glass bottling liquids in the domestic sector. The substitution of PET with glass can reduce the Global Warming Potential by 18.9%.

Vinci et al. [85] suggested, for glass packaging, that the product innovations allowed to reduce the thickness, weight of packaging, decreasing the CO_2 emissions by about 4–5%.

Recently, Wong et al. [90] emphasized that the increase in the production and consumption of beverages is receiving considerable attention in terms of environmental sustainability especially from the point of view of carbon emissions.

Among the few published studies on this item, [9], have highlighted that replacing glass bottles with PET ones, in the case of beer production, did not lead to a significant reduction in CF emissions, unless refillable PETs or Glass are used. According to [39], virgin glass is the best option for tomato puree.

In some studies, it has been suggested that the result of carbon emissions mapping could be indicated within a carbon label to allow consumers to make more environmentally friendly choices [79]. A few years earlier, [47] already claimed that a CF label is expected to make consumers attend to how their product choices affect GHG emissions and help them to identify low-carbon alternatives.

According to Roibás et al. [67] among the alternatives to reduce the CF of packaging, the company should be encouraged the use of renewable energy sources or recycled packaging materials.

Botto et al. [7] conducted a comparison between two types of Italian drinking water, focused on tap water and PET bottled natural mineral water, applying the carbon footprint methodology and quantifying the emissions in terms of CO_2 equivalent. The results showed that 1.5 L of tap water saves 0.34 kg CO_2eq in comparison with the PET water-bottle consumption. Consequently, tap water consumption (for the 2 L per day recommended) could prevent 163.50 kg CO_2eq of greenhouse gas emissions per year. Thus, the substitution of PET water bottles with tap water avoids a significant amount of GHG emissions associated above all with the production of PET bottles, equal to 59% of the total impact.

Paiano et al. [63] stated that the CF methodology allows to assess some of the impacts of the water and beverage packaging.

4 Assessment and Comparison Through the LCA Methodology of PET and Glass Packaging

In order to make the comparison between glass and PET packaging, the results based on a previous LCA analysis undertaken by the authors on the hollow glass production of a company in Southern Italy [27], have been benchmarked with data and results of an LCA study related to the production of PET [58]. Most data are comparable between them. Both analyses have been carried out in accordance with ISO 14040: 2006 and 14040: 2006 and 14044: 2018 as well as the software used was GaBi thinkstep (a specific LCA software to calculate the environmental impacts). The environmental impact categories used are the same: GWP (Global Warming Potential), AP (Acidification Potential), EP (Eutrophication Potential) POCP (Photochemical Oxidant Creation) ADP (Abiotic Resource Depletion) and ADPel (Abiotic Resource Depletion Elements); Abiotic Depletion Potential–Fossil Fuels (ADP-fossil fuels); Water Depletion (WD). For both studies, a midpoint approach was adopted. The system boundary adopted was "cradle to grave", using the CML 2001 impact categories (January 2016 version) without considering the label and cap of the bottles. Furthermore, the inventory phase was split into the parts of same stages: the upstream phase which considered the raw material acquisition and transport to the factories; the core phase which included the consumption of energy (electricity, natural gas and diesel), the depletion of substances for maintenance and treatment in the manufacturing stage as well as the waste produced to the landfill; the downstream phase which encompassed the transport of both glass and PET post consumption, waste collection, recycling and disposal.

The study of hollow glass was carried out considering the use of 66% of recycled material, while the LCA analysis of PET was carried out considering a recycling rate of 70% which is compensated in the lifecycle of the next related product.

Both functional units were 1 kg of finished hollow glass and 1 kg of PET resin and the assessment of environmental metrics has been scaled down to calculate the impact corresponding to the various packaging sizes. It has to be underlined that in our analysis, a cut-off of 1% in relation to the material incoming and outgoing flows (raw materials, primary packaging, waste products and substances for maintenance and treatment) was adopted, while no allocations or parameterizations were implemented. Differently, in their analysis [58] considered a cut-off under the tolerance limit of 5% for most data, whereas the authors carried out the credit allocation methods for the PET recycling system.

The assessment of the environmental impacts of the different packaging materials for bottled water is first assessed and discussed with regards to both the mass and volume units of reference material.

PET is a polymer of the polyester family and is a thermoplastic resin produced by the polymerization of ethylene glycol and terephthalic acid. This material was created in 1941, but only in 1973, following the patent of the chemist Nathaniel Wyeth, the bottle production began. Hollow glass, instead, a very ancient packaging material, is produced by mixing different raw materials (cullet, yellow sand, soda, calcium carbonate, dolomite), in a melting furnace.

To make an exhaustive comparative analysis of these materials, the environmental impact was firstly analysed comparing the production of 1 kg of glass and 1 kg of PET and then was carried out a comparison between the production of a single bottle made by glass and PET. A twofold analysis is significant because the quantification of environmental impacts based only on the production of 1 kg of PET and 1 kg of hollow glass can be misleading: as from 1 kg of hollow glass, it is possible to obtain approximately only 2 glass bottles, with an average weight of 0.46 kg each whereas from 1 kg of PET roughly 52 bottles, with an average weight of 0.019 kg each, can be produced. Hence, the comparison based on a single bottle produced has been also provided.

