# Carbon Footprint Assessment of glass packaging: a preliminary meta-analysis of circular economy policies

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**Abstract**: The food and beverage sector is the major user of glass packaging because it is still considered as one of the most reliable packaging for ensuring health, taste, and lowest environmental impacts. Glass packaging can be produced through the melting of sand, soda ash and limestone at high temperature (virgin glass), the remelting of cullet (recycled glass), or can be cleaned and sanitized to be re-used (reused glass).
The present study aims at reviewing studies on the carbon footprint of glass packaging systematizing them based on the circular economy policies recommended for making forward and reverse supply chain flows sustainable.
The adopted methodology consists of a preliminary meta-analysis, based on descriptive statistical methods, which synthetizes the existing literature and visualize the results of empirical studies related to the carbon footprint assessment (CFA) of glass packaging, by discussing the challenges of current models within the food and beverage supply chains.
The findings show that the reviewed studies seem to recommend roughly similar circular economy patterns that lead to carbon footprint reduction in different ways. By identifying the most recommended circular economy policies, these preliminary results suggest that the reuse of glass, could be a solution for reducing greenhouse gas (GHG) emissions. Given the limitations regarding the post-consumption collection of glass, rethinking the management of forward and reverse supply chain is a relevant issue. In this sense, deposit refund systems, door-to-door collection, and traceability systems, could be effective solutions to encourage the reuse of glass packaging, driving the transition towards the Sustainable Development Goals (SDGs).

**Keywords**: glass; GHG emissions; recycling; reuse; Food and Beverage supply chain.

## I. Introduction

The growing income levels and the subsequent changes in lifestyles caused an increase in packaging waste also in developing countries [1].
Packaging represents a relevant share of the global environmental impact: its brief life cycle significantly contributes to the overall material consumption but also affects the impact of the transport sector. As a matter of fact, nowadays, because of globalisation, products and their packaging are often transported over large distances causing $CO_2$ emissions. Developing Life cycle Assessment (LCA)-based analysis is then mandatory to provide useful and reliable guidelines concerning the environmental impact of packaging.
Glass has been used as packaging as early as its discovery. Glass is an inorganic permanent material, which may be recycled without properties modification. Since it is an inert material, it has protective properties, which make it suitable to contain food ensuring quality and safety [2], to be sanitized after use and to be potentially reused.
Glass packaging recycling and/or recovery allows for resource and energy savings, but also for the carbon dioxide emission reduction [3,4], but requires a prior separate collection of container glass by color to achieve efficiency [5]. Glass is then crushed into fragments and further sorted by removing other contaminant materials, such as metals, plastics, paper, ceramics, stones, and porcelain [4]. About 90% of glass fragments is mixed with virgin glass, consisting of silicone dioxide, soda ash, and limestone, as well as additional substances in smaller quantities (e.g., colorants). The mixture is then melted at temperatures of about 1400 °C and transformed into new glass products. Glasses from applications other than packaging are excluded from container glass recycling due to their different chemical composition and their potential content of hazardous substances, which could alter efficient melting or quality.
The scientific literature concerning environmental impact of packaging is wide and diversified as these types of studies are affected by the case study methodology.
The present study aims at offering a contribution to the carbon footprint assessment of glass packaging, reporting a comparative analysis among different carbon footprint assessment case studies regarding, even not exclusively, glass packaging and providing in-depth analysis on the recommended policies inspired by the circular economy paradigm.
Examining the research trends, the study allows to assess both different glass packaging systems as well as disposable, recyclable and reusable solutions, dealing with several aspects concerning the environmental

impact of packaging such us: material ecological properties, package weight, suitability for reuse.
The rapid review and preliminary meta-analysis contribute to develop and systematize the base of knowledge in terms of carbon footprint in the glass packaging sector.

