



**Key factors of Carbon footprint in the UK food supply chains: A new perspective of life cycle assessment**

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# Key factors of Carbon footprint in the UK food supply chains: A new perspective of life cycle assessment

## Abstract

**Purpose** – The purpose of this paper is to empirically identify key factors of UK food supply chains (SCs) that significantly contribute to CO<sub>2</sub> emissions (CO<sub>2</sub>e) taking into account the life cycle assessment (LCA). The UK food supply chain includes imports from other countries.

**Design/Methodology Approach** – This research develops a conceptual framework from extant literature. Secondary data obtained from ONS and FAOSTAT covering from 1990 to 2014 are analysed using Multilinear Regression (MLR) and Stochastic Frontier Analysis (SFA) to identify the factors relating to CO<sub>2</sub> emissions significance, and the efficient contributions that are being made to their reduction in the UK food supply chains.

**Findings** – The study results suggest that Transportation and Sales/Distribution are the two key factors of CO<sub>2</sub> emissions in UK food supply chains. This is confirmed by two multivariate methods, MLR and SFA. MLR results show that transportation increases UK CO<sub>2</sub> emissions by 10 tonnes of CO<sub>2</sub> emissions from one tonne of fruits and vegetables imports from overseas to the UK. Sales and Distribution reduces the UK CO<sub>2</sub> emissions by 1.3 tonnes of CO<sub>2</sub> emissions due to improved, technological operation activities in the UK. In addition, the SFA results confirm that the key factors are sufficient to predict an increase or decrease in CO<sub>2</sub> emissions in the UK food supply chains.

**Research limitations/implications** – This study has focused on the LCA of the UK food supply chain from limited data. Future studies should consider Sustainability Impact Assessment of the UK food supply chain, identifying the social, economic, regulatory and environmental impacts of the food supply chain using a re-defined LCA (all-inclusive assessment) tool.

**Practical implications** – This research suggests that food supply chain professionals should improve efficiency, e.g., the use of solar energy and biogas, and also integrate low-carbon policies and practices in food supply chain operations. Furthermore, governments should encourage policies such as mobility management programmes, urban redevelopment and privatisation to enhance better transportation systems and infrastructure to continuously reduce CO<sub>2</sub>e from the food trade.

**Originality** – Although logistics play a major role in CO<sub>2</sub> emissions, all logistics CO<sub>2</sub> emissions for other countries are not included in the ONS data. This research reveals some important insights into the UK food supply chains. Logistics and other food supply chain processes of importing countries significantly contribute to CO<sub>2</sub> emissions which are yet to be considered in the UK food SCs.

**Keywords** Food Supply Chain, CO<sub>2</sub> emissions, Sales and Distribution, low carbon operations

**Paper type** Research paper

## 1. Introduction

Forty per cent of UK fresh food supply is reliant on imports from European countries (e.g., France, Spain, Germany, the Netherlands and Ireland). Other nations – namely India, Ghana, Chile, South Africa and China – are also supplying varieties of fresh food to the UK. About 25 nations are responsible for 90% of the total UK fresh food supply (Defra, 2012). In all these, the UK Food Standards Agency plays a vital role in supporting food security and food quality. Nevertheless, the importation of UK fresh food generates a significant amount of CO<sub>2</sub> emissions (CO<sub>2</sub>e), contributing to the consumption-based emissions of the UK (Michalský and Hooda, 2015). Although the carbon footprint associated with UK consumption reduced in 2016 by 6% between 2015 to 2016, Defra estimated UK's consumption-based emissions as 784 MT CO<sub>2</sub> equivalent (Defra, 2017a). Despite the significant decrease from 601.3 MT CO<sub>2</sub>e (in 1990) to 398 MT CO<sub>2</sub>e (in 2016), the UK still generates more CO<sub>2</sub>e compared to other countries in Europe. Several studies (Davis and Caldeira, 2010; Barrett *et al.*, 2013; de Ruiter *et al.*, 2016) have also reflected on the size of the UK's carbon footprint, attributing to the imports from Europe, China and the rest of the world. Davis and Caldeira (2010) pointed out that the UK is the third highest net importer of CO<sub>2</sub>e following the USA and Japan at an amount of 253 MT CO<sub>2</sub>e per year. Barrett *et al.*'s (2013) research showed that the UK's territorial CO<sub>2</sub>e are much less compared to consumption-based CO<sub>2</sub>e. The differential growth between territorial CO<sub>2</sub>e and consumption-based CO<sub>2</sub>e is higher than that of most of the leading industrial economies in the world, including China, the USA, Germany, Japan and Canada. The consumption-based CO<sub>2</sub>e accounting provides an absolute picture of a country's

progress in both national and regional CO<sub>2</sub>e mitigation. Moreover, de Ruiter *et al.* (2016) stress that CO<sub>2</sub>e associated with the UK food supply chains (FSC) are widely generated from overseas operations.

