








ORIGINAL ARTICLE

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A user-friendly carbon footprint calculator for single malt Scotch whisky production with a simulated case study

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Abstract

Why was the work done: The Scotch whisky industry is committed to cutting carbon emissions to net zero by 2040. A consistent and accurate measurement of carbon emissions across the industry would enable distillers and their stakeholders to make informed decisions on sustainability. Accordingly, this work presents a user-friendly carbon footprint calculator.

How was the work done: Focusing on single malt Scotch whisky, the study defined the scope of the calculator and applied UK government carbon accounting methods. A web-based calculator was developed (<https://www.ai4whisky.com>) and evaluated using data from a simulated distillery producing 3,000 litres of pure alcohol (LPA) in a batch process.

What are the main findings: The calculator considers the distillery, maturation warehouse and bottling hall, accounting for raw materials and their transportation, energy consumption, product transportation and waste disposal within each facility. The case study calculated a carbon footprint of 2.83 kg CO₂e per 70 cL bottle of whisky. Scope 1, 2, and 3 emissions accounted for respectively, 15, 8, and 77% of the total. The calculator also visualised emissions by facility and highlighted key contributors to the overall footprint.

Why is the work important: The work addresses the challenges of achieving a consistent and accurate carbon footprint for whisky products. The calculator can be adopted by distillers, especially those without access to bespoke carbon accounting tools, or with limited data on the specific footprint of their supply chain. Furthermore, it can pave the way for a global standard method for carbon accounting in the Scotch whisky industry and for other distilled spirits.

Keywords

malt whisky, production, automation, carbon accounting, sustainability, net zero

Introduction

Single malt Scotch whisky is an increasingly significant category in the UK food and drink sector, with exports exceeding £2 billion in 2023. As defined by the Scotch Whisky Regulations (<https://www.legislation.gov.uk/ukxi/2009/2890/contents>), this category of whisky must meet strict criteria including production at a single distillery in Scotland, with only three ingredients (malted barley, yeast and water) and using pot stills. These regulations preserve the authenticity of single malt whisky and its global reputation as a premium product.

The Scotch whisky industry has recognised the need to address climate change and has committed to achieving net zero greenhouse gas (GHG) emissions by 2040 (<https://www.scotch-whisky.org.uk/industry-insights/sustainability>). The GHG emissions encompass *direct*, *indirect*, and *value chain* categorised as Scope 1, 2, and 3 (<https://ghgprotocol.org>). Scope 1 includes *direct* emissions from owned or controlled sources, such as on-site fuel combustion. Scope 2 covers *indirect* emissions from purchased electricity, steam, or heat, while Scope 3 accounts for *other indirect* emissions across the *value chain*, including raw materials, transportation, and waste.

The UK government has published carbon accounting guidelines to assist businesses in identifying, quantifying, and reducing GHG emissions. Some distilleries have assessed their carbon footprints (Beechener et al. 2020; Diageo 2021; Edrington 2021; Net Zero International 2023). However, these assessments lack comparability between distilleries due to variations in scope, and particularly, the protracted whisky production process. Differences arise in the production stages included in each assessment, as well as the specific factors considered at each stage, such as energy use, water consumption, and waste management. This inconsistency presents a barrier for distillers, stakeholders and customers in making informed and aligned decisions. In addition, current carbon accounting practices rely on either spreadsheet based systems or specialised software. Spreadsheet based methods can be cumbersome and challenging to navigate; while software-based solutions may streamline the process but can be prohibitively expensive and time consuming to use.

These considerations make such approaches inaccessible to many whisky producers, particularly small and medium sized distilleries with limited resources. Despite this, the carbon footprint of a bottle of whisky has been estimated (Beverage Industry Environmental Roundtable 2012), accounting for different production methods (column or pot distillation) and ingredients (barley, corn, rye).