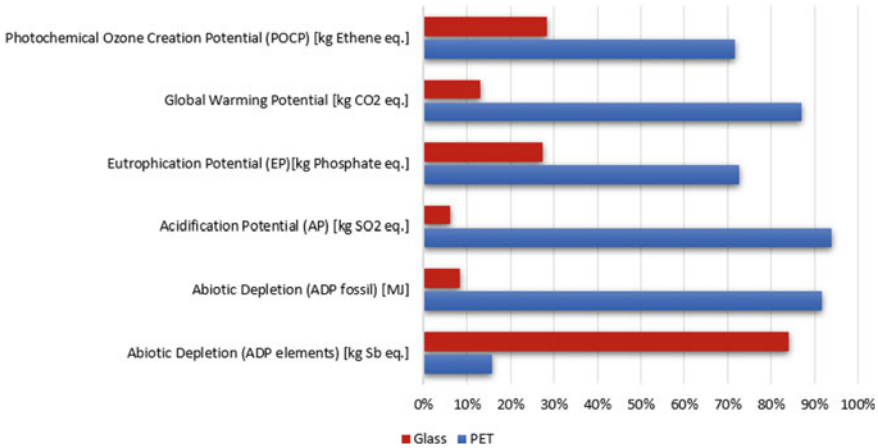

Fig. 3 LCIA per 1 kg glass and 1 kg PET. *Source* Personal elaboration by Gallucci et al. [27] and Marathe et al. [58]

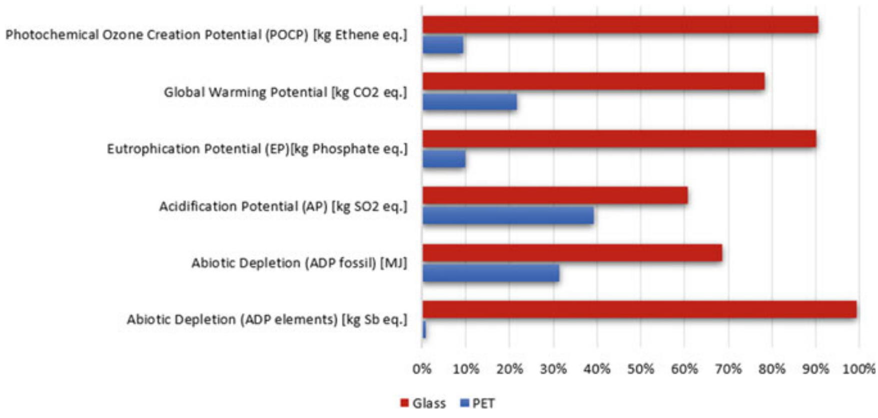

Fig. 4 LCIA per 1 L empty bottle. *Source* Personal elaboration by Gallucci et al. [27] and Marathe et al. [58]

Figure 3 shows the comparison between environmental impact categories in hollow glass and PET production.

As expected, the production of 1 kg of hollow glass has a lower environmental impact than the production of 1 kg of PET.

In particular, the benchmarking analysis shows that all the indicators, except ADPel, have less environmental impacts in the glass production. Specifically, comparing the GWP indicator it occurs that 1 kg of glass is equal to 0.656 kg CO_2eq, mainly due to natural gas consumption and raw materials like calcium carbonate, while 1 kg of PET is equal to 4.38 kg CO_2eq, due to the polymerisation process of PET production which is very energy intensive and strongly affected the result.

Differently, comparing the results of a single empty bottle, emerges a converse result: for all the impact indicators, the glass bottle has a significantly higher impact (Fig. 4). Particularly, the EP is 89% higher and the GWP (0.3 kg CO_2eq) roughly 73% higher than the PET bottle (0.08 kgCO_2eq) too. This is due to the previous consideration of the large number of bottles produced from 1 kg of PET and this evidence significantly lowers the environmental scores.

5 Carbon Footprint of the Water Packaging. The Italian Assessment

This section provides the CF of the Italian water packaging based on the total still water bottled consumption.

In the first part of this analysis, the current state of the bottled water sector was investigated at a European and Italian levels. Data relating to production, consumption, exports, sales channels, consumer preferences and sustainability of the entire sector were gathered to quantify future prospects, based on the Italian and European regulations. To obtain robust data, not affected by the production and consumption limitations of the supply chain during the pandemic, the analysis was conducted using water production and consumption data for the year 2019.

In the second part of the study, the GHG of mineral water bottles based on the current Italian consumption has been evaluated using the Carbon Footprint methodology, to highlight which among the glass and PET mineral water bottles have the better environmental performance. Moreover, further comparison between different post-consumption systems of these packaging has been undertaken to highlight their influence on the CF values.

