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Developing a Carbon Accounting Tool for SMEs in the Agri-Food Sector

Malak Alromaizan[a,b], Mohamed Afy-Shararah[b]*, Sandeep Jagtap[b], Lampros Litos[b], Konstantinos Salonitis[b]

[a]Saudi Industrial Development Fund, Riyadh, Saudi Arabia
[b]Sustainable Manufacturing Systems Centre, Cranfield University, United Kingdom
*Corresponding author. *E-mail address:* m.a.shararah@cranfield.ac.uk

Abstract

The global agri-food system accounts for about 37% of total annual greenhouse gas (GHG) emissions, and the agri-food Small and Medium Enterprises (SMEs) share is quite significant. Therefore, it has created an urgency for GHG reporting and management improvements. However, most tools available for GHG accounting are complex to utilize and expensive for SMEs to access. The methodology adopted in this study consists of a literature review of GHG emissions and measurement methods, an evaluation of the GHG Protocol and tool development of a GHG emission calculation tool. The literature review reveals that there has not been much research on the accuracy and position of emissions in agri-food systems, particularly in the value chain. Therefore, this paper reviews the existing GHG calculation tools focusing on the GHG Protocol. This work establishes a sector-specific calculation tool for the agri-food sector. The tool was designed following the most widely used standard, the GHG Protocol, alongside evaluating a local agri-food business to ensure a sector-specific assessment. The tool will not only support businesses in reducing GHG emissions in the environment and contribute to their emissions reduction plans and monitoring progress over time.

Keywords: Greenhouse Gas Protocol; Greenhouse Gas Emissions; Carbon footprint; Agri-food sector; Emission calculations

1. Introduction

Food production contributes to the emission of various greenhouse gases (GHG) into the atmosphere, including methane (CH_4), carbon dioxide (CO_2), and other gases that cause global warming. These gases are trapped in the atmosphere and can contribute to various environmental, and health, and most importantly climate change issues [1]. Industries not only pursue sustainability for these reasons but also to target cost and waste reduction by increasing the efficiency of their operations and increasing their competitive advantage by reaching out to new customers. In addition, most industries also value sustainability because of its long-term success and viability [2].

The urgency for change has been feeding into the industrial sector, from the scientists to the mainstream government; the ideas have then been incorporated into various businesses and academic thinking [4]. Creating a sustainable industrial system will require new frameworks, tools, and strategies, forming a systematic design approach that presents sustainable manufacturing, organizational change and a new supply chain design [5]. There is a need for guidance on GHG emissions accounting for small and medium-sized enterprises (SMEs) that are just beginning their path towards sustainability. The capacity of smaller enterprises to collect and report their emissions poses a significant obstacle [6]. Developing a tool for SMEs that quantifies and tracks embodied emissions in this field can decrease GHG emissions into the environment and help deliver better quality food by creating enhanced supply chain routes. This paper aims to develop a carbon accounting tool specific for SMEs in the agri-food sector to measure and manage GHG emissions in their supply chains using the GHG Protocol calculation method. It will include the application of the tool on a local agri-food company to validate the tool and ensure its functionality.

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2. Review of Agri-Food Systems GHG Emissions

Scientists estimated that global GHG emissions reached an all-time high in 2019 [7]. Industrial sectors contribute significantly to global climate change through their GHG emissions [8]. According to the IPCC 5th assessment report, the industrial sectors consume around 19% of the total energy and contribute 30% of the total GHG emissions. Currently the global community is interested in the Paris Agreement, an international, legally enforceable agreement on climate change to keep global warming at or below 1.5°C. To achieve this long-term climate goal, countries seek to reduce global GHG emissions as quickly as possible and create a climate-neutral environment by the middle of the century.

The global agri-food system emissions account for about 37% of total annual GHG emissions [6]. The biggest contribution comes from land use and production activities (71%), with the remainder coming from supply chain activities, including retail, transportation, consumption, fuel generation, waste management, industrial operations, and packaging [9]. Halocarbons and CO_2 from burning fossil fuels are the primary sources of potential global warming contribution [10]. The two main ways industrial sources contribute to GHG emissions are burning of fossil fuels for energy and emissions from industrial processes.