Following the significant sustainability impacts (e.g., land use CO<sub>2</sub>e, CO<sub>2</sub>e from transportation, food waste and energy use for storage) associated with fresh food revealed by literature, this study focuses on fruits and vegetables import by the UK from eight countries representing four continents. Furthermore, fruits and vegetables exports to developed countries – e.g., the UK, the USA, Japan and Canada – are rapidly expanding (Garnett, 2011), making it a fascinating area of study. Although meat and dairy contribute significant CO<sub>2</sub>e in the UK FSC (Scarborough *et al.*, 2014; Bates *et al.*, 2019), fruits and vegetables imports are consistently increasing at a high rate compared to different food categories (UK Trade Experimental Statistics, 2018). Table I shows greenhouse gas emissions (mainly CO<sub>2</sub>e) associated with food categories production and typical western diet. In contribution to that, Defra is working with all food industry players, the third sector, consumers and international organisations to secure a sustainable food system that reduces CO<sub>2</sub>e associated with the food supply. Efforts put in place include encouraging the use of local food, and education and research on sustainable FSC (Sustainable Development Commission, 2012). Nonetheless, more pragmatic policies, measures and approaches are needed to reduce CO<sub>2</sub>e associated with the UK's FSC other than voluntary measures.

Table I. GHG emissions (in CO<sub>2</sub>e) associated with food categories production and typical western diet

Greenhouse gas (GHG) emissions for food categories production (weighted) in the UK including import from EU and outside EU		Contribution of different food categories to diet-related GHG emissions (CO <sub>2</sub> e)	
Food Category	GHG emissions (kgCO <sub>2</sub> e/kg)	Food Category	Per cent of GHG emissions (CO <sub>2</sub> e) in typical western diet
Meat	35.9	Meat, Beans, Fish, and Other non-dairy proteins	57
Fruits and Vegetables	1.6	Fruits and Vegetables	11
Milk	1.8	Milk and Dairy	14
Poultry Meat	5.4	Bread, Potato, Pasta, Rice and Other starchy foods	6
Rice	3.9	Food and Drinks (High in Sugar and/or Fat)	5
Fish	5.4	Other Miscellaneous Foods e.g., Alcohol, Sources and Hot drinks	7
Tea	1.9		
Wheat/Oats	1.0		
Sugar	0.1		

Source: Adapted from Scarborough *et al.* (2014) and FCRN (2015)

Some studies on CO<sub>2</sub>e associated with the UK FSC (Marriott, 2005; Garnett 2006; Saunders and Hayes, 2007; Garnett, 20011; Porter *et al.*, 2018) reveal limited attention to Life Cycle Assessment (LCA). There is a lack of research that captures a broad assessment of the UK FSC, considering CO<sub>2</sub>e associated with all stages of the FSC activities. The FSC involves the farming process and its inputs, through to manufacturing,

distribution, preservation, retailing, food preparation and waste disposal. However, there is limited literature on the UK FSC considering CO<sub>2</sub>e estimation which includes all activities of FSC from outside the UK.

Therefore, the purpose of this paper is to determine key factors of the UK food supply chain that significantly contribute to CO<sub>2</sub>e, considering the life cycle assessment (LCA). The LCA enables the capture of environmental and other related impacts (mainly CO<sub>2</sub>e) throughout the life cycle of a food item. While existing LCA studies (e.g., Pullman and Wikoff, 2017) published in renowned journals such as the IJOPM focus on determining CO<sub>2</sub>e of a few stages of the life cycle or the domestic supply chain, this paper suggests all-inclusive assessment. In other words, we re-define LCA to consider the entire supply chain starting from overseas sources. Understanding LCA study from this perspective provides a more robust approach when estimating CO<sub>2</sub>e generated in the supply chain and a more holistic idea of how to practically reduce the carbon footprints. In this case, all activities of the FSC involving carbon use are considered in the LCA. Among others, the activities include land use, synthetic fertiliser use, organic soil farming, on-farm transportation, overseas storage, packaging, road transport, air transport, delivery, storage, distribution, and waste. To enhance implementation of sustainable policies and measures within specific areas of the supply chains, we group all the activities into areas of operations and supply chain management activities which we refer to as the “key factors”. Thus, Growers’ Field, Inland Logistics, Transportation and Sales and Distribution were considered. We further study whether the factors are efficient in using their resources to show a relationship between the UK FSC and CO<sub>2</sub>e, through re-defined LCA. In this article we use re-defined LCA to represent activities of FSC outside the UK that have CO<sub>2</sub>e. This is particularly important to measure carbon footprint for the food supplies exported to the UK.