## II. BACKGROUND

To date, a widely recognized and solid definition of a carbon footprint does not exist, but the notion of footprint does exist.
Indeed, the carbon footprint (CF) derives from the notion of ecological footprint (EF), which is a measure of human demand on the ecosystems, i.e., a standardized measure of demand for natural capital in contrast with the ecosystem capacity to regenerate. EF represents the amount of productive land and sea area needed to supply the resources a community consumes, and to absorb the related waste [6].
Wiedmann and Minx [7] proposed a mostly accepted definition of the carbon footprint as - a measure of the total amount of carbon dioxide emissions directly and indirectly generated by an activity or gathered over the life stages of a commodity [8].
The carbon footprint assessment can be applied to people, products, organizations, and countries [7,9,10], with different boundaries, which can overlap.
A product carbon footprint measures the greenhouse gas emissions over the whole life cycle of goods or services, from cradle to grave.
The methodologies to be adopted for conducting a carbon footprint assessment are not specified by the definition but should satisfactorily meet the requirements of the definition. A carbon footprint assessment can be carried out based on several functional units at different scales and using three principal methods: input–output analysis [11], life-cycle assessment [9] and the hybrid method [12]. The latter represent an active area of research and are being increasing used in practice.
Without considering the similarities, differences and deficiencies of the adopted carbon footprint assessment standards, this study focuses on the descriptive analysis of circular economy policies recommended by scholars which carried out the carbon footprint assessment of glass packaging.

## III. METHODOLOGY

As illustrated in Figure 1, the research design adopted for this study is based on two steps: (i) the collection of studies regarding (even not exclusively) the carbon footprint of glass packaging selected on Scopus, among papers published in indexed journals, books and conference proceedings; (ii) a meta-analysis to statistically synthetize existing literature and visualize the policy recommendations deriving from empirical studies.

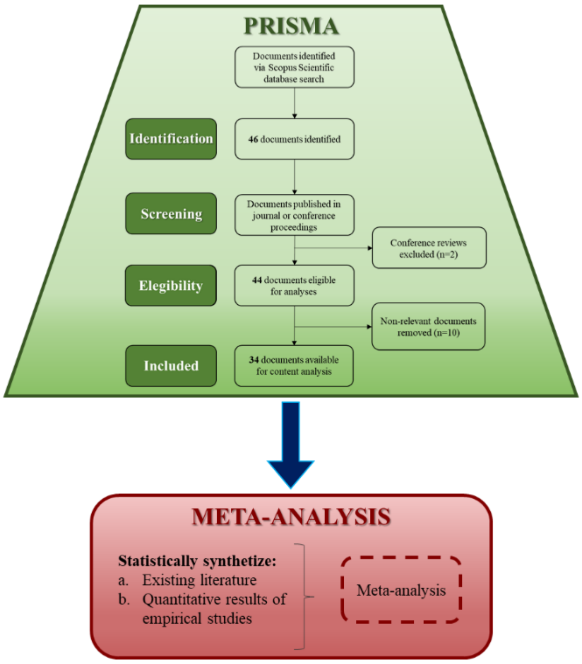


Fig. 1. The proposed Methodological framework

### A. *Data collection*

The study was based on the abovementioned methodology [13]. In our case data are represented by the records of each document included in the review. The selection of documents was performed using the Scopus database. Three keywords connected by Boolean operator AND were used to identify the most relevant documents in the analyzed research field, i.e., “glass”, “packaging”, “carbon” and “footprint”. The extraction was carried out on 22 April 2022 and generated 46 documents. Documents were filtered by subject area, language and document types, through the search protocols detailed in Table 1 and then adopting the PRISMA illustrated in Figure 1. Consequently 12 documents were deleted and a total of 34 documents were included in the meta-analysis.

TABLE I
SEARCH PROTOCOL

| | |
|---|---|
| **Search code** | TITLE-ABS-KEY (glass AND packaging AND carbon AND footprint) |
| **Subject areas** | All |
| **Document type** | Articles, reviews, chapters, conference papers |
| **Language** | English |

### B. *Preliminary meta-analysis*

Meta-analysis is a quantitative and scientific synthesis of research results. Since the 70s, meta-analysis has transformed many scientific fields, helping to establish evidence-based practice and research. At the same time, its implementation has engendered criticism and

controversy, in some cases general and others specific to particular scientific fields.
Through a preliminary meta-analysis, based on descriptive statistical methods, the study contributes to the literature on carbon footprint assessment of packaging glass by discussing the challenges of current models within the forward and reverse supply chain, but more importantly, by identifying the most recommended circular economy policies and proposing future research directions.