By 2050, food-related emissions are projected to increase by up to 30%, indicating an urgent improvement in sector-specific solutions [11]. Despite this, there is a lack of sector-specific studies on the standing and accuracy of agri-food systems scope 3 emissions [6]. Blanco urges further research into sector-specific supply chain emissions by examining scopes 1, 2, and 3 reporting by food and beverage processing businesses [12]. In addition, to the insufficient reporting of Scope 3 emissions, there are clear indicators to reduce their impact on climate change, the agri-food sector must enhance its GHG emissions reporting and management. Sector-specific guidance is required for more accurate emission reporting by businesses in the food chain that can be easily implemented to calculate emissions from categories with the highest GHG consumption [13]. A study conducted using 2018 data from 153 food processing companies identified purchased goods and services as the most relevant scope 3 category, followed by downstream and upstream transport and waste generated in operations [6].

The major challenge businesses face while effectively reducing corporate emissions is obtaining emissions data from vendors and customers [14]. Data is critical when calculating and measuring emissions, especially in the company's emission sources, which contains direct and indirect emissions from its supply chain [6]. Regarding the food industry, it is still unknown how accurately corporations report emissions linked with their production, particularly agricultural and land-use emissions from agricultural production. Companies must account for these indirect emissions to analyze the most significant emission sources properly and target the most cost-effective mitigation measures first, so allocating scarce resources where they will have the most significant impact [15].

3. Decarbonation and GHG Measurement

Decarbonization refers to the process of carbon reduction. It involves an economic system that compensates for and reduces the emission of CO_2 into the atmosphere; the process contains various steps. The initial step to decarbonization is recognizing the company's baseline and potential by measuring the GHG emission consumed by the company. Next, creating and announcing the targets that should then be followed and the strategies and programs for decarbonization should then be deployed. Lastly, the business's internal and external environment changes should be monitored and adjusted where appropriate.

3.1. Measuring GHG Emissions

Effective and precise climate action requires identifying and quantifying GHG emissions and their sources contributing to climate change [16]. Therefore, multiple calculation metrics have been developed to quantify carbon footprint. The main two methods are GHG Accounting and Life Cycle Assessment (LCA) which are compared in Table 1.

Table 1 Comparison of Different Measuring Methods [17]

	GHG Accounting using (GHG Protocol)	**Life Cycle Assessment**
Scope	Direct and indirect operations of the business's entire value chain	Product or service life cycle
Quantification	GHG emissions	Multiple metrics
Timeframe	Annual	Lifespan of the product of service
Standards	• GHG protocol – Corporate Standard • ISO 14064 – organizational GHGs	• ISO 14040 – LCA • ISO 14044– LCA • PAS 2050-1

LCA measures how much a product or service influences the environment. It covers every step of the product or service's supply chain, from cradle-to-grave. As a result, the product life cycle accounting and reporting standard can be applied to grasp a single product's whole life cycle emissions and concentrate efforts on the highest GHG reduction potential. The World Resources Institute and the World Business Council for Sustainable Development published the GHG Protocol to set worldwide frameworks for measuring and managing GHG emissions from corporate and public sector activities, value chains, and mitigation initiatives. The GHG Protocol is the most extensively utilized strategy for managing and mitigating GHG emissions at the company level [18].

3.2. Existing Measuring tools

The GHG Protocol has several resources and tools accessible online, which include standardized guidance reports and tools. Some sector-specific calculation tools are accessible such as cement, aluminum, iron, and steel but not specific to the agri-food sector [19]. In addition, GHG Protocol has developed guidance for the agricultural sector called “GHG Protocol Agricultural Guidance”. This guidance contributes to increased consistency and transparency in GHG accounting and reporting. However, due to the wide range of agricultural subsectors, this guidance tries to create an overarching framework that may be used by all subsectors [20]. Other tools like SimaPro and GaBi are software programs that use the LCA approach to measure a product’s sustainability [21]. However, these tools are not ideal for SMEs as they are costly and demand higher input data than the GHG calculators [22].