The GHG of mineral water bottles has been assessed on the current Italian consumption analysing the Environmental product declaration (EPD) which is an environmental certification (ISO 14025) embedding information on the environmental impact associated with the life cycle of a product based on the Life Cycle Assessment of the product.

In order to understand the current situation of the sector in Italy, five EPDs and a Carbon footprint report of several important brands operating in the water bottling sector were used for the comparison.

To carry out the analysis, only the still water bottles consumed in 2019 were used, which amounted to approximately 9,300,000,000 L.

All selected EPDs were made with a cradle to grave approach according to the reference Product Category Rules (PCR) “2010: 11 Bottled waters, not sweetened or flavoured” and the reference Central Product Classification (CPC) code 24410. The functional unit (FU) was 1 L of water bottled in different sizes.

5.1 European Bottled Water Sector

In Europe, the packaging sector is the main manufacturing sector for plastics, indeed it represents about 40% of the entire demand, equal to over 20 Mt [66].

In recent decades, due to the growing need for the conservation and protection of goods, the plastics sector has become one of the main fields responsible for environmental and health impacts [53]. Considering that, according to the latest EU statistics, in 2018 on average, only 41.5% of plastic packaging waste was recycled [22], significant improvements are required.

In the global debate on the use of plastic, one of the main problems is linked to the use of single-use formats, e.g. it is estimated that globally, in 2021 over 583 billion PET bottles will be produced [77], this will represent an important challenge in terms of recovery and reuse of marketed bottles due to the current limited recycling rates.

In 2019, according to our estimates, over 51 billion litres of bottled water were consumed in the European Union [76] and, taking into account that, 87.4% of the water placed on the market is packaged in PET bottles, whereas 12.4% in glass, 0.1% in cardboard and 0.1% aluminium [87], the amount of PET consumed annually in this sector is significant.

Notwithstanding the high-quality standards of tap water in European countries, many people prefer to drink bottled water, in many cases due to the negative perception of tap water [30]. At the same time, this preference is certainly a more expensive and less environmentally friendly choice considering the huge amount of plastic produced to bottle water every year.

Figure 5 shows the per capita consumption of bottled water in Europe for the different countries; in 2019 the average consumption of bottled water in Europe was 118 L per capita [75]. In particular, the main European consumer country is Italy with average water consumption of 222 L per capita [2].

This figure not only ranks Italy in first place in Europe, but even in second place in the world, preceded only by Mexico, where annually about 244 L per capita are consumed [52]. Differently, Finland and Sweden are the European countries that consume fewer litres of bottled water, their consumption represents only 8.5% and 5% of Italian consumption, respectively.

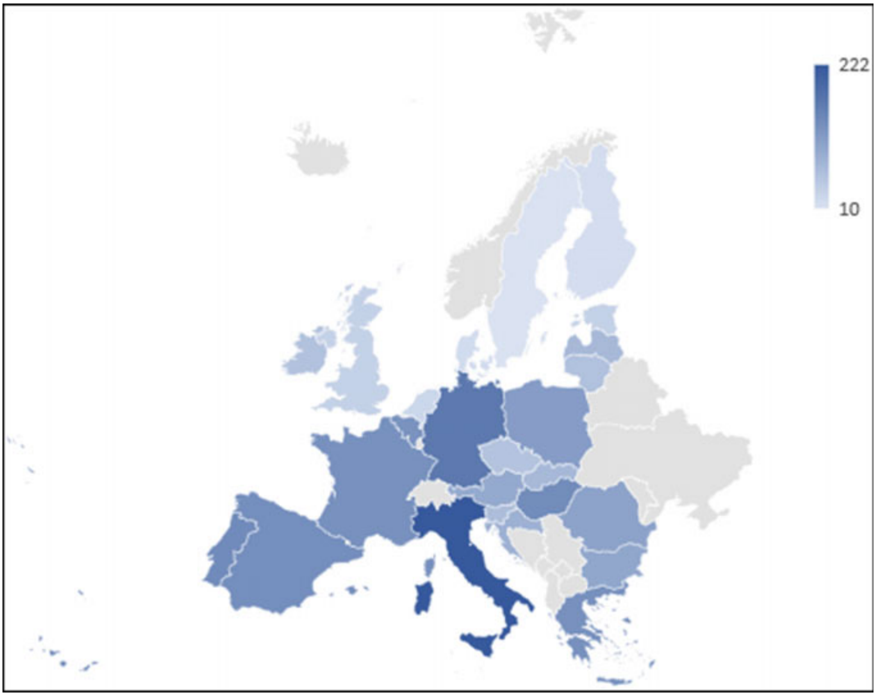

Fig. 5 European per capita consumption of bottled water (L). *Source* Personal elaboration by Acquitalia [2] and Statista [75]

5.2 *Italian Bottled Water Sector*

The Italian production and consumption of bottled water are represented in Fig. 6. In the last decade, the trend shows an increase in the consumption of over 17% and in the exports by 77%. With over 15 billion litres of water bottled, exports of 1,6 billion litres, and 160 plants across the country, the Italian bottled water annual revenue, was amounted to roughly 3 billion in 2019 [2]. In the same year, based on data from large retailers, it emerged that water represented 77% of the volume and 30% of the turnover of the entire beverage sector except for wines (ISMEA, 2020).