The study therefore addresses the following research questions:

RQ1. What are the key factors that significantly contribute to CO<sub>2</sub> emissions of UK food supply chains?

RQ2. What are the measures that policymakers and business managers can employ to reduce CO<sub>2</sub> emissions associated with UK food supply chains?

Drawing from existing studies (Pretty *et al.*, 2005; Smith *et al.*, 2007), a conceptual framework is developed to enable identification of all the stages of FSC from outside (exporting countries) to the UK. Secondary data have been obtained from the Office for National Statistics (ONS), and the Food and Agriculture Organisation of the United Nations Statistics (FAOSTAT). They are ranked through empirical analysis using Multilinear Regression (MLR) and Stochastic Frontier Analysis (SFA). This paper contributes to extant literature on the UK FSC by capturing and including LCA data of countries that export food to the UK to give a holistic view of the UK FSC. First, we undertake an empirical study identifying the key factors of the UK FSC, taking into account CO<sub>2</sub>e generated throughout the FSC which is cross-checked regarding data reliability by the use of two **multivariate** methods (MLR and SFA). This study provides pragmatic measures and approaches that policymakers and business managers can explore to mitigate consumption-based CO<sub>2</sub>e, more specifically in the fresh FSC.

The rest of the paper is organised as follows. The next section provides a literature review on the UK FSC focused on fruit and vegetables followed by a review of life cycle assessment, carbon footprint and mitigation measures. Next, in section three, we explain the research methodology including the conceptual framework, data collection and the model. This is followed by an analysis of the empirical results in section four and discussions including managerial implications in section five. Finally, we provide a conclusion, key contributions and research limitations, and offer suggestions for future research.

## 2. Literature

### 2.1 FSC (FSC): UK Fruits and Vegetables

Food supply chains produce Greenhouse gases (GHGs), mainly CO<sub>2</sub>e, throughout all the stages of the life cycle from farming processes through to warehousing, production, storage, distribution, retailing, consumption and disposal of waste (Garnett, 2006). Many studies have examined the CO<sub>2</sub>e generated throughout a FSC; e.g., Garnett (2006) Garnett (2011), López *et al.* (2015), Porter *et al.* (2018) and Vitali *et al.* (2018). There is significant evidence in the literature on attempts made in reducing the CO<sub>2</sub>e associated with FSC (Gadema and Oglethorpe, 2011; Oglethorpe and Heron, 2013; Ramanathan *et al.*, 2014). Ramanathan *et al.* (2014) suggest use of collaboration to reduce CO<sub>2</sub>e; Oglethorpe and Heron (2013) and Hendry *et al.* (2019) advocate local FSC; and Gadema and Oglethorpe (2011) focus on carbon labelling and carbon footprint.

Modern FSC entails many stages and mostly spans multiple nations and continents (Schoenherr *et al.*, 2015). In that regard, examining the food supply of a country needs a holistic perspective, taking into account where the food is grown and what stages are involved through to the final consumer. Nevertheless, food miles

– the distance from farm to the fork of the final consumer (Moxham, 2004; Pullman and Wikoff, 2017) – have played a role as a relative CO<sub>2</sub>e indicator. Conversely, Coley *et al.* (2011) question the use of food miles as a driving force for communicating the value of CO<sub>2</sub>e. Likewise, early research by Watkiss (2005) argued that a single indicator based on food miles (total food distance) is an inadequate indicator. So, estimating CO<sub>2</sub>e associated with the entire FSC needs to be assessed through a wider lens, taking into consideration all stages of the FSC in communicating the “true” value of CO<sub>2</sub>e arising across every activity that contributing to producing and consuming the food item. This will enable tailoring appropriate measures to tackle that stage or factor within the FSC while stakeholders make wiser decisions.

The UK’s FSC emits between 152Mt CO<sub>2</sub> and 159Mt CO<sub>2</sub> (Audsley *et al.*, 2010), which makes up 20% of the overall UK total emission. Further, in 2014, UK FSC CO<sub>2</sub>e increased and was responsible for 176 million tonnes of CO<sub>2</sub>e (Tassou *et al.*, 2014). Bates *et al.* (2019) claim that food consumption generates 30% of the environmental impacts of households, while the Committee on Climate Change (2019) estimated UK’s consumption related CO<sub>2</sub>e as 784 MtCO<sub>2</sub>e. This is a significant contribution to the UK’s total CO<sub>2</sub>e and calls for urgent attention. Food is imported from across the globe and the UK shift from manufacturing to services is one reason for the drift in CO<sub>2</sub>e in the UK FSC (Baiocchi and Minx, 2010). Among the food imported by the UK, fruit and vegetables are the leading food import in terms of trade value and CO<sub>2</sub>e. Fruits and vegetables have overtaken food items such as sugar, coffee, fish cereal, meats and beverages (Defra, 2017b). Fresh fruit and vegetables are supplied by various local and global producers to help maintain price stability and resilience of food supply (Parson, 2013), while also complementing domestic production.