## IV. RESULTS

Figure 2 shows the distribution of documents' publication regarding the carbon footprint of glass packaging and related citations obtained per year.

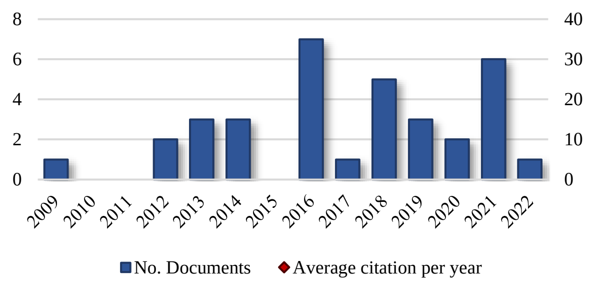


Fig. 2. Distribution of documents' publication and related citations obtained per year

The first study in the field dates back to 2009 [14]. Until 2014 the number of published documents was on average relatively low, never exceeding 3 papers per year. There has been a sudden spurt in 2016, when the number of published documents more than doubled compared to the previous period, highlighting a turning point towards a more consistent scientific production. The publication trend for 2022, in fact, seems to confirm the constantly increasing interest about the carbon footprint of glass packaging. On the date of document extraction from Scopus (22 April 2022)already one study had been published in the analyzed field of research [15].
Considering the average citations per year, documents published in 2016 represents milestones in the research field registering to date a value of 34. However, considering their relatively recent publication, the six documents published in 2021 highlight great individual and cumulative potentials to be cited in the future.
As illustrated in Figure 3, the analysis of the 34 documents included in the meta-analysis shows that the majority (71%) are studies regarding the carbon footprint of food and beverage products in which glass packaging represents part of the entire assessment. Only 29% of documents refer to research efforts regarding exclusively the glass packaging intended as autonomous product or as waste [e.g., 16,17,18].

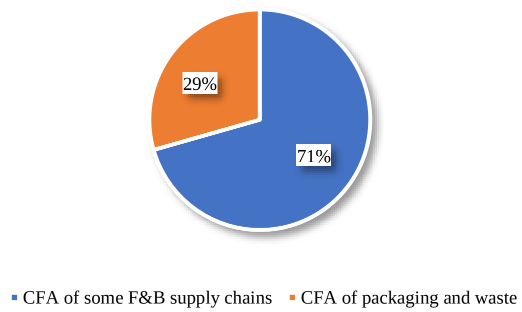


Fig. 3. CFA studies by field of application

Figure 4 highlights that, among the studies regarding the carbon footprint of glass packaging as part of the F&B supply chain assessment, the most analyzed product is beer (10 documents) (see for example [19,20,21,22,23]), followed by wine (5 documents) (see for example [24,25]) and olive oil (3 documents) (see for example [26]. Studies regarding the CFA of glass packaging applied to food products are instead less widespread than those applied to beverages. This is clearly due to the preeminent market use of glass packaging for beverages, even if application of glass packaging is widespread also for tomato sauces [27] and vegetable preserves [28].