The Italian leadership in bottled water consumption is probably due to the awareness that bottled water is qualitatively better and more controlled than that of our tap. To confirm this thesis, in a recent survey it emerged that 29% of Italian families do not trust drinking tap water [44]. Even the significantly lower cost of tap water has not limited the use of bottled water: in this regard, it has been estimated that the cost per litre of water is about 250 times lower than the average price of water bottle currently sold in a supermarket [52].

According to the habits and preferences of consumers, the consumption of bottled water in Italy is mainly represented by still water, which represents 69% of total consumption, whereas the consumption of sparkling water is equal to 31%.

Since the 1980s, plastic has gradually monopolized the market, replacing glass, and becoming the first material used for bottling water. However, the ever increasing attention to the environmental sustainability of packaging and awareness of the possible risks associated with the use of plastic are forcing companies to find new solutions.

In Italy, 82% of the water is sold in PET bottles (Table 1), among which 86% is linked to the use of 1.5 and 2 L sizes, generally used for domestic and family

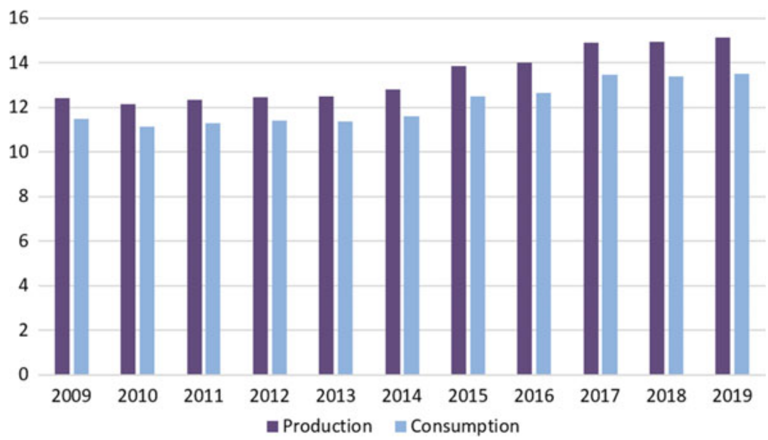

Fig. 6 Italian production and consumption of bottled water (billion litres). *Source* Personal elaboration by Acquitalia [2]

Table 1 Packaging material for still water bottled consumption. *Source* Personal elaboration by Acquitalia [2]

Material	Bottle size (L)	Water 10^9 L	Percentage
PET		7.6	82
	0.5	0.61	8
	1.5	5.34	70
	2	1.22	16
	Others	0.46	6
Glass	1	1.5	16
Paper, aluminium cans	Various	0.2	2

consumption, whereas, the 0.5 L bottles, mainly used for outdoor consumption, represent about 8%. With a much lower diffusion than PET and characterized by consumption mainly into the HORECA (hotels, restaurants and catering) sector, glass is currently used to 16%. It has to be noted that, due to a very limited quantity of 0.75 L glass bottles consumed, the glass category includes both 0.75 L and 1 L size. Finally, with a very low share, but great growth in recent years, 2% of the water is sold in aluminium cans or cardboard packaging.

5.3 *Carbon Footprint Assessment*

As cited above, the Carbon Footprint is a measure that expresses the total greenhouse gas emissions generated by a product, over its entire life cycle. These impacts are expressed in units of CO_2 equivalent and the functional unit chosen is 1L water. Figure 7 shows the average values of CO_2eq per 1 L of water bottled in different

Fig. 7 Carbon footprint per material and size on average. *Source* Personal elaboration by EPD Vera [17], EPD Lete and Sorgesana [18], EPD Cerelia [19], EPD Levico [20] and EPD Frasassi [21]

sizes, encompassing caps (aluminium, steel, PP or HDPE), labels (paper or PP) and glue.

Considering the sizes of PET bottles, the 0.5 L one is the most impactful: however, if compared with the glass bottle, it emerges that its impact is significantly lower. By an impact of 0.14 kg CO_2eq, the most convenient size among those analysed is the 2 L one.

Then, considering the life cycle of the two materials, it is better to use PET for bottling water if the volume is chosen over the mass.

5.4 A Comparison as Regards to the Post-Consumption Options of Water Bottles

It must be stressed that the post-consumption options (reuse, recycling or disposal) of the packaging can determine a different impacting result.

PET bottles are traditionally considered single-use, and this facilitates the principle of use and throw-away, which has generated several environmental problems. Conversely, glass bottles can be reused multiple times especially in the household and this aspect must be considered in the whole environmental analysis. In this regard, a further comparison was made between bottled water in PET and glass bottles. The functional unit for both analyses was one litre of still bottled water again.