Regarding the agriculture field alone, a review mentions that several GHG calculators for calculating emissions from specific crops or entire farms have arisen in the public domain, and large businesses may have customized many more for "in-house" usage. These tools are computational models with embedded data that may be adjusted to produce a customized assessment of GHG emissions for a given crop and user [21]. A study reviewed 11 tools in which The Cool Farm Tool was identified as the most highly regarded, freely accessible, and recommended tool for single crop evaluations [21]. The Cool Farm Tool was developed in Excel by incorporating various global empirical models into a GHG calculator [23]. It is a successful software tool that qualifies on-farm GHG emissions and soil carbon sequestration [24]. Furthermore, PalmGHG tool allows producers to calculate the GHG balances of oil palm products. It quantifies the key sources of emissions and sequestration for a palm oil mill and its supply base [25][26]. The main research gap has been identified during the literature review as a lack of research evaluating and measuring consumed emissions specific to the agri-food sector.

4. Greenhouse Gas Protocol

GHG Protocol is meant to establish a global standardized framework that is comprehensive by measuring and managing the emissions of GHG from operations of public and private sectors, mitigation actions, and value chain [27]. The GHG Protocol is categorized into three different scopes depending on the emission source [28].

4.1. Scopes of the GHG Protocol

As stated by the GHG Protocol’s Corporate Accounting and Reporting Standard, GHG emissions are categorized into three scopes. Direct GHG emissions from sources within a business’s control or ownership are considered scope 1 emissions, which include combustion-related emissions from boilers, furnaces, and vehicles. Scope 2 emissions are indirect GHG emissions associated with purchasing energy, steam, heat, or cooling. Scope 3 emissions are the operational computation from assets the business does not own or control but implicitly touches in its value chain [29]. All businesses should quantify scope 1 and 2 emissions when reporting and disclosing GHG emissions. However, according to the GHG Protocol, scope 3 emissions quantification is unecessary. On the other hand, more companies are looking deeper into their value chain to understand the overall impact of their activities on GHG emissions. Furthermore, while scope 3 emission sources may account for the bulk of an organization’s GHG emissions, they frequently present chances for emissions reduction. Although the organization has no control over the emissions, it may be able to influence the actions that cause the emissions [28].

There have been a few existing agriculture tools, however, extensive research showed no tool tailored toward the agri-food sector to collect and measure emissions. To identify and report GHG emissions in agri-food, an approach following the GHG Protocol’s Corporate Accounting and Reporting Standard framework was taken to develop a GHG inventory. This included evaluating a local agri-food company as a baseline and validating the tool while ensuring its functionality.

4.2. GHG Inventory Design

Companies can discover potential emissions reductions and set reduction objectives based on reliable baseline data by developing a companywide GHG inventory [28]. A GHG inventory is a list of emission sources and the associated emissions quantified using standardized methods giving a broad overview of a company's overall emissions [30]. Step-by -step process is described in Sections 4.3 and 4.4.

4.3. Define Business Goals

To maintain long-term success in a competitive business environment and to be ready for future national and regional climate legislation, SMEs in the agri-food field must be able to evaluate and manage their GHG risks.

4.3.1. Supply Chain Evaluation

The local agri-food company’s entire supply chain was completely evaluated before designing the GHG inventory to determine a baseline for businesses in the field. The entire network of all the individuals, organizations, resources, activities, and technology involved in creating and selling a product was evaluated. This process chain encompassed everything from the delivery of raw materials from the supplier to the manufacturer to its eventual delivery to the end user as guided by the GHG Protocol framework [28].

4.3.2. Organizational and Operational Boundaries

Inventory boundaries, including operational and organizational boundaries, define the business processes and emissions included in a company's GHG inventory. The operational boundaries classify the emissions directly or indirectly from the organization's operations and facilities. In contrast, organizational boundaries specify the business operations and facilities included in the inventory. Each corporation will have a unique organizational boundary because of variations in legal and organizational structures. The GHG Protocol defines three methods for establishing organizational boundaries [28] [31], which consist of:

- Equity Share
- Operational Control

- Financial Control

The tool was developed for agri-food businesses based on the equity share approach aiming to report emissions from scopes 1, 2, and 3.

