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# BRIDGING THE GAP: HOW GHG ACCOUNTING TOOLS CAN SUPPORT BEER COMPANIES IN THE IMPLEMENTATION OF CIRCULAR ECONOMY STRATEGIES

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**ABSTRACT**
This study presents a greenhouse gas (GHG) accounting tool developed for Italian breweries aimed at the quantification of the carbon footprint (CF) of organizations, thus enabling a self-assessment of their contribution to climate change. The tool builds on a Microsoft Excel interface that allows breweries to input site-specific data related to materials, energy, emissions, and waste across their life cycle in accordance with both the GHG Protocol and the ISO 14064-1 standard. A methodological framework is developed based on 6 steps, which include: i) organizational and operative boundaries definition, ii) identification of the databases for the calculations of emission sources and emission factors, iii) calculation of CF which allows iv) to perform a screening study and the hotspot identification, followed by v) a check with literature to vi) perform a CE strategies assessment. This procedure made it possible to build a valuable and reliable tool, in line with international standards and easy to replicate in other contexts. The tool indeed enables companies to identify environmentally relevant processes (hotspot analysis) and to implement relevant circular ecosystem innovation. This is possible thanks to its ability to create collaboration within ecosystem actors and allow a trial-and-error process.

## 1. INTRODUCTION

### 1.1 The role of GHG accounting tools as enablers of circularity

The awareness of living in a linear economy, where we take resources, make products, use them and discard them, while recognizing the limits of planetary resources and energy use, in a world that is a "system" threatened by pollution and waste, build the basis for circular economy (CE) thinking (Bocken et al., 2016, Konietzko et al., 2020).

The CE's main principles are the maximization of resource value and the minimization of emissions, resource consumption, waste, and pollution (Ghisellini et al., 2016; Kirchherr et al., 2017). Among the several studies concerning the integration of CE into businesses, the one of Konietzko et al. (2020) identified four main strategies supporting and enabling CE in business: narrowing (use less material and energy), slowing (extend products and components lifespan), closing (reuse products and components) and regeneration (avoid toxic materials, use renewable energy and regenerate ecosystems). This approach highlights the importance of implementing CE throughout the supply chain from input materials to final products, representing an opportunity and challenge for businesses, including businesses in the beverage industry (Ho et al., 2024). Actors in the supply chain indeed play a crucial role in the implementation and success of the CE, serving as the foundation for driving the necessary changes (Hazen et al., 2020).

Among the instruments which help businesses in making CE-related decision along their supply chain, the Carbon Footprint (CF) is a highly useful decision-making tool that allows organizations to have a deeper knowledge and, consequently, to exert a greater degree of control over the potential environmental impacts of their activities in relation to Greenhouse Gases (GHG) emissions (Valls-Val and Bovea, 2022). GHG accounting operates as the quantitative backbone of CE strategy design and monitoring. Carbon accounting within the CE has emerged as a key priority for professional organisations, as climate change represents a pressing global challenge and carbon emissions continue to rise worldwide. Although research on carbon accounting is still relatively recent, both public and private entities are

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increasingly required to quantify their GHG emissions, not only to comply with sustainability goals but also to reduce operational costs and enhance overall efficiency (Ionescu, 2023). At the organisational level, inventories built under the GHG Protocol Corporate Standard and ISO 14064-1 standard make visible direct and indirect emissions across the value chain, thus enabling firms to prioritise interventions and coordinate actions with ecosystem partners.

Recent organisational CF tools (e.g., for universities) further show how routine accounting, dashboards, and scenario screening can guide internal governance and external reporting (Valls-Val & Bovea, 2022). In line with circular ecosystem innovation principles, emphasising experimentation, collaboration, and platformisation, tools translate measurement into decision-relevant insights, supporting strategies that narrow, slow, close, and regenerate material and energy flows (Konietzko et al., 2020).

Nevertheless, the existing body of literature provides limited in-depth analyses on the potential of GHG accounting and reporting tools explicitly designed to support the identification and implementation of CE strategies. To address this gap, the present study initiates a research stream at the intersection of GHG accounting and CE strategies, proposing the development of accessible and user-friendly tools to facilitate their practical adoption.

In addition, GHG accounting tools, which build on the same logic and methodological assumptions of Life Cycle Assessment (LCA) tools, are among the simplification strategies following the logic of LCA standardisation (Beemsterboer et al., 2020). Their appeal is particularly strong for non-expert users, as they typically combine a user-friendly and customisable interface with the ability to generate immediate feedback (Beemsterboer et al., 2020). These features make them a powerful instrument for informing strategic decision-making and advancing the transition towards CE practices.

### 1.2 The Carbon Footprint accounting tool in the agrifood sector

In agri-food value chains, CF complements product-level LCA by providing comparable, year-on-year monitoring of operations and supply chains. In particular, the brewing industry is one of the biggest consumers of water and energy and one of the largest industrial producers of wastewater, solid waste, by-products, and emissions to air (Olajire, 2020). In addition, within the food industry, the brewing sector occupies a strategic position due to its high volumes of production, reaching 1,88 billion hl in 2023. Moreover, beer is the most popular alcoholic beverage worldwide, and the third-most popular drink overall after water and tea (Statista source, 2025).