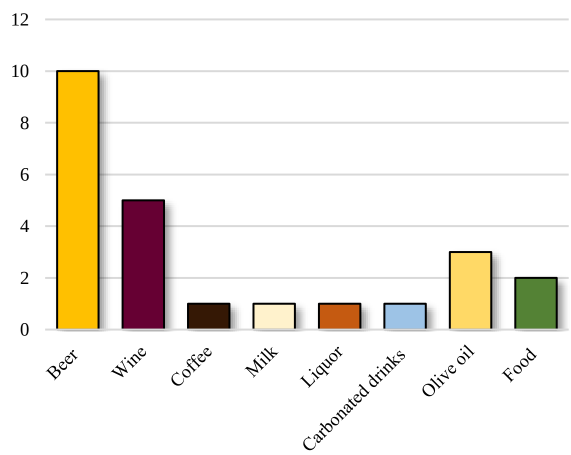


Fig. 4. Distribution of CFA studies according to the analyzed F&B supply chain

As shown in Figure 5, most of the studies, approximately 74%, report that to reduce the carbon footprint of glass packaging an increase in the use of recycled glass should be ensured, both to produce other glass packaging or to simply avoid the landfill disposal [29,30].
53% of the analyzed documents propose instead the use of lightest glass packaging which would ensure a decrease in the carbon footprint of glass primary production [31,32], but also in the carbon footprint occurring during logistics operations and distribution phase, which depends mainly on the transported commodity weight across the forward and reverse flows of the supply chains [33].

Half of the studies suggest the substitution of glass packaging with other less impacting materials in terms of GHG emissions [34], while only 47% of documents bet on glass packaging reuse [35,36] through the adoption of proper return and refill schemes, including deposit-refund systems.

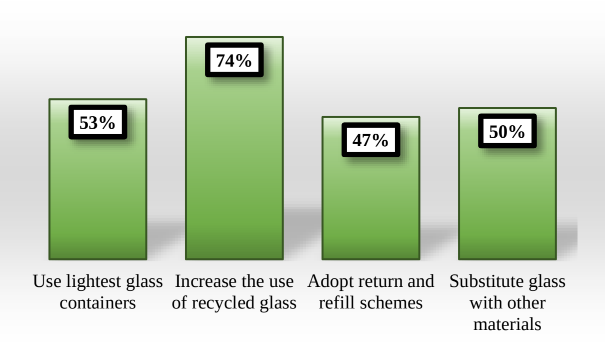


Fig. 5. Distribution of CFA studies based on the recommended circular economy policy

Turning the attention to the average citations per document registered by studies which recommend the abovementioned circular economy policies (Figure 6), the most cited studies on average are those proposing an increase of the recycled glass share in the glass production, followed by the innovative management systems addressed to the glass packaging reuse. Case studies in this field, to date, register an average citations per document equal to 20.63, showing an emerging interest by scholars, certainly worthy of further scientific efforts. Less cited on average are the documents which propose the glass packaging substitution. This is probably due to the scarce scientific interest in developing new materials whose production is not always more sustainable than others, especially when considering the reuse options. The production of light PET, for example, was proved to have a lower carbon footprint than glass production, but it can be recycled fewer times and is not reusable as glass packaging.


Fig. 6. Average citations per document based on the recommended circular economy policy

## V. Conclusions

Even if glass has traditionally been the favoured packaging for beverages and processed foods, it has increasingly come under pressure from PET and cans, because the latter have lower costs. To ensure survival, glass packaging needs to evolve and make itself more relevant and competitive in the mass market, benefiting from the opportunities of circular economy [37].

As highlighted by previous results, the reviewed studies seem to recommend roughly similar circular economy patterns that lead to successful implementation, although they demonstrate that there are different ways in which each carbon footprint reduction strategy can be applied.

Since cullet is infinitely recyclable without any loss of mechanical properties, its exploitation is fundamental for glass to remain an attractive packaging material, relevant to the demands of modern times and consumers.

Most recommended circular economy policy suggest incremental innovation, as in the case of the glass containers light-weighting; almost every major F&B producer reduced the weight of its packaging over the last decade in order to decrease their carbon footprint.

Given the difficulty of moving beyond traditional product delivery, mainly due to supply chain limitations or product limitations, dependent by the inherent nature of the product, other radical circular economy policies, such as those implying return and reuse management systems (e.g., deposit refund systems, door-to-door collection, and traceability systems) are significantly sparser, despite their increasing scientific interest.

Although this meta-analysis aimed to be comprehensive, there might be studies that are missing, because of the search criteria.

Nonetheless, this rapid review offers some practical insights in how circular economy could be used to decrease the carbon footprint of glass packaging. It presents a range of recommended policies from more system-level to consumer-focused approaches.

Furthermore, the study outlines some success scientific factors for each type of the recommended circular economy policies which could be considered to increase chances of a practical implementation within the forward and reverse supply chains to achieve the specific Sustainable Development Goals.

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