4.4. Major GHG Emission Sources

After setting organizational and operations boundaries, it is critical to establish and identify the major GHG emission sources to calculate the GHG emission. Both energy-related and non-energy-related GHG emissions come from chemical reactions in the industrial process, such as nitrous oxide (N_2O) and CH_4 belonging to scope 1 emissions. In addition, business operations create indirect GHG emissions, but they come from sources not owned or managed by other organizations. Scope 2 and Scope 3 emissions are two types of indirect emissions. Identified direct and indirect emissions under scopes 1, 2, and 3 categories of the local company were established. The indirect emissions that occur due to the operations in the reporting company but from sources not owned or controlled by them were identified under Scope 3. However, assessing GHG emissions across the entire value chain is a bit complicated. Therefore, the technical guidance developed by the GHG protocol is utilized to assess scope 3 emissions. According to the GHG protocol, scope 3 contains 15 major categories. However, not all of them were considered as not all of them apply to the local company and the agrifood sector.

4.4.1. Emission Factors and Calculations

Two data types are required to calculate emissions: activity data and emission factors. The term activity data refers to a measurable level of an activity that produces GHG emissions, for example, liters of fuel consumed, or kilos of material purchased. An emission factor is a factor that translates data activity into GHG emissions; for example, kg CO_2 released per liter of fuel consumed, or kg CO_2 released per kilograms of material produced [29]. Most SMEs, and many larger businesses, will calculate their scope 1 GHG emissions based on the acquired amounts of commercial fuels (such as natural gas and heating oil) using published emission factors [28]. The primary inputs for calculating scope 3 GHG emissions include activity data, such as fuel consumption or passenger miles, as well as public or third-party emission factors [28]. The total amount of GHG produced due to direct and indirect human activities, usually expressed in equivalent tons of carbon dioxide (CO_2e). It is the international unit of measurement used to describe the global warming potential (GWP) of all GHG (CO_2, CH_4 and N_2O) relative to CO_2 [32].

GHG emissions are determined by multiplying GHG activity data with emission factors. The total direct emissions of scope 1 were calculated in terms of metric tons (MT) of CO_2e. Indirect energy related to GHG emissions is mainly generated from electricity consumption. Therefore, emissions originating from electricity usage were calculated by multiplying electricity consumption (kWh) by the grid emission factor (GEF). The latest GEF for UK grid electricity was extracted from International Energy Agency (IEA) database. Relevant emission factors related to the UK were obtained from the EPA database and GHG protocol. However, company-specific emission factors, which are not publicly available, are not used for calculations, and the company must define such factors prior to the calculations. A company must define emission factors by evaluating its entire value chain in the categories of purchased goods and services and waste generated in operations [33].

5. Carbon Accounting Tool Development

The calculation tool is developed using Excel for all identified scopes 1, 2 and 3 emission sources. The tool consists of multiple spreadsheets, starting with an introduction sheet expressing the aim of the tool and data entry fields, as seen in figure 1.

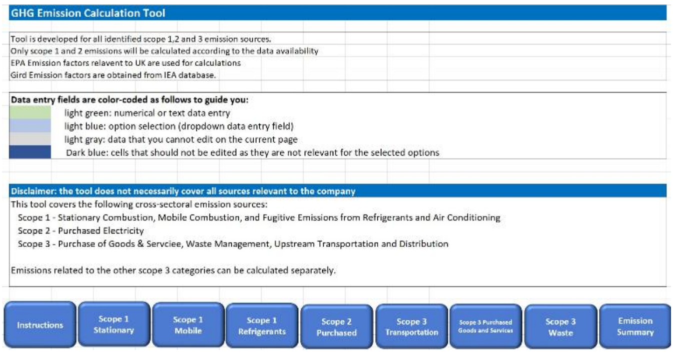
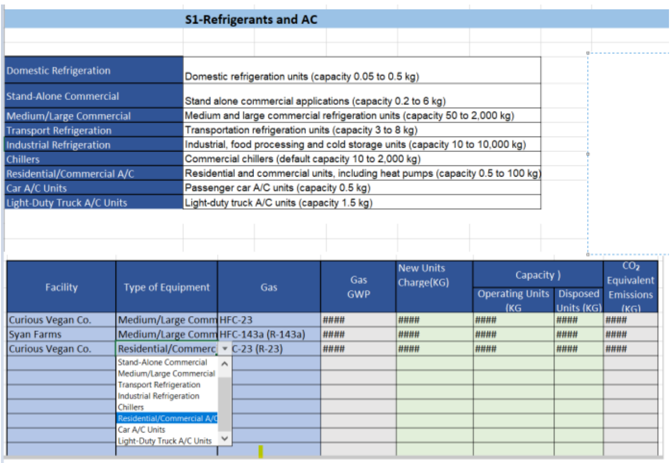