The use of GHG accounting tools provides valuable support for monitoring value chain activities, responding to the urgent need for reporting and management improvements emerging in the agri-food sector, which accounts for 37% of global GHG emissions (Alromaizan et al., 2023).

Among agri-food companies, the brewing sector is particularly challenging with respect to the reduction of climate-changing emissions. Literature consistently identifies hotspots in agriculture (malting barley and hops), packaging (glass and aluminium), thermal energy for brewing and utilities, and distribution logistics (Olajire, 2020).

European Beer Product Environmental Footprint Category Rules (PEFCR) guidance and industry sources stress the importance of life-cycle thinking and harmonised datasets for comparability across formats (The Brewers of Europe, 2020; Beer PEFCR). However, most applications provide an up-to-date snapshot of the impacts on climate change (Bowler et al., 2024) without converting CF evidence into a structured, repeatable process to screen CE strategies for breweries.

### 1.3 Research gap and aim of the study

Despite growing interest in CE within brewing, as demonstrated by several international studies exploring the integration of CE strategies within the beer industry (Ho et al., 2024), some barriers remain, and a practical, standards-aligned organizational CF tool tailored to breweries and explicitly geared toward CE strategy assessment is still missing. The agri-food supply chain is a highly complex network, and effective CE strategies must engage all the actors of the supply chain (Esposito et al., 2020). In addition, there are sector-specific barriers, like internal company barriers or market barriers, to overcome (Angova, 2023).

In this contest, to spread the use CF methodology to support beer companies in the assessment of their CE strategies, the development of a calculation tool could be a valuable path to pursue. Therefore, with this paper, we aim to fill this gap by addressing the following research questions:

- RQ1: How is it possible to build a valuable GHG accounting tool supporting beer companies in CE strategies assessment?
- RQ2: In which way could a GHG accounting tool help beer companies to overcome the barriers in the adoption of CE practices?

The overall objective is thus to demonstrate how to develop a reliable and complete GHG accounting tool supporting Italian breweries in the transition towards a more sustainable and CE model. The tool facilitates companies in GHG accounting activities; the user-friendly interface is designed to be attractive for users and encourages data collection in the framework of a wider company commitment to measure and reduce GHG emissions. It allows for pre-assessing the potential effect on climate change resulting from the implementation of CE strategies, to compare results, and to replicate the study over the years, since it is based on the same standardized methodology.

The remainder of this paper is organized as follows. Section 2 illustrates the materials and the methodology behind the GHG accounting tool, with an introduction to the reference standards and the description of the assessment process. Section 3 provides the results of the GHG accounting tool design and testing, as well as outlining the possible barriers to the development of CE strategies in the beer sector, the opportunities given by a GHG accounting tool, and future developments. Finally (Section 4), conclusions are provided addressing the research questions.

## 2. MATERIALS AND METHODS

### 2.1 Methodological framework

The methodological framework developed in the context of the present study is detailed as follows and illustrated in Figure 1.

The first activity is the analysis and comparison of available GHG accounting standards (GHG Protocol and ISO 14064-1); then there is the definition of organizational and operational boundaries; the database with the identification of emission sources (ES) and emission factors (EF) is then built, and calculation formulas are set. The GHG accounting tool is then tested by input inventory data collected from a sample of selected representative companies. This screening study allowed the identification of environmental hotspots. The reliability of the results was checked by reviewing studies within the available literature. After a positive check, the priority CE strategies to be assessed using the GHG accounting tool were identified.

### 2.2 GHG Protocol and ISO 14064-1

GHG Protocol and ISO 14064-1 standard provide requirements for quantifying the GHG impact of an organization (Gao et al., 2014), or in other terms, its CF.

The GHG Protocol Initiative is a multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), governments, and others convened by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (WRI, 2004). In 2004, the Initiative published the GHG Protocol Corporate Accounting and Reporting Standard, a document providing a step-by-step guide for companies to use in quantifying and reporting their GHG emissions. It provides sector-specific and general calculation tools and deals with the quantification of GHG reductions resulting from the adoption of mitigation methods in its project protocol (Gao et al., 2014).

ISO 14064-1 standard details principles and requirements for designing, developing, managing, and reporting organization-level GHG inventories released in 2006 by the International Standard Organization (ISO). It includes requirements for determining GHG emissions and removal boundaries, quantifying an organization's GHG emissions and removals, and identifying specific company actions or activities aimed at improving GHG management. It also includes requirements and guidance on inventory quality management, reporting, internal auditing, and the organization's responsibilities in verification activities (ISO, 2018).

During the development of the two assessment standards, efforts were made to harmonize the methodologies, but some minor differences remain. Table 1 summarizes the different aspects of the two methodologies.

Both standards require quantifying direct GHG emissions separately for all Kyoto Protocol GHGs, such as $CO_2$, $CH_4$, $N_2O$, $NF_3$, $SF_6$, and other appropriate GHG groups (HFCs, PFCs, etc.) in tonnes of CO2e and GHG removals. The two standards require defining the organizational boundaries following the same two alternative approaches: control and equity share. On the contrary, reporting boundaries are set in a different way in the two standards. As for the quantization of CF, the two standards give several different quantification methods. However, the quantification based on GHG activity data multiplied by GHG emission or removal factors is recommended and widely used (Gao et al., 2014).