In order to identify the environmental impact of glass post-consumption systems, the authors amounted the CF of 1L water bottled (Fig. 8).

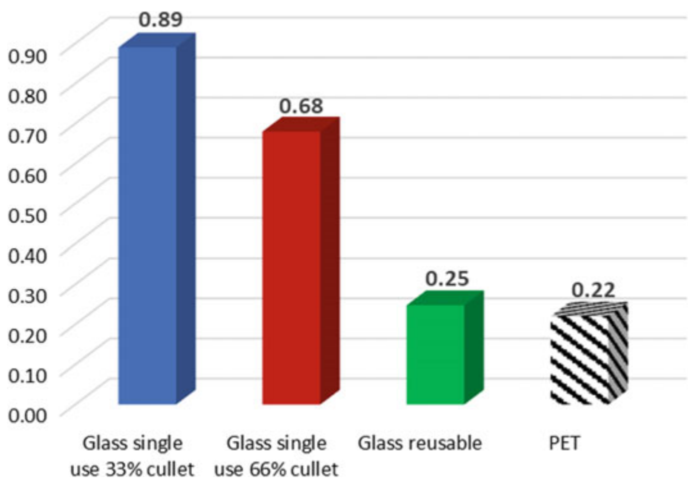

Fig. 8 Global warming potential of 1 L bottled water per 1 L size (kg CO_2eq). *Source* Personal elaboration by EPD Levico [20], EPD Frasassi [21], Gallucci [27] and San Benedetto [69]

Specifically, two glass bottles containing different percentages of glass cullet (33 and 66%) were compared to evaluate the reduction in CF linked with the increase in the amount of recycled material of the single bottle. Furthermore, it was useful to evaluate the performance of the reuse system of a glass bottle to make a comparison with recycling. Finally, the CF of a 1L PET water bottled amounted.

Notwithstanding the use of cullet is a key factor in reducing the CF for single-use bottles, reuse is still the best choice for glass bottles, assuming reuse by three times.

Figure 8 indeed displays the significantly lower impact of the reusable glass bottle, equal to about 64% and 72% in comparison to the single-use glass bottles with 66% and 33% of cullet respectively. Furthermore, results shown in Fig. 8 pointed out that the life cycle of the single-use glass bottles, is considerably more impactful than the PET one. Furthermore, despite the analysis emerged that the CF of a PET bottle is less impactful than a reusable glass bottle, it must be stressed that results suggest a very slight difference between the two bottles confirming the goodness of the reuse system.

The benchmarking among environmental impact indicators shows the importance of interpreting data and results based on LCA metrics to supporting environmental choices and finding a solution to the encountered critical issues. As Fig. 8 shows the improvement of the reuse process of the glass bottle can compensate for the higher CF value of its single use.

The LCA analysis has encouraged the analysis of the reusable system of glass bottles comparing this system with the Italian traditional packaging separate collection system.

Although in Italy the practice of returning glass bottles to the manufacturer in the past was widespread, the introduction of plastic as packaging has changed the behaviours. The lightness, resistance, the simplicity of processing compared to other materials, jointly with the removal of the costs of transport, handling and storage of the empties bottle have made plastic bottles more advantageous for producers. At the same time, consumers were attracted by the deposit cost to zero and the responsibility of returning the empty bottles. The disposable model has increasingly consolidated in the market, although it is converse to the waste hierarchy provided by the EU legislation.

A reusable bottle (it can be a glass bottle, but also a PET plastic bottle), can be returned to the supplier, so that it can be reused. In Italy, in 2017, as it happens in other countries, the Italian institutions organized the management of returnable bottles without being successful. In a market where the introduction of single-use bottles is constantly increasing, the theoretical reusing the same bottle up to 30 times [74], could represent a simple, but effective choice for the protection of the environment.

Currently, the glass bottle reuse system in Italy is in disuse, indeed, only 10% of the glass bottles for water consumed in the country are returned to the same distributor to be reused after the washing and sterilization and filling processes. This figure is in contrast with the northern European countries, where the use of this system is widespread. Based on data in Fig. 8, particularly the CF of the glass 33% recycled and the glass reused, we estimated that if all water glass bottled in the Italian consumption, were returned to the distributor for the reuse, saving of approximately 852,000 t CO_2eq, could be achieved compared to the current situation. This amount could be comparable with the yearly emissions of roughly 570,000 cars [82].

Furthermore, the process mainly used in Italy for glass recycling involves numerous steps that contribute to increasing the impact of the product. Once the bottles have been delivered to the special container for glass collection, a vehicle collects and takes them to the collection centre where the material is stored, cleaned, divided by colour, and crushed. Then, the cullet will be transported to the glass factory for melting and manufacturing of the new product. The new bottle returns to the water producer for the bottling phase. Therefore, this system requires many steps that contribute to a high impact, mainly generated by the transport of the glass according to its weight, but by the high temperatures in the melting phase too which will contribute to very high energy consumption.