Fruits and vegetables imported by the UK were estimated at £5.2billion in 2015 as against £199million for export with the EU countries (namely the Netherlands, Germany, France and Spain) supplying 40% of the fruit and vegetables. The remaining 60% are supplied by Africa, Asia and the rest of the world (AHDB, 2016). Fruit and vegetables produced in the UK is less than 10% (Defra, 2017b), therefore, large volumes of fresh fruits and vegetables are imported into the UK regularly, leading production of significant amount of CO<sub>2</sub>e yearly. Previous studies reveal that the UK fruits and vegetables supply is responsible for about 2.5% of the UK GHG emissions (Garnett, 2006). However, there is still a gap between theoretical emphasis and empirical studies in estimation of CO<sub>2</sub>e of the UK fruits and vegetables supply chain. Also, to appropriately determine CO<sub>2</sub>e generated within the UK fruits and vegetables supply chains, new research needs to take account of the LCA of the food supply chain. Studies that have examined the activities of the UK FSC and its related CO<sub>2</sub>e implications are summarised in Table 1.

## 2.2. Life Cycle Assessment (LCA), Carbon Footprint, Policies and Measures for CO<sub>2</sub>e Mitigation

Life cycle assessment (LCA) is commonly referred to as environmental accounting of all aspects of resources’ use and environmental effects associated with the system from cradle to grave (Curran, 1996; 2008; Finnveden *et al.*, 2009; Krishna *et al.*, 2017). Curran (2008) clearly highlights that LCA provides a holistic view of the environmental aspects related to a product over the start of its life cycle, ranging from raw materials’ extraction, production distribution through to the use, reuse and disposal of the product. This enables assessment of the environmental aspect of food product in four stages: (i) defining the big aspect of the product life cycle, (ii) description of the activities and energy flows within the product systems, (iii) detailing the product for impact assessment, and (iv) critical review and interpreting the life cycle of the product (Krishna *et al.*, 2017). Assessment of the environmental effects of food can consist of five relevant indicators: GHG emissions, the use of land, acidification, freshwater withdrawals weighted by scarcity of local water, and eutrophication (Poore and Nemecek, 2018). However, measuring carbon footprint is often considered as one of the LCA indicators. Also, this methodology is widely accepted by practitioners and academics (International Trade Centre, 2012; Jensen, 2012).

Carbon footprint enables the estimation of greenhouse gas (GHG) emissions (mainly CO<sub>2</sub>e) of the entire FSC –from the extraction or preparation of raw materials through all stages of production, storage, transportation, distributions, usage of food item and disposal (International Trade Centre, 2012; Rööß *et al.*, 2013). Therefore, based on the evidence from the literature, this study uses LCA as a method of estimating the carbon footprint of the entire FSC, starting from the exporting country (outside the UK). The main limitation of using LCA is truncation of the system boundary of LCA (Lenzen, 2000), its complexity, and its time-consuming nature (Caro, 2019). Nonetheless, this study has invested time, attention and limited LCA in the capturing of CO<sub>2</sub>e associated with all stages of the FSC, considering all hotspots and big aspects of the food life cycle. Using this LCA method will help capture CO<sub>2</sub>e generated at every stage in the FSC.

A considerable number of studies have examined the FSC using LCA (Mogensen *et al.*, 2009; McCarthy *et al.*, 2015; Noya *et al.*, 2018). However, these are limited to examining CO<sub>2</sub>e of one stage or a few stages of the FSC. For example, Mogensen *et al.* (2009) estimated CO<sub>2</sub>e associated with transporting vegetables. Further, the study estimated the environmental impacts (e.g., acidification, eutrophication and land use) associated vegetables and other food stuffs. Nevertheless, extant literature focuses on the UK fruits and vegetables using LCA, while consideration of all stages of overseas FSC processes is limited. There is not much evidence of

literature that considers a wider scope of using LCA as a carbon footprint of the entire of FSC, taking into account all activities of exporting countries. Research by Marriott (2005) and Garnett (2006) considered a few aspects of carbon footprint, but not all stages of the FSC. Such limitation is also seen in relevant literature such as Schahczenski and Hill (2009) who focus on organic agriculture, Cadarso *et al.* (2010) who focus on sea transport and Greene and Plotkin (2011) who focus on freight transportation. Lack of statistical data is mentioned as the cause for limited contribution from academics (Garnett, 2006). Recently, de Ruiter *et al.* (2016) argued that complexity of the UK FSC could be the reason for this. Nevertheless, the amount of CO<sub>2</sub>e associated with the UK FSC – e.g., transportation – is alarming (Defra, 2013) and demands the attention of all stakeholders (policymakers, business managers, researchers, FSC professionals and consumers).