In this study, the CF tool for Italian breweries has been developed according to both the GHG Protocol and the ISO 14064-1. Both guidelines follow an approach based on the LCA methodology to assess GHGs corporate inventory annual emissions.

### 2.3 Organizational and operational boundaries

As for ISO 14044, the first step of an LCA is the definition of the goal and scope, which includes the identification of the system boundaries of the study. In the context of a corporate CF assessment, the company shall define its organizational boundaries. The organization may comprise one or more facilities, and emissions or removals may originate from one or more GHG sources or sinks. Organizational boundaries setting is the way a company consolidates its facility-level GHG emissions and removals

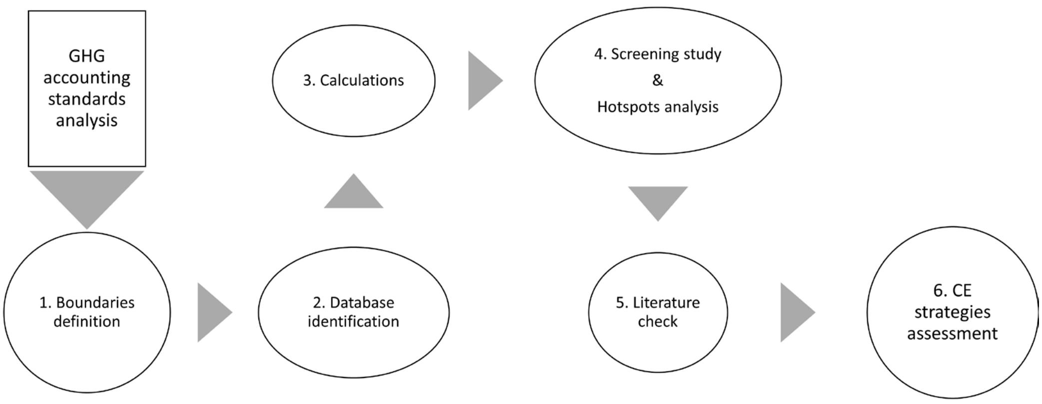


**FIGURE 1:** Methodological framework based on a 6-steps approach followed in the study. Procedural steps followed to design a GHG accounting tool allowing the assessment of possible circular economy strategies within the beer industry sector.

**TABLE 1:** Comparison of ISO 14064-1 and GHG Protocol.

| | ISO 14064 | GHG Protocol |
|---|---|---|
| Publisher | ISO | WRI&WBCSD |
| Date | 2006, 2018 (update) | 2004, 2011 (revise) |
| Goal | To define principles and guidelines for the accounting, reporting and verification of an organization's GHG inventory | |
| Principle | Relevance, completeness, consistency, accuracy, transparency | |
| GHG | Kyoto Protocol GHGs | |
| GWP | Latest IPCC's GWP | |
| Organizational boundaries | Same approach for consolidating GHG emissions: equity share and control (financial and operational) | |
| Operational/Reporting boundaries | Category 1 (direct emissions), Category 2 (energy indirect emissions), Categories 3-6 (other indirect emissions) | Scope 1 (direct emissions), Scope 2 (energy indirect emissions), Scope 3 (other indirect emissions) |
| Indirect imported energy emissions accounting method | Compulsory location-based approach, optional market-based approach | Compulsory dual reporting (location and market-based approaches) |
| Treatment of biogenic emissions and removals | Anthropogenic biogenic emissions and removals shall be quantified and reported separately. Non-anthropogenic emissions and removals may be quantified and reported separately. | Emissions from biomass or biologically sequestered carbon shall be reported separately from the scopes |

according to one of the following two approaches: equity share and control.

Under the control approach, a company accounts for all GHG emissions from operations and facilities over which it has control. Control can be defined in either financial or operational terms, and companies shall choose one of the two criteria. The financial control takes place when a company controls the operation of another company by directing the financial and operating policies of the latter with the goal of having economic benefits from its activities. The operational control is realized when a company controls the operations of another company with the full authority to introduce and implement its operating policies.

The equity shares approach lets a company account for GHG emissions and removals from operations according to its share of equity in the operation. This approach reflects the company's economic interest in terms of risks and rewards flowing from an operation, and it is aligned with the company's percentage ownership of that operation. Thus, both the GHG Protocol and ISO 14064-1 suggest the same approaches to define organizational boundaries. In the context of the present study, organizational boundaries follow the operational control approach.

Operational boundaries consist of the identification of the emissions associated with the company operations, included in the organizational boundaries, and categorizing them as direct and indirect emissions.

According to the GHG Protocol, emissions are classified in scopes:

- Scope 1 considers all direct emissions arising from stationary combustion, mobile combustion, industrial processes, and fugitive emissions;
- Scope 2 accounts for indirect emissions from imported energy flows.
- Scope 3 includes all indirect emissions generated from other sources. Indirect emissions are further categorized into 15 categories, and the company should perform a screening study to determine which are the most relevant according to its business goals and following some relevance criteria. The criteria are the size of the contribution to the overall impact, the influence on potential emissions reduction, the risk exposure of the company, the importance for stakeholders, the outsourcing of activities, the presence of sector guidance, and the correlation with spending or revenues for the company. These criteria indicate the level of detail and the type of effort that should be dedicated to each accounting category.