Figure 1 Introduction sheet

The next sheet is the instruction sheet which contains specific input instructions for each category and scope. During the development of the tool, the calculations of scope 1 emissions were set using the emission factors extracted from the GHG Protocol and EPA database. Under scope 1, three major categories were considered: stationary combustion, mobile combustion, and fugitive emissions due to refrigerant and AC. For stationary combustion, natural gas, and liquid petroleum gas (LPG) are the main fuel types used in the company. The relevant unit is selected from a dropdown; mmBtu, scf and therms for natural gas and gallon, mmBtu and kg for LPG. Relevant emission factors will be automatically selected according to the assigned unit. The amount of fuel used monthly could be inserted and if not available. Under mobile combustion, the tool is developed for both distance-based and fuel usage-based methods. Any method can be selected according to the data availability with a dropdown for both the fuel source, gasoline or diesel, and vehicle type. Relevant emission factors will be automatically selected according to the type of vehicle.

Under the fugitive emissions due to refrigerant and air-conditioning, the screening method is applied to calculate GHG emissions. The type of equipment considered in the tool is described in detail on the spreadsheet, as displayed in figure 2. The equipment and gas for each entered item can be selected from a dropdown list. Relevant emission factors will be automatically selected according to the type of equipment and gas selected. The number of new units of refrigerant in kilograms must be entered along with the capacity for all units utilized and eliminated throughout the reporting period. The total GHG emissions are calculated at the bottom of the sheet and linked to the Emission Summary Tab.

Scope 2 emissions are related to electricity, where the primary inputs for calculating include supplier-specific, local grid, or other published emission factors, as well as metered energy usage. The location-based method in the tool is applied to calculate the emissions from electricity usage. After a dropdown selects the reporting year, the grid emission factor will be automatically applied, figure 3. The total GHG emissions for that activity will be calculated at the bottom of the table and available in the Emission Summary Tab.



S1-Refrigerants and AC

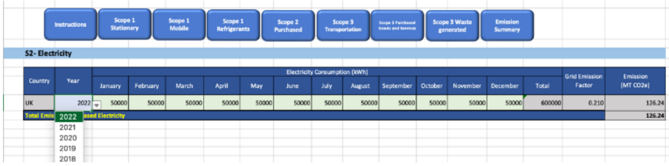
Domestic Refrigeration	Domestic refrigeration units (capacity 0.05 to 0.5 kg)
Stand-Alone Commercial	Stand alone commercial applications (capacity 0.2 to 6 kg)
Medium/Large Commercial	Medium and large commercial refrigeration units (capacity 50 to 2,000 kg)
Transport Refrigeration	Transportation refrigeration units (capacity 3 to 8 kg)
Industrial Refrigeration	Industrial, food processing and cold storage units (capacity 10 to 10,000 kg)
Chillers	Commercial chillers (default capacity 10 to 2,000 kg)
Residential/Commercial A/C	Residential and commercial units, including heat pumps (capacity 0.5 to 100 kg)
Car A/C Units	Passenger car A/C units (capacity 0.5 kg)
Light-Duty Truck A/C Units	Light-duty truck A/C units (capacity 1.5 kg)

Facility	Type of Equipment	Gas	Gas GWP	New Units Charge(KG)	Capacity) Operating Units (KG	Disposed Units (KG)	CO2 Equivalent Emissions (KG)
Curious Vegan Co.	Medium/Large Comm	HFC-23	####	####	####	####	####
Syan Farms	Medium/Large Comm	HFC-143a (R-143a)	####	####	####	####	####
Curious Vegan Co.	Residential/Commerc	C-23 (R-23)	####	####	####	####	####

Stand-Alone Commercial
Medium/Large Commercial
Transport Refrigeration
Industrial Refrigeration
Chillers
Residential/Commercial A/C
Car A/C Units
Light-Duty Truck A/C Units