Some useful policies and measures have been suggested in the literature, e.g., Brand and Preston (2010) advocate cap-and-trade and carbon price, Sundarakani *et al.* (2010) suggest green purchase and supply, Barrett *et al.* (2013) present policy-oriented research, and Ramanathan *et al.* (2014) discuss carbon footprint and carbon labelling. Very recently, the work of de Sousa Jabbour *et al.* (2019) suggested that low-carbon operations can contribute to a more sustainable society. The low-carbon operations entail a number of aspects, e.g., design of product, production and processes, transportation, packaging and distribution to reduce energy consumption and CO<sub>2</sub> emissions (Du *et al.*, 2015). It is believed that the empirical research on reducing CO<sub>2</sub>e in the UK FSC will provide coherent and robust findings to enable stakeholders to provide more realistic policies and measures towards the stages (factors) involved in the FSC that generate significant amounts of CO<sub>2</sub>e. Studies that have examined the activities of the UK FSC and its related CO<sub>2</sub>e implications are summarised in Table II.

**Table II.** Studies on activities of UK food supply chains and its related CO<sub>2</sub>e implications.

Study	Findings
Jones (2002)	CO <sub>2</sub> e associated with supply of fresh food to the UK consumers transported by trucks or planes is greater than rail.
<b>Marriott (2005)</b>	Significant portion of CO <sub>2</sub> e is associated with fresh food import from EU and non-EU countries. Majority of this CO <sub>2</sub> e is caused by food transport.
<b>Garnett (2006)</b>	CO <sub>2</sub> e are generated throughout the life cycle hotspots of FSC. The hotspots include transportation, storage and waste.
<b>Saunders <i>et al.</i> (2006)</b>	CO <sub>2</sub> e per tonne of apples produced in the UK are higher than in the New Zealand due to higher use of energy.
McKinnon and Piecyk (2012)	Significant amount of CO <sub>2</sub> e produced from transport operations.
<b>Hulthén and Gadde (2009)</b>	Modified distribution facilities (e.g., trucks and distribution centres) efficiently utilised can reduce fuel consumption and CO <sub>2</sub> e.
Audsley <i>et al.</i> (2010)	A significant proportion of CO <sub>2</sub> e (101 Mt CO <sub>2</sub> -equivalent emissions) from global land use change attributable to the UK FSC.
<b>Garnett (2011)</b>	FSC produces CO <sub>2</sub> -equivalent emissions at all stages in its life cycle, starting from the farming process and its inputs, through to manufacturing, refrigeration, distribution, retailing, food preparation and waste disposal. Evidence shows that in addition to technological mitigation, there is need to shift patterns of consumption.
<b>Defra (2013)</b>	176 Mt of CO <sub>2</sub> -equivalent is generated within the UK domestic food sector in 2011 and significant amount is generated from food transport.
Mangalassery <i>et al.</i> (2014)	Adopting zero tillage systems such as crop residue cover play significant role in reducing CO <sub>2</sub> e.
Tassou <i>et al.</i> (2014)	FSC is responsible for 176Mt CO <sub>2</sub> e emissions while food waste counts for 15Mt CO <sub>2</sub> -equivalent emissions. CO <sub>2</sub> e are generated throughout the FSC, e.g., agriculture, manufacturing, domestic operations, storage, transport, retail and catering.
de Ruiter <i>et al.</i> (2016)	The UK is increasingly reliant on outsourcing countries and the CO <sub>2</sub> e associated with the FSC is increasingly generated from overseas operations.