ISO 14064-1 classifies emissions in 6 main category groups, further detailed in many subcategories. The first and second categories correspond to respectively first and second scopes of the GHG Protocol, the remaining categories account for all other indirect emissions, considering the same level of analysis as the GHG Protocol. Also, the ISO standard indicates some criteria to evaluate in a screening step the significance of indirect emissions, which are: magnitude of the impact, level of influence, contribution to the company's risk or its business opportunity, presence of sector-specific guidance, outsourced activities and employee engagement to emission reduction.

The CF assessment tool is designed to generate results in line with both GHG Protocol and ISO 14064-1 requirements.

## 2.4 Database

### *2.4.1 Emission sources*

In order to identify the emission sources to be included in the calculation tool, an interview with the representatives of the main brewery companies involved in the study was conducted.

Three representative companies have been reached: one craft, one medium, and one big company, thanks to the collaboration of Fourgreen srl, an intermediary company providing services to HORECA businesses. Their involvement aimed to gain a reliable and comprehensive understanding of all processes that could vary depending on the company's size. This screening process is necessary to design a GHG accounting tool covering all potential processes and activities and being representative of the Italian brewery sector. The interview was guided by a draft checklist for input data collection that had been customized according to the breweries' suggestions.

In some cases, where information on beer life cycle processes was not available, secondary data were obtained thanks to the Product Environmental Footprint (PEF) screening report (The Brewers of Europe, 2015) and PEF Category Rules (PEFCR) of beer (The Brewers of Europe, 2020) and the PEF screening report of Packed Water (The European Federation of Bottled Waters, 2015). Generic processes, like an average meal delivered at the canteen, have been modelled thanks to information obtained from an LCA study of an international conference series in Europe (Neugebauer et al., 2020).

A complete list of the default emission sources included in the CF tool database is reported in the Appendix. The tool can be further customized by adding other ES to adapt to the specific requirements of the case study under analysis.

#### *2.4.2 Emission factors*

The database includes default emission factors (EF) corresponding to the default emission sources. Since the tool is designed for Italian companies, some EF are specific to the Italian context and come from governmental Italian sources such as the natural gas emission factor (ISPRA, 2022). Other EF are provided by European authorities such as the Association of Issuing Bodies (AIB) that each year publishes the annual results of the calculation of residual mixes (AIB, 2024) and the rest are taken from international institution like the UK Department of Environment, Food and Rural Affairs (DEFRA), the US Environmental Protection Agency (EPA) or commercial database like Ecoinvent 3.10, Agribalyse 3 and the World Food LCA Database (WFLDB) using the life cycle impact assessment method IPCC 2021 GWP100 – total based on the latest version of the IPCC report "AR6 Climate Change 2021: The Physical Science Basis" through the LCA software SimaPro 9.6.

The detailed list of default Scope 1 and Scope 2 EF used in the GHG accounting tool is presented in the Appendix.

The list of default emission factors for Scope 3 categories is not included in the present paper. The sources of indirect emission factors are the databases Ecoinvent 3.10., Agribalyse 3 and the World Food LCA Database (WFLDB).

### 2.5 Calculations

The calculations behind the results implemented in the tool consider for each emission source the corresponding EF multiplied by the activity data, which are defined as the quantitative information related to any life cycle process inventoried within the system boundaries, directly measures emissions and consumptions of all life cycle activities. Examples of activity data are the kg of gaseous emissions, the $m^3$ of water withdrawal, the kWh of electric energy consumption, or the km of vehicle transport, given as quantitative information related to the emission sources in the input data spreadsheet.

The formula set in the tool that automatically calculates $CO_2$e emissions is the following:

$$CF = \sum_{i=1}^{n} AD * EF \ [ton\ CO_2e] \quad (1)$$

Where:
i represents the number of emission sources (ES),
AD is the activity data collected for each ES,
EF is the emission factor relative to each ES,
CF is the total carbon footprint expressed in tonnes of equivalent $CO_2$.

## 3. RESULTS AND DISCUSSION

### 3.1 Tool design and testing

The tool was designed using Microsoft Excel and structured in two main modules: i) input data, containing the collection of all activity data, and ii) output data, presenting the results of the calculation, as described in sections 2.4 and 2.5.

Figure 2 illustrates the Instruction sheet in which the user can find useful information on how to fill in the document and how to read the results shown in the output spreadsheets.

The tool was tested by asking the three breweries involved in the design of the tool to collect data and compile the input spreadsheet. After the testing period, the tool has been improved in order to be clearer and easier to compile for non-expert users.

### 3.2 Input data

Input data required by the tool comprises some general information about the company, the scope of the study, like the organizational and operational boundaries, the reporting period, and the data owner involved in data collection. The specific input data spreadsheet corresponds to the life cycle inventory analysis (LCI) phase, as conceived by ISO 14040 on LCA methodology, and guides the collection of all activity data for every scope (GHG Protocol approach) or category (ISO 14064-1), as defined in the operational boundaries.

Figure 3 shows an extract of the input data spreadsheet.

### 3.3 Output data

After compilation of input data, the tool automatically calculates the CF of the organization and shows the results in different ways, one for each output data spreadsheet, both in table and graph format, in order to make them easier to interpret.