This study reports a user-friendly carbon footprint calculator for single malt Scotch whisky. To achieve this, a clear scope of carbon accounting is defined, and a web-based calculator developed in alignment with UK government carbon accounting methods. Its application is demonstrated by a simulated case study based on the batch production of single malt Scotch whisky in a small to medium sized distillery. It is anticipated that the calculator will simplify the assessment of carbon footprint and be adopted by distillers, particularly those without access to bespoke carbon accounting tools or with limited supply chain data. By offering a consistent methodology, this could pave the way for a standard calculation across the sector. Although designed for single malt Scotch whisky, the calculator is adaptable to blended malt, grain whisky, and other distilled spirits (Hill and Jack 2023).

Materials and methods

Production process

The production of single malt Scotch whisky (Bringhurst et al. 2022) involves the following key process steps; barley is malted by soaking, germinating, and drying to activate enzymes that convert starches into sugars. The malted barley is then mashed with hot water to extract sugars and other nutrients, producing wort. Yeast is added to the wort with fermentation generating alcohol and flavour and aroma active congeners. This 'wash' is distilled twice in copper pot stills to concentrate the alcohol. In Scotland, the distillate at about 63% ABV (alcohol by volume) is matured in oak casks for at least three years to create the whisky 'character'. Before bottling, the whisky is typically filtered to achieve the required clarity and then diluted with water to 40% ABV (or higher).

Carbon accounting

The carbon footprint was calculated using the following equation:

$$C_e = \sum E_i \times C_i$$

Where: C_e is the sum of carbon emissions (kg CO₂ e) for a group of activities, E_i is the activity data (e.g. tonnes, kWh, litres) and C_i is the carbon emission conversion factor (kg CO₂ per activity data), sourced from the UK government GHG emission conversion factors (<https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2024>).

Table 1.

Process data used in the simulated case study (adapted from Beechener et al. 2020)

Cat.	Distillery				Maturation warehouse *				Bottling hall									
	Type	Sub-type	Volume	Unit	Type	Sub-type	No. of casks	-	Type	Sub-type	Volume	Unit	Recycling content	Unit	No. of items			
Raw materials	Barley malt	-	5.00	tons	Casks	-	20	-	Glass bottle	-	0.90	kg	38.00	%	5438			
	Water	-	41.34	m ³	-	-	-	-	Paper label	-	0.0009	kg	73.00	%	5438			
	Yeast	Cream yeast	61.79	kg	-	-	-	-	Internal cardboard	-	0.10	kg	50.00	%	5438			
		Dry yeast	0.00	kg	-	-	-	-	External cardboard	-	0.40	kg	30.00	%	453			
	-	-	-	-	-	-	-	-	Water	-	1.4	m ³	-	-	-			
Raw material transportation	Barley malt	HGVs (average)	6.72	tons	Casks	HGVs (average)	0.95	tons	Glass bottle	HGVs (average)	5.14	tons	50.00	km	-			
			15.00	km			50.00	km	Paper label	HGVs (average)	0.01	tons	50.00	km	-			
	Cream Yeast	HGVs (average)	0.065	tons			Ship	0.95	tons	Internal cardboard	HGVs (average)	0.57	tons	50.00	km	-		
			200.00	km						200.00	km	External cardboard	HGVs (average)	0.19	tons	50.00	km	-
	Energy consumption	Electricity	Grid supply	709.00			kWh	Electricity	Grid supply	701.00	kWh	Electricity	Grid supply	30.00	kWh	-	-	-
		Natural gas	Gross CV	7676.00			kWh	Natural gas	Gross CV	701.00	kWh	Natural gas	Gross CV	30.00	kWh	-	-	-
Product transportation	New-make spirit	HGVs (average)	2.80	tons	Matured spirit	HGVs (average)	3.19	tons	Bottled Whisky	HGVs (average)	9.66	tons	-	-	-			
			15.00	km			35.00	km			40.00	km	-	-	-			
Waste disposal	organic waste	Combustion	0.00	tons	Organic waste	Combustion	0.00	tons	Organic waste	Combustion	0.00	tons	-	-	-			
			Composting	0.00			tons	Composting			0.00	tons	-	-	-			
			Landfill	0.00			tons	Landfill			0.00	tons	-	-	-			
			Anaerobic digestion	21.00			tons	Anaerobic digestion			0.00	tons	-	-	-			
			Recycle	0.00			tons	Recycle			0.0002	tons	-	-	-			
	Other solid waste	Combustion	0.00	tons	Other solid waste	Combustion	0.00	tons	Other solid waste	Combustion	0.00	tons	-	-	-			
			Landfill	1.00			tons	Landfill			0.00	tons	-	-	-			
			Water	Standard			22.61	m ³			Water	Standard	0.01	m ³	Water	Standard	0.005	m ³