Figure 2: Sample from Refrigerants/AC datasheet

The tool considers the following major scope 3 emissions: transportation, purchased goods and services, and waste generated in operations, as these categories have the highest consumed emissions in the agri-food industry [6]. All indirect emissions related to transportation can be calculated under this section: upstream transportation & distribution, downstream transportation & distribution, employee commuting, business travels, emissions due to waste transportation, and emissions due to non-road vehicles & machinery. The mode of transportation and the type of vehicle can be selected through a dropdown. The relevant emission factor will be automatically selected according to the type of vehicle, and calculation will be performed by entering the monthly distance travelled in miles. Indirect emissions related to the purchased goods and services can be calculated under this next category by identifying the type of raw materials used for production and the quantity in kilograms. As relevant emission factors are not available publicly, they must be generated considering the value chain. Finally, emissions related to water consumption can be calculated by entering water consumption. Relevant emission factors must be derived according to the water source and energy related to water pumping. The total GHG emissions for that activity will be calculated at the bottom of the table and available in the Emission Summary Tab, and a sample of the data collection and data entry sheet can be seen in figure 4.

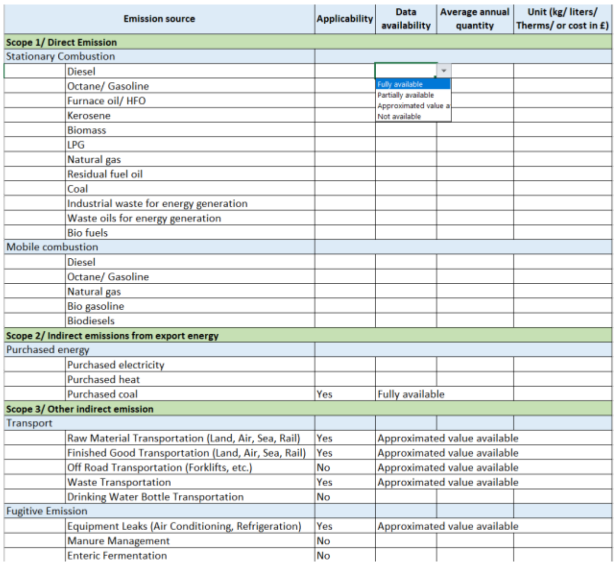


S2- Electricity

Country	Year	Electricity Consumption (kWh) January	February	March	April	May	June	July	August	September	October	November	December	Total	Grid Emission Factor	Emission (MT CO2e)
UK	2022	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	600000	0.210	126.24
Total Emis… ased Electricity																126.24

2022
2021
2020
2019
2018

Figure 3: Scope 2 monthly datasheet



Emission source		Applicability	Data availability	Average annual quantity	Unit (kg/ liters/ Therms/ or cost in £)
Scope 1/ Direct Emission					
Stationary Combustion					
	Diesel				
	Octane/ Gasoline		Fully available		
	Furnace oil/ HFO		Partially available		
	Kerosene		Approximated value a		
			Not available		
	Biomass				
	LPG				
	Natural gas				
	Residual fuel oil				
	Coal				
	Industrial waste for energy generation				
	Waste oils for energy generation				
	Bio fuels				
Mobile combustion					
	Diesel				
	Octane/ Gasoline				
	Natural gas				
	Bio gasoline				
	Biodiesels				
Scope 2/ Indirect emissions from export energy					
Purchased energy					
	Purchased electricity				
	Purchased heat				
	Purchased coal	Yes	Fully available		
Scope 3/ Other indirect emission					
Transport					
	Raw Material Transportation (Land, Air, Sea, Rail)	Yes	Approximated value available		
	Finished Good Transportation (Land, Air, Sea, Rail)	Yes	Approximated value available		
	Off Road Transportation (Forklifts, etc.)	No	Approximated value available		
	Waste Transportation	Yes	Approximated value available		
	Drinking Water Bottle Transportation	No			
Fugitive Emission					
	Equipment Leaks (Air Conditioning, Refrigeration)	Yes	Approximated value available		
	Manure Management	No			
	Enteric Fermentation	No			

Figure 4: Sample of data collection & data entry

6. Implementation

The developed tool has been utilized to calculate the carbon emissions of an agri-food business in the UK. The case study is a local vertical farming company with the aim to supply people with higher-quality food in a more sustainable and environmentally conscious manner. In a technologically advanced and enhanced container, it uses controlled environment agriculture (CEA) technology in the production of crops in multiple species of basil, micro radish as well as coriander, peashoot, micro sunflower and garlic chive. The first step in the GHG calculation project was to understand and evaluate the company's goals and efforts towards sustainability. This was done by visiting the facility in person and conducting multiple interviews with the company's founders and its directors. To get clarity on the value stream and agree on its boundaries, a map-out of the current process and supply chain of the company was established to determine the emission sources.