As we can note, as distribution plays a key role in impact assessment, it is necessary to take into account the distance between the bottling plant and the distributor. In the reuse process, it is necessary to consider the impacts generated both by the transport for recovery of the glass bottle and by the industries which provide for the preparing and cleaning of the bottles [83]. According to Amienyo et al. [3], the best performance occurring in the range of 1–5 times of the glass reuse, because of the operational phases affecting the result, whereas [74] identify to 8 times the glass reuse, suitable period before scuffing of bottles.

In Landi et al. [50] made an environmental comparison for glass wine bottles, between two end-of-life scenarios: recycling and reuse. From the analysis emerged significant environmental savings in all the impact categories for the reuse scenario, mainly due to the avoided impact generated by glass melting and bottle forming which represents very energy-intensive phases.

A further enhancement of the glass bottle reuse system consists in the reduction of the new packaging production and waste post consumption as well.

5.5 PET and R-PET in the Beverage Industry

In recent years, consumer awareness about the environmental issues associated with PET single-use bottles has led the entire sector to support new recycling solutions to reduce waste and maximize the reuse of materials.

The industry, also thanks to the recently stringent EU regulations on the reuse of recycled materials, is making efforts to reduce the amount of plastic needed for bottle manufacturing, and, at the same time, increasing the R-PET content in order to minimize the environmental impact.

To achieve these results, water bottling companies are constantly investing in new recycling technologies to use greater quantities of recycled materials.

Plastic recycling is one of the most important aspects in the field of waste disposal. Through the separate collection, it is possible to have both economic advantages and benefits for the environment, creating employment and creating new products from waste materials ready to be re-marketed. In this context, above all recycling PET plastic bottles could represent an important step forward in reducing packaging waste and avoid the dispersion of the bottles in the environment, particularly into the sea.

Although a lot of thermoplastics can be recycled, recycling PET bottles is much more convenient than many others. This is due to the plastic bottles for drinks and water bottles are made almost exclusively of PET, which makes them more easily identifiable in a recycling stream.

Economically, the entire petrochemical industry and, as a consequence also the PET market, are heavily affected by oil price trends, particularly if global threats occur. Since February 2020, due to the Covid-19 pandemic, there was a global collapse in the oil price and consequently in the PET prices.

Compared to R-PET, virgin PET has become much cheaper [37]. For this reason, the effects of this sharp reduction in the PET prices have temporarily slowed down the market development and the R-PET use.

The R-PET generation process involves the recycling of plastic post-consumption. After the collection phase, PET is sorted, cleaned, and transformed into tiny flakes.

It is important to underline that R-PET requires less energy for production than virgin PET bottles [4] and also guarantees minimization of the use of natural resources.

In recent years, the second life of PET plastic bottles regarded a wide range of uses, from the furniture sector to clothing. It can be used to produce new plastic beverage bottles, but also in the production of tubes and containers or used in the textile industry [68] for fleeces, knits and carpets manufacturing. In Europe, in 2018, it has been estimated that the largest use of R-PET (30%) occurred for sheet production, whereas 24% for fibre. Instead, due to a higher quality of R-PET required in food and beverage packaging, only 18% of the total was sold for food bottle production [15].

Over the years, the efforts of the bottled beverage industry have made it possible to rationalize the amount of material used for the primary packaging. Indeed, the weight of both PET and glass water bottles has been significantly reduced. Compared to twenty years ago, a 0.5 L PET bottle is currently 51% lighter [36]; whereas glass bottles are about 30% lighter today. This has allowed producers to obtain important improvements in terms of efficiency in the use of material resources and reduction of energy consumption in the manufacturing process and greenhouse gas emissions as well.

According to the EU [12]/904—on the reduction of the impact of certain plastic products on the environment, the collection targets for plastic bottles have significantly increased in comparison with current rates: 77% of plastic bottles should be collected since 2025 and 90% since 2029.

Currently, as we can see from Fig. 9, in the EU in 2019 about 64% of the PET bottles put on the market were collected. Despite this, collection rates vary significantly across regions: some countries such as Germany and Finland exceed 93% of collected PET bottles, while other countries such as Bulgaria reach a maximum of 20%.