General results are first represented in two different tables: the first, in one spreadsheet, is referred to GHG Protocol and reports results following both location and market-based approaches, the second, in another spreadsheet, is referred to as ISO 14064-1, reporting only location-based results. Both tables show the amount of $CO_2$e emissions related to Scope 1 or Category 1, distinguished for each relevant Kyoto Protocol greenhouse gas. Indirect emissions (Scope 2 and Scope 3, or categories from 2 and on) are

TOOL DI CALCOLO CARBON FOOTPRINT
ISTRUZIONI PER LA COMPILAZIONE

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Il Tool è composto da diversi fogli di lavoro, di cui uno, il foglio "Dati di Input", permette l'inserimento dei dati in Input da parte dell'Utente e gli altri sono fogli di Elaborazione dati e Output dei risultati visualizzabili solo in lettura.

Per determinare i processi e le attività dell'Organizzazione su cui effettuare lo studio, in linea con la Norma ISO 14064, il Tool fornisce all'Utente uno strumento per effettuare una **Analisi di Significatività preliminare**, con l'obiettivo di individuare i processi e le attività dell'Organizzazione significative.
L'Analisi di Significatività è fornita nel Foglio di lavoro "Significatività" . I processi che risultano avere una significatività bassa possono essere esclusi dallo studio della CFO.

**Foglio di lavoro "Dati di Input"**
Il foglio di lavoro "Dati in Input" permette all'Utente di fornire in ingresso le informazioni necessarie per il calcolo dell'impronta carbonica di Organizzazione secondo gli standard GHG Protocol e ISO 14064.

La compilazione dei dati in ingresso richiede la conoscenza di informazioni dettagliate relative alle diverse attività aziendali.

Come informazione preliminare viene richiesto di fornire dati sui volumi di vendita dell'anno di rendicontazione, sia in termini aggregati in hl, sia in termini più dettagliati specificando il numero di pezzi venduti o i kg per ogni tipologia di prodotto.
Queste informazioni sono funzionali per il calcolo di dati necessari per diverse attività, come, per esempio, la fase d'uso dei prodotti venduti o il loro fine vita.

In seguito, la schermata di Input si sviluppa secondo la classificazione prevista dal GHG Protocol, suddividendo le attività aziendali in Scope 1, Scope 2 e Scope 3.
Lo Scope 3 è a sua volta suddiviso nelle Categorie ritenute significative.

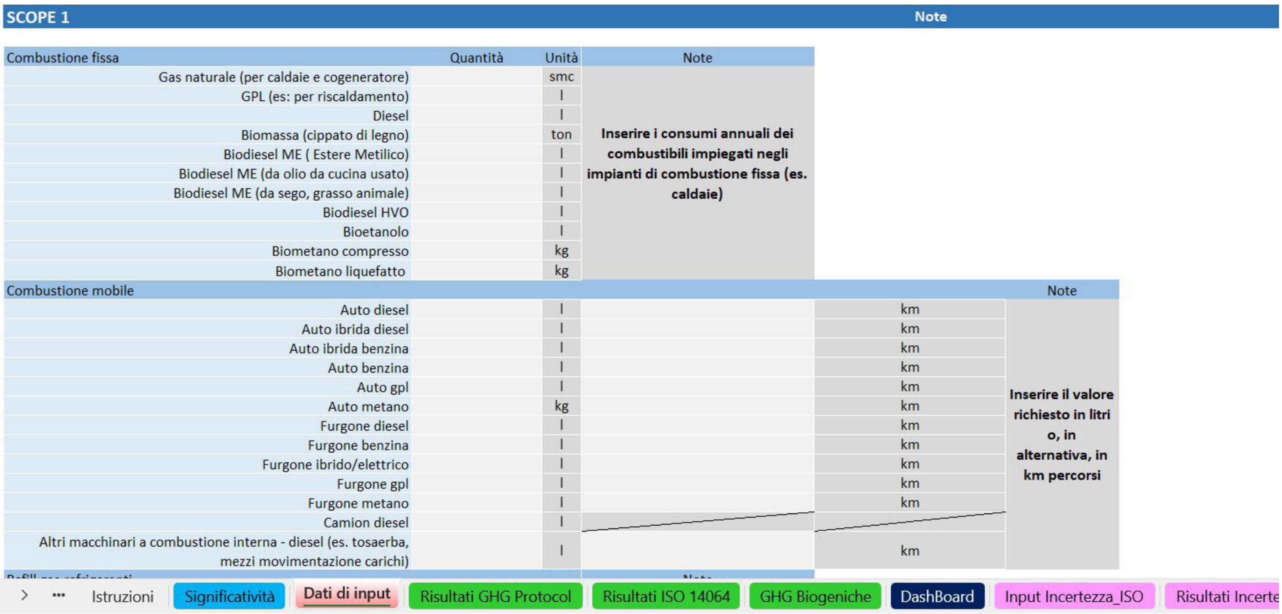
Per rendere più chiara la richiesta del dato da insierire, il Tool fornisce, nella colonna Note, informazioni o spiegazioni aggiuntive con l'obiettivo di agevolare l'Utente.