### 3. Methodology and conceptualisation

Based on a critical literature review, a conceptual framework capturing all activities (inputs) of FSC was developed for Life Cycle Assessment of the UK FSC (see Figure 1). Secondary data were obtained from ONS and FAOSTAT covering the period from 1990 to 2014. Multiple linear regression (MLR) and Stochastic Frontier Analysis (SFA) was used to cross-check the reliability of data. MLR (Faul *et al.*, 2009) is used to investigate the relationship the UK CO<sub>2</sub>e (as dependent variable) and FSC processes, both key factors and all activities that generate CO<sub>2</sub>e (as independent variables). SFA, as suggested by Aigner *et al.* (1977), is adopted and the works of Farrell (1959) and Meeusen and van Den Broeck (1977) are followed to estimate the technical efficiency of the decision-making units (i.e. selected countries and their fruits and vegetables supply to the UK). We choose the SFA over the alternative efficiency estimation approach, Data Envelopment Analysis (DEA) (Banker *et al.*, 1984) because SFA has gained wide acknowledgment in the food, agriculture, economics and environmental literature (Lee and Tyler, 1978; Battese, and Coelli, 1992; Coelli and Battese, 1996) due to its versatility, consistency with theory and relative ease of estimation (Baten *et al.*, 2009). In that regard, the CO<sub>2</sub>e associated with the UK FSC is studied as a production function that relates the inputs (the key factors of CO<sub>2</sub>e captured by the conceptual framework) and output (UK CO<sub>2</sub>e) with the aim of estimating the technical efficiency. We adopt MLR and SFA approaches to help explore the reliability of available data and test the conceptual framework of key factors of CO<sub>2</sub>e for circumstantial evidence. Multivariate data analysis approaches namely MLR and SFA – have the capability of making sense of limited data. Moreover, the use of MLR and SFA has offers the ability to statistically test the hypotheses, and also handle and examine multiple variables (determinants) (Cohen *et al.*, 2013). Fahmy-Abdullah *et al.* (2018) and Song and Chen (2019) followed the SFA approach to study supply chain sector efficiency. Also, Ambrose *et al.* (2010) and Dubey *et al.* (2018) considered the MLR approach in the context of supply chains. However, both approaches are yet to be employed jointly in a single research work in the food supply chain context.

#### 3.1 Development of conceptual Framework of Key Factors of CO<sub>2</sub>e

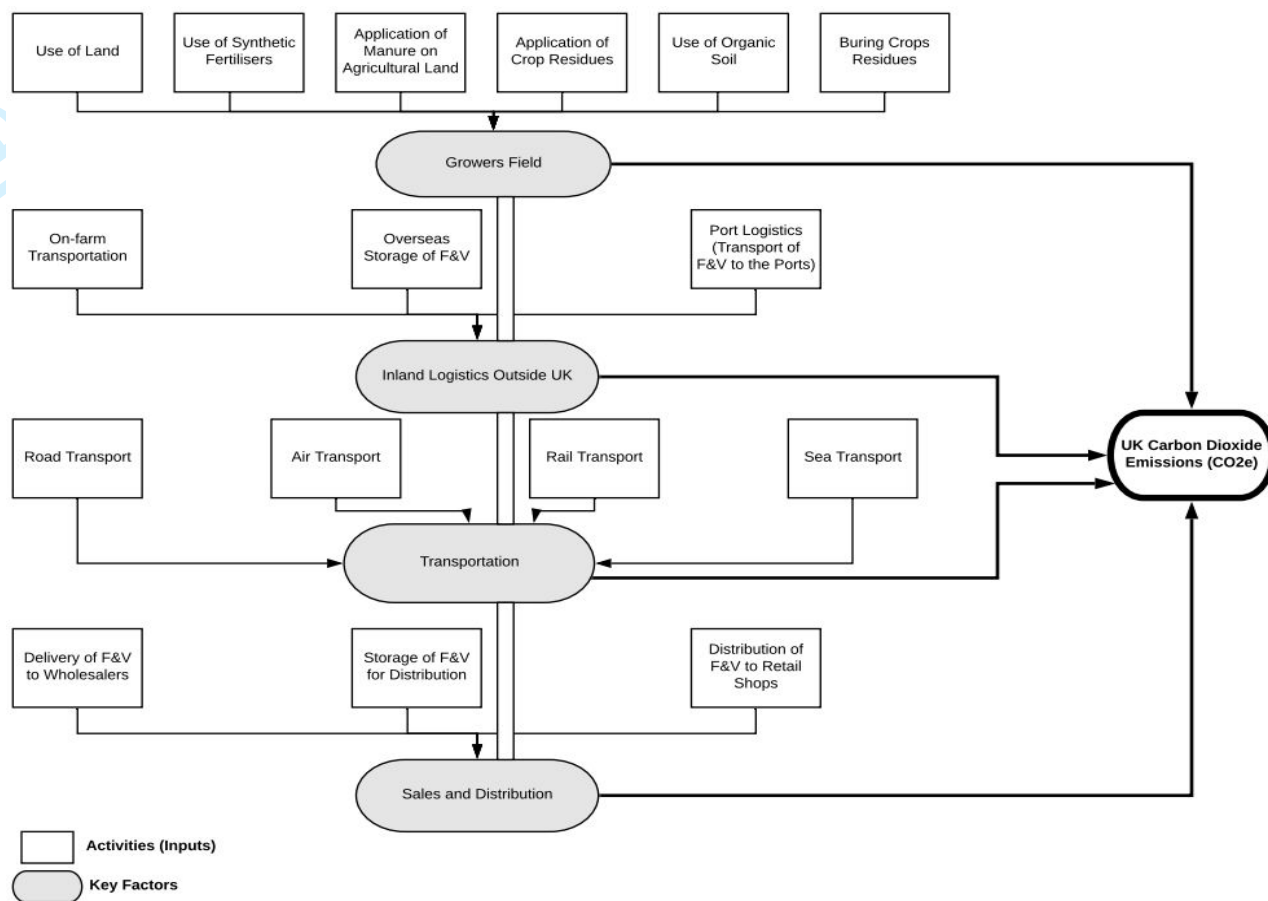
The conceptual framework of the study reveals collective ideas of the research studies from Pretty *et al.* (2005) and Smith *et al.* (2007). All CO<sub>2</sub>e-related activities that take place throughout the FSC are considered and categorised into four main factors, and presented in Figure 1: (i) Growers' Field, (ii) Inland Logistics outside the UK, (iii) Transportation, and (iv) Sales and Distribution.