* The simulation replicated 10 years of maturation with identical conditions for each year, assuming an annual 'angel's share' of 2% from the original liquid volume, a 75% occupancy in the maturation warehouse, and that the carbon emission factors remain constant over the maturation period.

Results and discussion

Definition of carbon accounting scope

The production process was divided into three: the distillery, maturation warehouse and bottling hall (Figure 1). Each facility is composed of five catalogues for carbon accounting, including raw materials, raw material transportation, energy consumption, product transportation and waste disposal.

Development of the calculator interface

Considering the three production facilities and five catalogues, a web-based calculator interface was developed using the carbon accounting method described above. The calculator enables users to input production data and generate detailed carbon footprint reports. These reports provide insight into total process emissions, individual bottle footprints, breakdowns by scope and source, and key emission contributors. The web-based tool can be found at <https://www.ai4whisky.com/>

Case study

After entering the simulated data from Table 1 into the carbon calculator, the total carbon emission for the batch production was 15.38 tons CO₂e. This corresponded to 2.83 kg CO₂e per 70 cL bottle of whisky (40% ABV), or 7.08 kg CO₂e per LPA. These results are in broad agreement with previous carbon footprint assessments (Beverage Industry Environmental Roundtable 2012), which reported 2.97 kg CO₂e per 75 cL bottle (2.77/70 cL) of whisky across the supply chain. However, the emissions reported here were about three times higher than 2.4 kg CO₂e per LPA reported in the InchDairnie assessment (Beechener et al. 2020). This was expected, as this excluded emissions from waste disposal, maturation, packaging materials, and bottling.

The carbon footprint contribution was visualised (Figure 2). Overall, the Scope 1, 2 and 3 emissions accounted for 15, 8 and 77% of the total carbon footprint (Figure 2a). Scope 1 direct emissions originated from the distillery and maturation warehouse, while Scope 2 indirect emissions were associated with the maturation warehouse. Scope 3 (other indirect) emissions spanned all three facilities (Figure 2b).

Figure 1.

Carbon accounting scope - facility and catalogues.