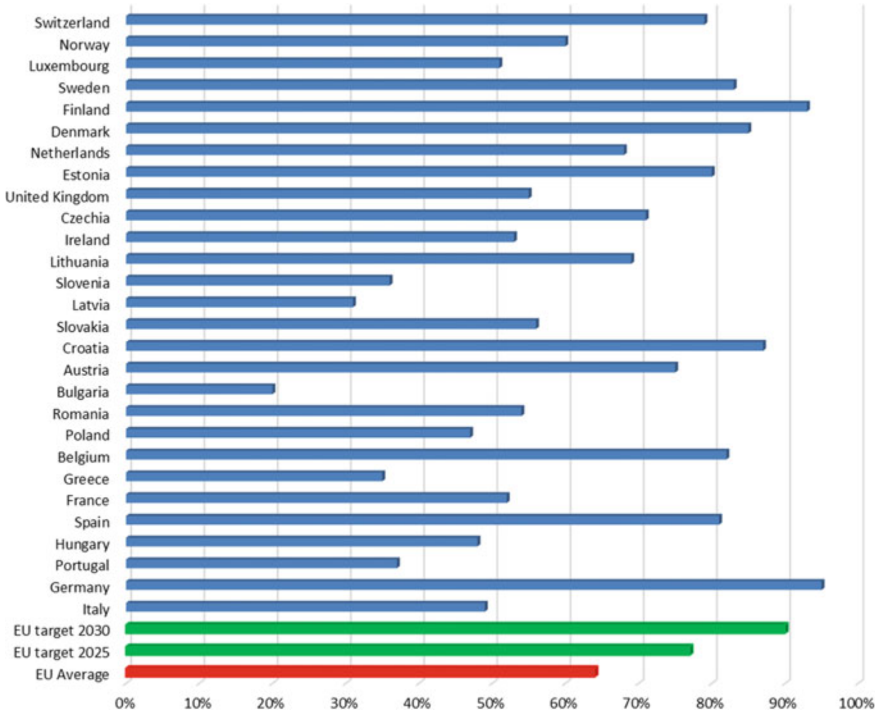

Fig. 9 PET bottle collection rate per country in 2019. *Source* Personal elaboration by ICIS [38]

Furthermore, according to the EU Directive above, since 2025, in the EU Member States, all PET bottles placed on the market must contain at least 25% of recycled plastic with a goal of 30% by 2030. In 2017, the average amount of R-PET contained in the new water bottles was between 11 and 14.5% [16, 38].

Within this context, in order to evaluate and quantify the effects and benefits generated by European legislation on the Italian market, the current CO_2eq emission of the entire sector was estimated and compared with the objectives set by the EU for 2025 and 2030 in terms of R-PET rate of the new PET bottles. In the analysis, the main bottled water sizes consumed in Italy were 0.5, 1.5 and 2 L, which were used as a reference. Taking into account that the EPDs available in Italy displayed an average use of R-PET of 11% in the production of water bottles, we measured the CO_2eq emissions associated with each format referring to the current R-PET rate.

The analysis showed that, despite the high impact generated by the single 0.5 L PET bottle in comparison with the other sizes, in the Italian market, due to the very high percentage of 1.5 L bottles sold, the total emissions of the entire market are mainly generated by the latter format. We estimated that the entire consumption of PET water bottled (7.6 billion L, Table 1) generates annually about 1,201,857.6 t CO_2eq. Particularly, the 1.5 L size represents 71.1% of the total amount of CO_2eq

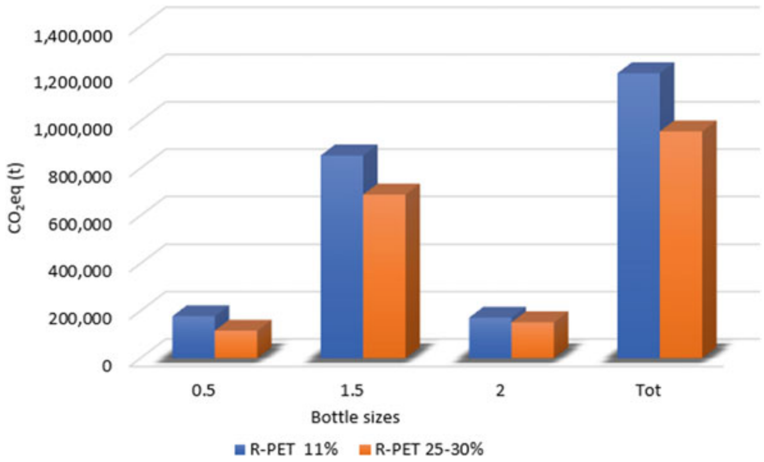

Fig. 10 CO_2eq emissions of the Italian still water bottled

emissions whereas the 0.5 L and 2 L sizes represent 14.7% and 14.2% of the total respectively.

Furthermore, considering the EU targets about the R-PET content, mentioned above, the corresponding average emissions have been estimated. Figure 10 shows the current and perspective CO_2eq emissions. Based on these results, a comparison highlights that the reduction of CO_2eq emissions is significant. In regard to the value per category, the increase in R-PET would allow the greatest rate reduction, equal to 34.5%, in the smaller size (0.5 L) whereas a reduction in CO_2eq emissions of 11.4% occurring in the larger size (2 L). In absolute terms, the 1.5 L size, which is the most marketable, allows saving approximately 165,484.2 t CO_2eq per year. Overall, compared with the current scenario, a reduction in total emissions by about 20.5%, equivalent to saving by approximately 246,014 t CO_2eq emissions, has been estimated.

In Italy, a further step forward for the use of recycled PET was made in October 2020. Indeed, in 2020, law n.126 was presented aimed at guarantee producers the opportunity to manufacture bottles in 100% recycled PET previously limited to 50%.