Growers' Field is used in this study to refer to all pre-farming activities, farming and F&V harvesting activities. Growers' Field CO<sub>2</sub>e arise from the use of land, synthetic fertilisers, application of organic manure, use of organic soil, application of crop residues and burning of crop residues. Farming in the selected countries reflects these identified hotspots and activities (Tilman *et al.*, 2011). The use of energy on fields is not included in our data due to the complexities of capturing them.

Inland logistics outside UK CO<sub>2</sub>e include CO<sub>2</sub>e associated with on-farm transportation, storage (including heating, drying, ventilation, lighting) (Toka *et al.*, 2015) and port logistics (transport to port areas for transportation) (Xue-gong, 2007). F&V produced are transported from farming lands to warehouses where food is stored for further processing. Storage of F&V normally needs three days before they are transported to the UK. Activities at this point such as packaging and labelling generate considerable amounts of CO<sub>2</sub>e but most are excluded in this study due to lack of data. However, transport from the storage to the ports by heavy duty vehicles is included to Inland Logistics outside the UK.

Transportation is another factor of food supply chain. CO<sub>2</sub>e associated with the UK FSC are continuously discussed as a significant (Wakeland *et al.*, 2012). F&V imported to the UK are usually transported by Sea (transoceanic), road (heavy duty vehicles), air (airplanes) and rail (trains). These mode of transportation of F&V from overseas are considered.

Sales and Distribution are considered as CO<sub>2</sub>e generated by delivery (transporting) F&V from the ports to the wholesalers' warehouses in the UK, storage (awaiting distribution) and distribution (transporting) of F&V to retailing shops. The complexity of capturing CO<sub>2</sub>e associated retailing shops and waste created by cosmetics standards of retailers and at home by consumers are not included in Sales and Distribution CO<sub>2</sub>e factor due to lack of data. Figure 1 provides the conceptual framework of the UK FSC considering all the stages of activities and hotspots that generate CO<sub>2</sub>e which culminates in the overall UK CO<sub>2</sub>e.



**Figure 1.** A conceptual framework of CO<sub>2</sub>e in the UK FSC

3.2 Data Collection

We use secondary data collected from FAOSTAT (2017) and ONS (2017). The sample observations, covering 1990 to 2014, are determined but there is lack of availability of most recent years for most of the selected countries. The result is a panel data with 400 observations, covering eight countries representing four continents (namely China and India for Asia; Colombia and Costa Rica for South America; France and Spain for Europe; and Ghana and South Africa for Africa). We selected these countries due to the increase in horticultural trade with the UK fostered by improved storage facilities, high quality, safety of produce and improved agricultural input – e.g., pesticides, seeds and fertilisers and irrigation methods (Dolan and Humphrey, 2004).

The key factors and all inputs captured by the conceptual framework are the explanatory variables and the dependent variable is the UK CO<sub>2</sub>e. Table III presents the selected countries and their fresh fruit and vegetable supply to the UK, storage centres, storage before export and the exporting port centres. Table IV presents a summary of all input variables and explanations. Table V presents a summary of key factor variables, dependent variable and explanations used for the dataset. The utilisation of data is consistent with the work of Elhedhli and Merrick (2012) that provides kg CO<sub>2</sub> (direct) per tonne\*km by a different mode of transportation, safe fruit and vegetable trade in the UK, and estimation of CO<sub>2</sub>e considering food miles.

**Table III:** Selected Countries, Fruit and Vegetables, Farming Community, Storage Facility Centre, Days of Storage and Ports for Export

Country	Selected Fruit and Vegetables	Selected Farmland/Farming Community	Storage Facility Centres	Days of Storage	Export Centres/Ports
China	Banana Pepper	Guangdong	Guangdong Fruit, Vegetable and Non-staple Food Company.	3	Port of Shenzhen Guangzhou Baiyun International Airport, Guangdong Sheng, China
Colombia	Banana Pineapple	Colanta SA company Farmland, Girón, Santander,	Storage Facility, Colanta, 66, Girón, Santander, Colombia	3	Barranquilla Port  El Dorado International Airport