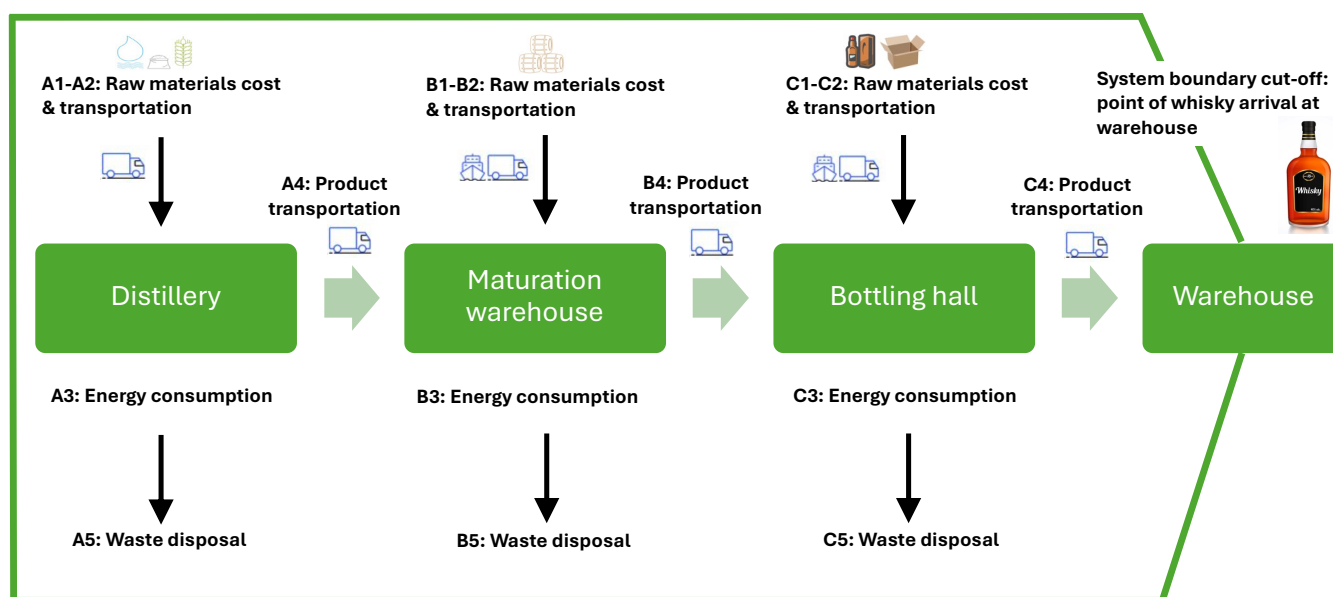
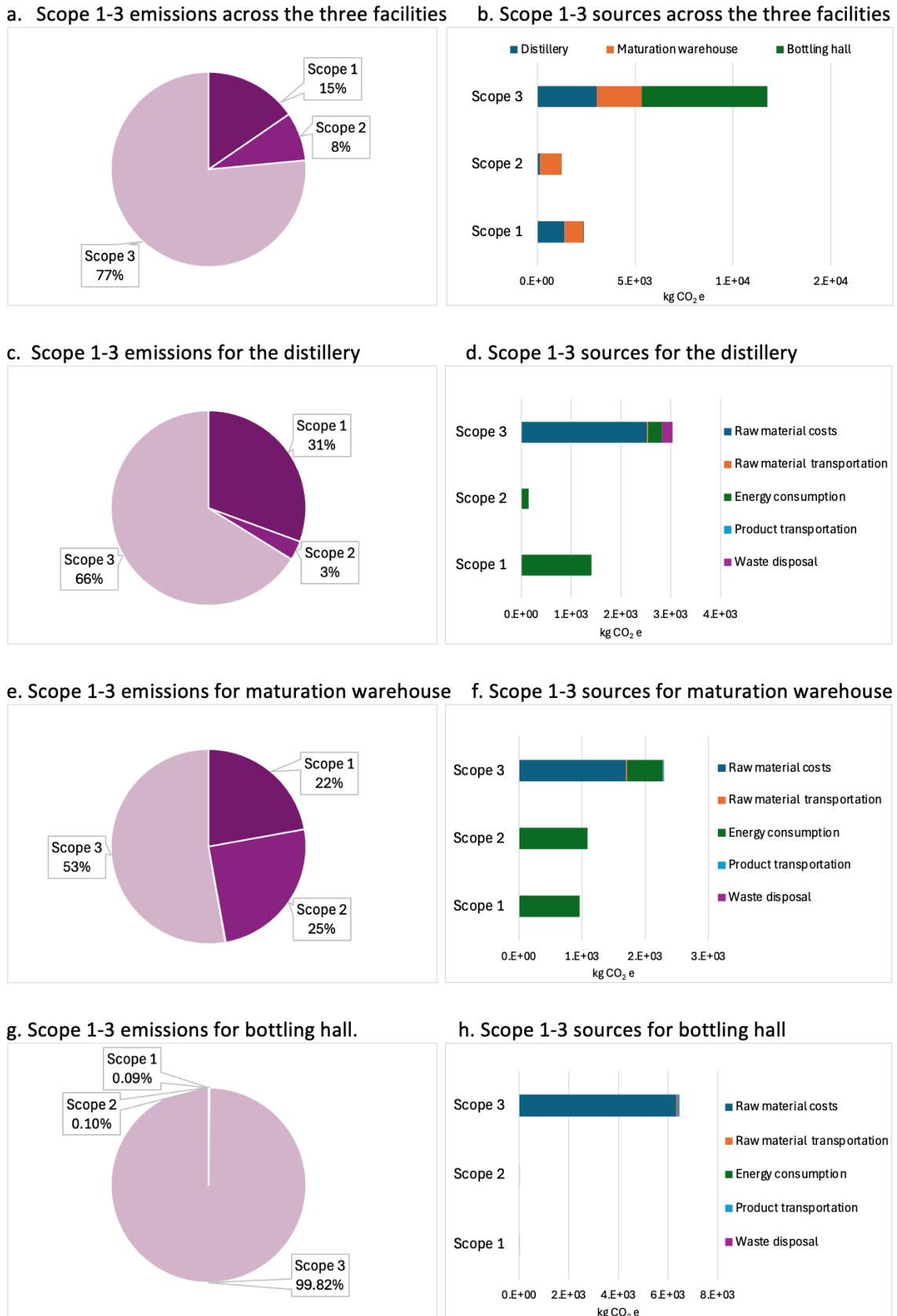