Therefore, even in Italy, as in the rest of Europe, it will be possible to produce fully recycled bottles, reducing harmful emissions and thus respecting the environment. Inevitably, this will also provide a great boost to Italian companies engaged in the Circular Economy.

Based on this initiative, an analysis to evaluate the potential improvement of the environmental performance of the entire sector was carried out. The analysis provides indications on the use of increasing rates of R-PET in the production of new bottles.

This analysis, unlike the previous ones, aims to evaluate exclusively the use of PET and R-PET in the production of bottles, without evaluating the impact associated with the cap, label and water. This is necessary to quantify more accurately the CO_2eq emissions avoided due to the R-PET use.

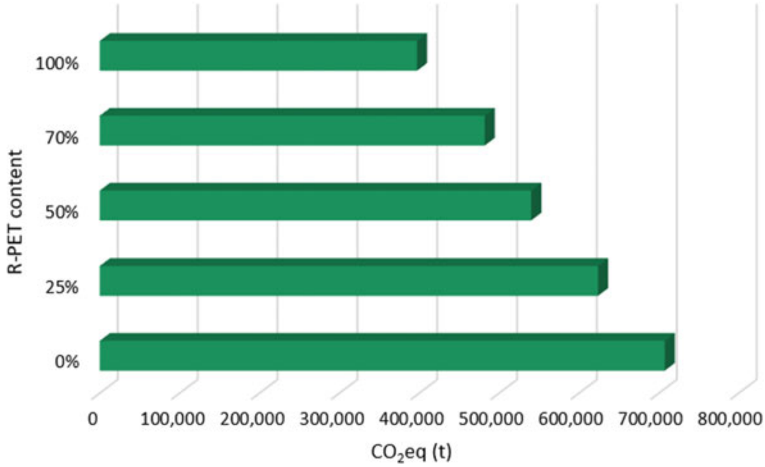

Fig. 11 Decreasing of CO_2eq emissions due to R-PET use for the entire Italian PET requirement in the still water bottle production. *Source* Personal elaboration by Acquitalia [2] and Marathe et al. [58]

Then, we estimated the amount of PET needed annually to satisfy the entire market. About 5.5 billion still water PET bottles are consumed annually in Italy, which is equivalent to about 110 million tons of PET. Taking into account the CO_2eq emissions of 1 kg PET according to [58], we assessed the CF of the Italian PET water bottles. As the Fig. 11 displays, the increase of R-PET content boosted to a significant reduction in CO_2eq emissions, achieving a minimum level of roughly 400,000 t CO_2eq if the R-PET is increased to 100%.

Considering that, until 2020, many Italian companies had been limited by the previous legislation in terms of percentages of R-PET usable in the production of the bottles, it is desirable that better results than those required by European legislation can be achieved, overcoming the minimum use of 30% of R-PET by 2030.

6 Conclusions

The packaging sector spun to a very critical debate about its sustainability. The challenges to be addressed encompass the more stringent targets by the EU legislation, the environment and economics as well.

This chapter provided an evaluation of the sustainability of the most used packaging for mineral still water. Particularly it investigated the glass and PET to analyse their environmental impact and undertake a comparison among them in regard to their manufacturing and post-consumption options too. LCA methodology has been used to assess the impact indicators of the different packaging and the CF to evaluate one of the mineral water bottles based on the current Italian consumption.

The results stressed the better performance of the 1 kg glass than 1 kg PET, conversely, the resulting performance from 1 L of water bottled.

Furthermore, post-consumption methods have been investigated to understand their influence on environmental impact for each material. Particularly the reuse system positively affects the glass Carbon Footprint, indeed, compared to a glass bottle made of 33% of recycled material, the reusable glass bottle has a 72% lower impact than the first one. Notwithstanding 1 L PET bottle is lower impactful than the glass one, results suggest a very slight difference between the two bottle materials, if the glass reuse is applied. Particularly, the last option could save roughly 852,000 t CO_2eq concerning the current Italian consumption of water glass bottled.

Further analysis provides suggestions on the use of increasing rates of R-PET in the production of new bottles. Results highlighted the decrease of the Carbon Footprint of PET bottles by the increasing R-PET content, with reference to the Italian level. Particularly, if the 5.5 billion still water PET bottles yearly consumed in Italy were produced increasing the R-PET content to 100%, over 300,000 t CO_2eq could be saved.

The efforts to counteract the GHG emissions provided for the stringent EU legislation, need a deep analysis about both the sustainability of the packaging materials but also their end-of-life options.

This framework provided useful guidelines to better manage the sustainability of the water packaging and suggest to researchers and policymakers the issues and challenges being faced in order to move towards the path of the green new deal.

CRediT Authorship Contribution Statement

Annarita Paiano (corresponding author): conceptualization, methodology, writing—original draft preparation, writing—review and editing and supervision.

Teodoro Gallucci: scientific literature and reviewing.

Andrea Pontrandolfo: investigation, data curation and validation, writing - original draft preparation, writing—review and editing.

Tiziana Crovella: resources and visualisation.

Giovanni Lagioia: reviewing and editing.

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