Il dato va inserito nella corrispettiva cella di colore chiaro indicata di seguito dalla freccia. Va inserito SOLO la quantità espressa in numero, NON inserire unità di misura o altre informazioni

| Combustione fissa | Quantità | Unità di misura | Note |
|---|---|---|---|
| Gas naturale (per caldaie e cogeneratore) | | smc | |
| GPL (es: per riscaldamento) | | l | |
| Diesel | | l | |

Istruzioni | Significatività | Dati di input | Risultati GHG Protocol | Risultati ISO 14064 | GHG Biogeniche | DashBoard | Input Incertezza_ISO | Risultati Incertezz...

**FIGURE 2:** Instruction sheet extract of the Greenhouse Gases (GHG) accounting tool. The sheet presents detailed instructions for completing the data input sheet, as well as guidance on how to interpret the resulting utputs (revised caption; high-resolution image to be provided by authors).



SCOPE 1 — Note

| Combustione fissa | Quantità | Unità | Note |
|---|---|---|---|
| Gas naturale (per caldaie e cogeneratore) | | smc | **Inserire i consumi annuali dei combustibili impiegati negli impianti di combustione fissa (es. caldaie)** |
| GPL (es: per riscaldamento) | | l | |
| Diesel | | l | |
| Biomassa (cippato di legno) | | ton | |
| Biodiesel ME ( Estere Metilico) | | l | |
| Biodiesel ME (da olio da cucina usato) | | l | |
| Biodiesel ME (da sego, grasso animale) | | l | |
| Biodiesel HVO | | l | |
| Bioetanolo | | l | |
| Biometano compresso | | kg | |
| Biometano liquefatto | | kg | |

| Combustione mobile | | | | | Note |
|---|---|---|---|---|---|
| Auto diesel | | l | | km | **Inserire il valore richiesto in litri o, in alternativa, in km percorsi** |
| Auto ibrida diesel | | l | | km | |
| Auto ibrida benzina | | l | | km | |
| Auto benzina | | l | | km | |
| Auto gpl | | l | | km | |
| Auto metano | | kg | | km | |
| Furgone diesel | | l | | km | |
| Furgone benzina | | l | | km | |
| Furgone ibrido/elettrico | | l | | km | |
| Furgone gpl | | l | | km | |
| Furgone metano | | l | | km | |
| Camion diesel | | l | | | |
| Altri macchinari a combustione interna - diesel (es. tosaerba, mezzi movimentazione carichi) | | l | | km | |

Istruzioni | Significatività | Dati di input | Risultati GHG Protocol | Risultati ISO 14064 | GHG Biogeniche | DashBoard | Input Incertezza_ISO | Risultati Incerte...

**FIGURE 3:** Input data sheet extract of the GHG accounting tool. The sheet contains the list of all input and output processes inventoried to be filled with the corresponding activity data by each company (revised caption; high-resolution image to be provided by authors).

expressed in terms of tons of $CO_2e$ without any distinction among specific GHGs. A third table in the following spreadsheet contains results related to biogenic $CO_2$ emissions that shall be reported separately from the results of the other scopes or categories.

Detailed results relative to direct, indirect from imported energy, and indirect from other sources emissions are presented in different spreadsheets, with the details of each emission source inventoried.

To conclude, a dashboard summarizing all the results in graph format is presented at the end of the document, and you can see an extract in the following Figure 4.

### 3.4 Selection of CE strategies in the beer ecosystem

After having performed a screening study on beer production for the three selected representative companies, a literature check was conducted to verify the compliance between our results and those of similar studies. Results suggest that, considering the environmental hotspots identified, possible CE strategies may include more efficient water consumption, via the prevention of water losses and the reuse of treated wastewater; energy efficiency improvements, like energy recovery implementation and renewable energy usage; gaseous emissions and solid waste reduction, both process and packaging waste (Olajire, 2020).

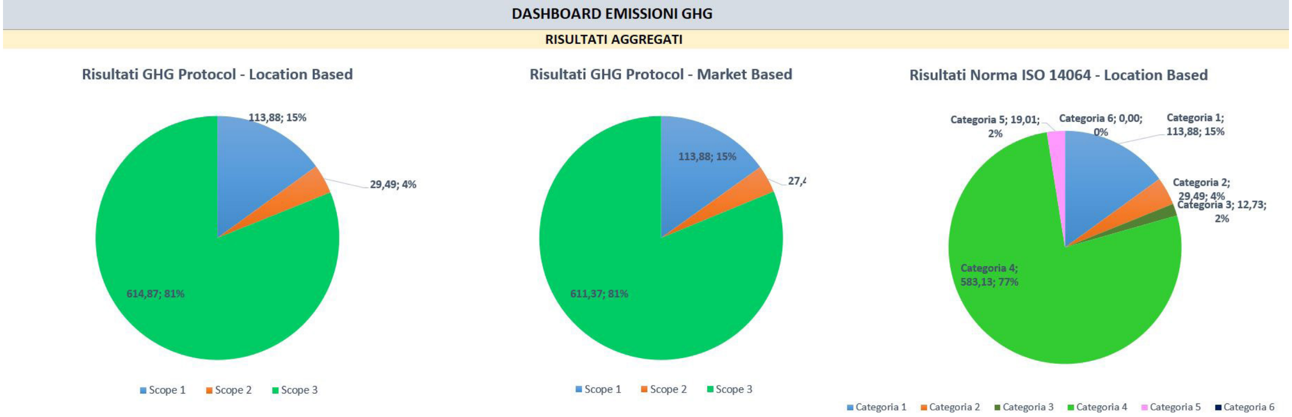



**FIGURE 4:** Dashboard summarizing results of the GHG accounting tool. The company carbon footprint assessment, according to both GHG Protocol and ISO 14064 standard, are presented in the form of pie charts, with varying levels of detail regarding the contributions (revised caption; high-resolution image to be provided by authors).