Figure 2.

Distribution of Scope 1-3 carbon emissions across (i) three production facilities and (ii) their respective emission sources in the simulated case study. Carbon emissions profiles are for the distillery (c/d), maturation warehouse (e/f), and bottling hall (g/h), with the breakdown of emissions by the defined catalogues.



In the distillery (Figure 2c/d), Scope 1 and 3 dominated the carbon emissions. Scope 1 emissions were primarily due to energy consumption, with Scope 3 emissions driven by raw materials. In the maturation warehouse (Figure 2e/f), about half of the carbon footprint came from Scope 3 emissions, mainly due to raw materials and energy consumption, while Scope 1 and Scope 2 emissions constituted the remaining half, primarily due to energy consumption. For the bottling hall (Figure 2g/h), almost 100% of the carbon emissions were classified as Scope 3, driven by raw materials.

Further, the calculator displayed the percentage contributions of each process to the total carbon footprint (Figure 3). Accordingly, the major impact ranged from raw materials for the bottling hall (41%), energy consumption in the maturation warehouse (17%), raw materials for the distillery (16%), distillery energy use (12%), and raw materials for the maturation warehouse (11%). These insights could help carbon reduction strategies across the production chain, including the conversion of whisky by-products to biofuel (Kang et al. 2020; O’Shea et al. 2023; Stewart et al. 2024), reducing energy through high gravity fermentation (Stewart 2010; Zhuang et al. 2019), and the development of