As SMEs face a significant obstacle in collecting data, a user-friendly data collection method was created and tailored for the agri-food sector. It was utilized to thoroughly evaluate of the applicability of all emission sources at a reporting company and determine data availability as seen in Figure 4. The data collection tool simplifies data gathered for scope 3 requiring communications with vendors and partners. The data input itself is also user-friendly, with the first column displaying all emission sources by scope, the second column being a dropdown to verify the availability of data, the third column is data entry for the average annual quality and the fourth column is to verify the units used. Due to the sensitivity of the data, the results could not be shared publicly. However, a survey has been conducted to gather feedback on the tool from the founder and directors. They found the report and graphs to be a clear representation and visualization that can be used to understand the current emissions levels and to track them over the years. The tool was regarded to be straightforward and cost-effective, and it offers a user-friendly approach to understand their emissions. Moreover, the activity data within each scope was considered to be detailed enough to provide their desired output. Also, the tool captured all the major emission sources of the agri-food sector as per the literature review and feedback from the company.

7. Discussion and Conclusions

There is an urgency for improvements in agri-food GHG emissions reporting and management because the agri-food sector consumes substantial amount of energy and contribute significantly to the GHG emissions . The literature showed the importance of carbon footprint reduction and its criticality. Calculating and reporting a GHG inventory that includes all supply chain processes starts with developing an effective emissions reduction plan. However, there is a lack of sector-specific evaluations of supply chain emissions in food firms [6]. Consequently, this research was initiated to design a tool to assist agri-food sector SMEs to quantify and track emissions.

The tool will support agri-food businesses in reducing GHG emissions and monitoring progress over time. It is designed using the most widely followed, the GHG Protocol. The tool was developed using MS Excel, designed to calculate scopes 1, 2 and 3 emissions while utilizing emission factors extracted from the GHG Protocol and EPA database. For scope 3, the tool emphasizes emissions that are expected to have the highest emission consumption in the agri-food sector, aiming at customizing the tool toward a specific field. However, that will require more details which will be accomplished in the project's next stage. As acquiring emissions data from vendors and clients establishes a difficult obstacle [14], a data collection tool was also developed to simplify such processes for SMEs. This paper aims on supporting agri-food SMEs in collecting, calculating, and reporting their GHG emissions by developing a user-friendly interface calculation and tracking tool. It is the first existing research tying a developed GHG tool with the agri-food industry and lays the foundations for further research to support a agr-food sector GHG calculation tool.

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References

[1] Xu, X., & Jain, A. (2021). *Food production generates more than a third of manmade greenhouse gas emissions – a new framework tells us how much comes from crops, countries and regions.* Retrieved from The Conversation.

[2] Marchi, D. V., & Di Maria, E. (2013). Environmental Strategies, Upgrading and Competitive Advantage in Global Value Chains. *Bus. Strat. Env.*, 22: 62-72.

[3] Garcia-Garcia, G., Coulthard, G., Jagtap, S., Afy-Shararah, M., Patsavellas, J., & Salonitis, K. (2021). Business Process Re-Engineering to Digitalise Quality Control Checks for Reducing Physical Waste and Resource Use in a Food Company. *Sustainability*, (13)12341.

[4] Neri, A. (2018, September 1). *Industrial sustainability: Modelling drivers and mechanisms with barriers.*

[5] Rich, N., & Afy-Shararah, M. (2020). *Systems for Manufacturing Excellence: Generating Efficient and Reliable Manufacturing Operations.* London: Kogan Page.

[6] Schulman, D. (2021). Supply chains (Scope 3) toward sustainable food systems: An analysis offood&beverage processing corporate greenhouse gas emissions disclosure. *Cleaner Production Letters, 1*, 100002.

[7] Gronewold, N. (2019, Decemeber 4). *Greenhouse gas emissions to set new record this year, but rate of growth shrinks.* Retrieved from Science.

[8] Kucukvar, M. (2015). A global, scope-based carbon footprint modeling for effective carbon reduction policies: Lessons from the Turkish manufacturing. *Sustainable Production and Consumption*, 47-66.