Studies demonstrate that the main waste generated by the brewing process is grain husks, yeast, and $CO_2$, but out of the three, spent grain is the most important one, making up around 85% of the total waste of a brewery. Literature results show that the gasification of spent grain minimizes the total volume of residue to be disposed of and can be used to produce syngas for heat generation at breweries, substituting fossil fuels (Ortiz et al., 2019). Consistently, another study has investigated the opportunity to convert malt residues into fuel and colorants as substitutes for raw materials (Jackowski et al., 2021).

An interesting experiment is the symbiotic solution created by a rooftop hydroponic aquaponic model integrated with breweries. The authors demonstrate that this new agroecological model allows the recycling of nearly all waste resources (malt residues, yeast residues, wastewater, rainwater, heat, electricity, and gaseous emissions), reducing costs and improving system sustainability (Horn et al., 2020).

CE strategies can also be applied to packaging management, like those aiming at building a continuous loop packaging system supported by the Cradle to Cradle® (C2C) certification program (Niero et al., 2017). Aluminium cans closed closed-loop recycling, or the use of returnable packaging, could be other solutions to be tested by the GHG accounting tool.

Echoing Konietzko et al. (2020) categorization proposal of CE strategies and after discussions on the feasibility of CE solutions with the beer companies that participated in the development of the screening study, we have identified and classified six different strategies, illustrated in Figure 5.

### 3.5 Discussion on opportunities arising from the tool

GHG accounting approach encourages companies to broaden their view to include all relevant actors in their value chain, from suppliers up to end users. In the same way, effective CE strategies require to involvement of different company stakeholders, like raw materials producers, distributors, or customers. Both innovation approaches support the adoption of an ecosystem perspective, going beyond the product system and the business model. A business ecosystem is defined as a set of stakeholders, including producers, suppliers, service providers, and end users, who contribute to a common goal (Konietzko et al., 2020). Some studies have identified three main groups of principles guiding circular ecosystem innovation (Konietzko et al., 2020):

1. Collaboration within the ecosystem actors;
2. Experimentation via a trial-and-error process to implement greater circularity;
3. Platformization of interactions among organizations.

There is a need for a collaborative approach to catalyze the transition to circular business models and to implement circular practices efficiently. Engaging value chain partners in this transition starts with a good understanding of the processes and their potential for sustainable improvement. Based on the widespread assumption that only what is measurable is manageable, there is a clear need for a standardized, consistent, and high-quality method of measuring and reporting the environmental performance of organizations and products. Furthermore, standardization, considered as one of the simplification approaches used in LCA to manage the complexity of product systems and to meet user expectations regarding LCA results, while remaining consistent with the resources available to the analyst (Beemsterboer et al., 2020), can be another opportunity arising from the GHG accounting tool.

From the brewery sector perspective, the advantage is twofold: the first lies in the possibility to evaluate the relative sustainability of brewing processes by considering the CF among other sustainability parameters (Olajire, 2020). The second advantage is represented by the use of a shared assessment tool, enabling the comparison of circular performances and practices among the different stages of the life cycle of the brewing process and involving all the sectoral actors (Esposito et al., 2020).

Designing a GHG accounting tool that considers a wide range of emission sources, with relative emission factors, throughout the beer value chain, and enabling the pre-as-