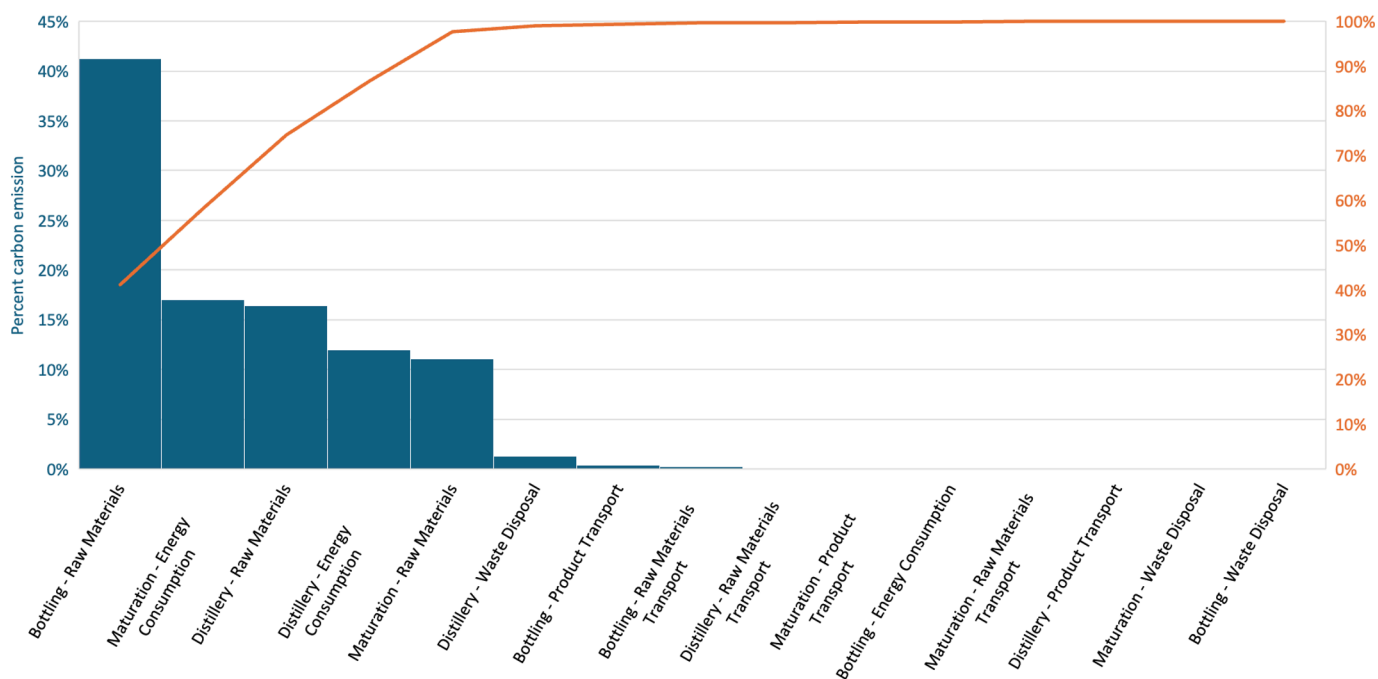
low carbon bottles (<https://www.diageo.com/en/news-and-media/press-releases/2024/johnnie-walker-unveils-worlds-lightest-whisky-glass-bottle>)

The purpose of the case study was to demonstrate the application of a carbon footprint calculator in a simulated single malt distillery environment. While the results demonstrate the feasibility of the calculator, the data may not fully represent real world conditions. To address this, efforts are underway to test the calculator in collaboration with Scottish distilleries. Additionally, ongoing improvements include: (i) integrating the tool with data sources (such as energy bills) and distillery management systems (to enable automated and seamless data input); (ii) introducing data security and privacy standards, including encryption of data in transit and at rest, as well as role based access controls; and (iii) adding features to accommodate the operational needs and workflows of distilleries to maximise usability and relevance.

The calculator has been developed for single malt Scotch whisky. While it offers a robust foundation, adapting it to blended whisky products, which account for approximately 90% of global whisky sales, will require further development. We also

Figure 3.

Emission contributions, with the percentage emissions (blue bar) and the cumulative percentage (orange curve).



recognise the trend among global food and drink companies to report product level emissions using supplier specific data, rather than relying solely on sector averages such as those in the UK government greenhouse gas (GHG) emission factors and standard life cycle assessment (LCA) databases. As such, this tool is particularly suited to smaller single malt producers, who often lack the resource to generate bespoke emissions data but require accessible and credible carbon footprint calculations.

Conclusions

A carbon accounting framework and on-line calculator were developed to assess the carbon footprint of single malt Scotch whisky, segmenting emissions by facility, source and scope. A simulated case study demonstrated the application of the tool and revealed a carbon footprint of 2.83 kg CO₂e per 70 cL bottle of whisky, with visual breakdowns. Although the initial results are promising, further work is underway to test the calculator in real world settings and to expand its functionality. The tool will support distillers, investors, and policymakers in tracking and comparing sustainability performance across the industry.

Author contributions

Shiwen Zhuang: conceptualisation, methodology, investigation, writing (original draft, review and editing), project administration, funding acquisition.

Yeqi Huang: methodology, website design and build.

Annie E. Hill: conceptualisation, writing (review and editing).

Luo Mai: conceptualisation, methodology, writing (review and editing), funding acquisition.

Conflict of Interest

The authors declare no conflicts of interest.

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