[9] Crippa, M. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat Food 2*, 198–209.

[10] Moomaw, W. (1996). Industrial emissions of greenhouse gases. *Energy Policy*, 951-968.

[11] Bager, S. (2019). The Big Facts: FoodEmissions Supply Chain Emissions. *CGIAR Research Program on Climate Change,Agriculture and Food Security.*

[12] Blanco, C. (2016). The state of supply chain carbon footprinting: analysis of CDP disclosures by US firms. *Journal of Cleaner Production*, 1189-1197.

[13] Hansen, A. D. (2022). The status of corporate greenhouse gas emissions reporting in the food sector: An evaluation of food and beverage manufacturers. *Journal of Cleaner Production*.

[14] Li, M. (2020). Since acquiring emissions data from vendors and clients constitutes a formidable obstacle,. *Environmental Science & Technology*, 400–411.

[15] Hertwich, E. (2018). The growing importance of scope 3 greenhouse gas emissions from industry. *IOP Publishing Ltd.*.

[16] Ortas, E. (2016). Carbonaccounting: a review of the existing models, principles and practical applications. *Corporate Carbon and Climate Accounting*, 77–98.

[17] Sinistore, J. (2022). Comparing Life Cycle Assessment and Greenhouse Gas Inventory. Retrieved from WSP Global.

[18] Ascui, F. (2011). As frames collide: making sense of carbon accounting. Accounting, Auditing & Accountability Journal, 978–999.

[19] GHG Protocol. (2020). *About Us*. Retrieved from Greenhouse Gas Protocol: https://ghgprotocol.org/about-us

[20] WRI . (2015). *GHG Protocol Agricultural Guidance.* Greenhouse Gas Protocol, World Resource Institute.

[21] Herrmann, I. (2015). Does it matter which Life Cycle Assessment (LCA) tool you choose? – a comparative assessment of SimaPro and GaBi. *Journal of Cleaner Production*. Retrieved from SimaPro: simapro.com

[22] Whittaker, C. (2013). A comparison of carbon accounting tools for arable crops in the United Kingdom. *Environmental Modelling & Software*, 228-239.

[23] Jonathan, H. (2011). A farm-focused calculator for emissions from crop and livestock production. *Environmental Modelling & Software*.

[24] Cool Farm Alliance . (2020). *Greenhouse gases*. Retrieved from CFA.

[25] Bessou, C. (2014). Pilot application of PalmGHG, the Roundtable on Sustainable Palm Oil greenhouse gas calculator for oil palm products. *Journal of Cleaner Production*, 136-145.

[26] ChasebI, D. (2015). Pilot application of PalmGHG, the Roundtable on Sustainable Palm Oil greenhouse gas calculator for oil palm products. *Journal of Cleaner Production*, 136-145.

[27] GHG Protocol. (2020). About Us. Retrieved from Greenhouse Gas Protocol: https://ghgprotocol.org/about-us

[28] WBC & WRI. (2004, March). *Greenhouse Gas Protocol- A Corporate Accounting and Reporting Standard.* World Resources Institue, World Business Council for Sustainable Development.

[29] WRI & WBC. (2013). *Technical Guidance for Calculating Scope 3 Emissions.* World Resources Institute, World Business Council for Sustainable Development. Retrieved from World Resources Institute, World Business Council for Sustainable Devel.

[30] EPA . (2021). *GHG Inventory Development Process and Guidance*. Retrieved from EPA Environmental Protection Agency

[31] Diary Innovation Center for U.S. (2019, November). *Scope 1 & 2 GHG Inventory Guidance.* Retrieved from GHG Protocol.

[32] Breisinger, M. (2012). *Greenhouse Gas Assessment Emissions Methodology.* Inter-American Development Bank.

[33] IPCC. (2014). AR5 Synthesis Report: Climate Change 2014. Intergovernmental Panel on Climate Change.

[1] Jagtap, S., Trollman, H., Trollman, F., Garcia-Garcia, G., Parra-Lopez, C., Duong, L., Martindale, W., Munekata, P., Lorenzo, J., Hdaifeh, A., Hassoun, A., Salonitis, K. & Afy-Shararah, M. (2022). The Russia-Ukraine conflict: its implications for the global food supply chains, Foods, 11 (14) Article No. 2098.

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Alromaizan, Malak

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