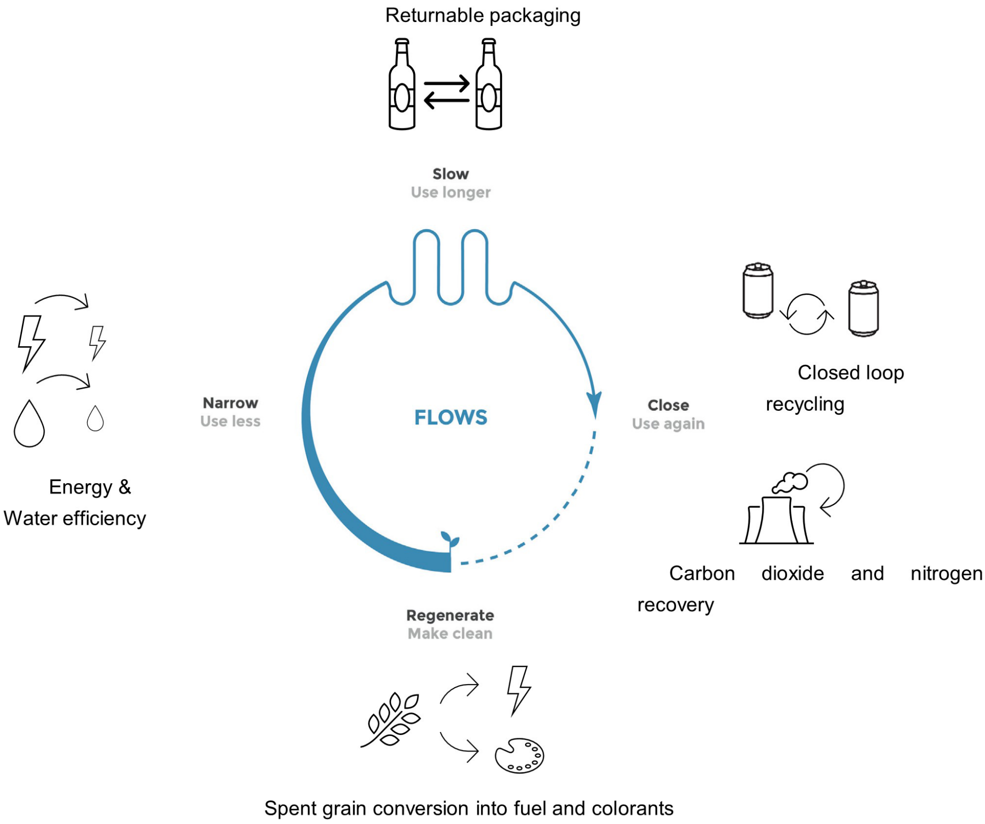



**FIGURE 5:** Circular economy (CE) strategies in the brewing sector. Readaptation from (Konietzko et al., 2020). Slowing, closing, regenerating and narrowing strategies applied to the beer sector with some suggestions on possible feasible solutions.

sessment of potential CE strategies is our proposal to support beer companies in the implementation of CE strategies.

The tool will increase companies' awareness of the potentially most impactful processes and the effectiveness of improvement actions with a view to the CE, leveraging greater involvement of value chain partners.

Practical implications include: (i) prioritizing supplier engagement for high-impact categories; (ii) integrating CF outputs into procurement Key Performance Indicators (KPIs); (iii) using the dashboard for internal communication and external reporting; and (iv) coupling the tool with CE pilots (narrowing, slowing, closing, regenerating) to enable iterative learning.

Our testing confirms that Scope 3 categories, particularly packaging, upstream agriculture, and energy supply, dominate organizational CF, in line with prior findings in brewing and food sectors (Olajire, 2020; PEFCR Beer). Beyond hotspot identification, the tool supports CE strategy formulation by quantifying potential improvements (e.g., renewable electricity market-based reductions; closed-loop aluminium; spent-grain valorization), and by structuring multi-actor dialogues around material and energy loops.

From a managerial point of view, the GHG accounting tool helps to develop the CF of breweries, thus allowing those companies to have critical data for external communication. As demonstrated also by (Rossi et al., 2025), an ecodesign tool, as well as a GHG accounting tool, can be considered as green marketing instruments, providing the foundation for developing an emission-reduction management strategy which, when effectively communicated through suitable indicators and KPIs, can move beyond a purely technical function to become a valuable instrument of strategic communication with stakeholders.

Implications for practitioners and value chain actors relate to the multiplicity of applications for the tool: managers can employ it to establish baselines, identify emission hotspots, compare alternative CE scenarios, and track progress over time, while large buyers may leverage harmonized reporting from suppliers to foster alignment and accelerate coordination across the ecosystem.

Transferability is high for process-agnostic modules (e.g., energy, logistics), while product- and context-specific modules (e.g., ingredients, packaging formats) require sectoral tailoring. We therefore suggest modular deployment for other agri-food subsectors.

## 4. CONCLUSIONS

The goal of the study is to show that a GHG accounting tool can support beer companies in the assessment of CE strategies. The tool presented here builds on both the GHG protocol and the ISO 14064-1 standards and is based on 6 subsequent steps which include: i) organizational and operative boundaries definition, ii) identification of databases for the calculations of emission sources and emission factors, iii) calculation of the CF, iv) performing a screening study and hotspot identification, v) conducting a check with literature to vi) perform a CE strategies assessment.

This made it possible to build a valuable and reliable tool, in line with international standards and easy to replicate in other contexts. The tool enables companies to identify environmentally relevant processes (hotspot analysis) and to implement relevant circular ecosystem innovation. This is possible thanks to its ability to create collaboration within ecosystem actors and allow a trial-and-error process.

Possible limitations could arise due to data collection effort, necessary to fill the input data spreadsheet, and manual data entry, which may introduce inconsistencies. Most of the time, companies have neither the time nor the knowledge to fulfil these tasks. Another limit could be the lack of automated adjustment of emission factors in case of any assessment method updating.

Future developments could address this limitation by providing training courses to companies' data owners on CF accounting and CE principles. The design of a more user-friendly web-based version with automated data ingestion (Application Programming Interfaces (APIs) to utilities, Enterprise Resource Planning (ERPs), and metering systems) can be a solution to address both company involvement raising and dynamic EF updating, thanks to the adoption of another simplification strategy following the automation logic (Beemsterboer et al.,2020).

Finally, the development of the 7-step methodological framework provides a basis for future development and adaptation of the assessment process to other agri-food subsectors to test transferability and benchmarking.

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