## Colombia

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2	Costa Rica	Melons Banana	Limón Central	Almacen Villalazo, Limón, Siquirres, Costa Rica	3	Port of Puerto Limon Limon International Airport
3						
4	Spain	Grapes Lettuce	Province of Murcia	Moving and Storage La Seda, Mudanzas y Guardamuebles La Seda	3	Noatum Container Terminal Valencia, Port of Madrid Ciudad Real Airport
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6	France	Apple Tomatoes	D'aucy	D'aucy, Prince de Bretagne	3	Nantes Saint-Nazaire Port Lann Bihoue Airport
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8	Ghana	Banana Pineapple	Nyanyano, Kasoa, Central, Ghana	Jej River Farms Awutu	3	Tema Ports and Harbours Kotoka International Airport, Accra
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10	India	Mango Banana	Sericulture Maharashtra	Cold Chain Solution of India	3	JSW Jaigart Port Chhatrapati Shivaji International Airport
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12	South Africa	Apple Pears	Elgin, Southern Africa	Interpaarl Logistics	3	Transnet Port Terminals - Cape Town Cape Town International Airport
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**Note:** Three (3) days is the estimated days for storage based on the work of UNL (2017) that suggests safe standard for storing fruits and vegetables

**Table IV.** Selected Activities of the UK FSC (Input Variables)

Variable (As presented in the model)	Description of Variable	Authors' Calculation and Source of Data Collection [multiple sources; but main source: FAOSTAT (2017)]
Land use (Land use)	This is the emissions produced by the use of cropland and land use change by the country	Calculation based on cropland emissions.
Synthetic Fertilisers (SF)	This is the emissions produced by the use of synthetic fertilisers in a country for agricultural activities.	Calculation based on synthetic fertilisers emissions.
Manure Applied (MA)	This is emissions produced by applying manures on agricultural soils by farmers.	Calculation based on manure applied to soils emissions
Crop Residues Applied (CR)	This is emissions from crop residues and pasture renewal left on agricultural lands by farmers.	Calculation based on crop residues on soils.
Organic Soil (OS)	This is emissions from cultivated organic soils under cropland.	Calculation based on organic soil cropland emissions.
Burning Residues (BR)	This is the emissions produced by the combustion of a portion of crop residues burnt on farming fields.	Calculation based on burning residue emissions.
On-farm transportation (OFT)	This is emissions from use of heavy-duty vehicles for transportation of fruits and	Calculation based on heavy-duty transport emissions (as a proxy) for fuel and machinery use for

1		vegetables from farmland to the overseas storage as a proxy for farm produce logistics.	transporting fruit and vegetables.
2			
3			
4	Overseas storage (OVS)	This is the emissions from storage of fruits and vegetables from overseas at the warehouses before transporting it to the port for export.	Calculation based on storage emissions provided by Wakeland <i>et al.</i> (2012) and work of UNL (2017).
5			
6			
7			
8			
9	Port logistics (PL)	This is emissions from the transport of fruits and vegetables from the warehouse to the ports (either the airport or cargo port or train station).	Calculation based on distance from the overseas storage and emissions by heavy-duty vehicle transport of the fruits and vegetables.
10			
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15	Road (Hdv)	This is emissions from road (heavy-duty) transport of fruits and vegetables from home grown country to the UK.	Calculation based on distance from between the cities (home grown country capital and London, considering the location of the port) and emission by heavy-duty vehicle transport.
16			
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23	Air (Plane)	This is emissions from air (plane) transport from fruits and vegetables from home grown country to the UK.	Calculation based on the air travel distance from between the cities (home grown country airport nearest to overseas storage and Heathrow airport) and emission by plane transport.
24			
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30	Rail (Train)	This is emissions from train transport of fruits and vegetables from home grown country to the UK	Calculation based on the travel distance from between the cities (home grown country rail station nearest to overseas storage and St. Pancras Station) and emission by train transport.
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39	Sea (Transoceanic)	This is emissions from sea (transoceanic) transport of fruits and vegetables from home grown country to the UK.	Calculation based on the travel distance from between the cities (home grown country cargo port station nearest to overseas storage and London Port) and emission by train transport.
40			
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46	Delivery (DV)	This is emissions from transport of fruits and vegetables from the port by heavy-duty vehicles to warehouses of retailers in the UK.	Calculation based on the travel distance from the port in London to the retailer's large storage (warehouse) using Tesco Groceries Warehouse (as the storage point) and emission by heavy-duty vehicle transport.
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54	Storage for Distribution (SfD)	This is emissions from storage of fruits and vegetables at the warehouse before transported to sales point warehouse.	Calculation based on storage emissions provided by Wakeland <i>et al.</i> (2012) and work of UNL (2017).
55			
56			
57			
58			
59	Distribution (Distr)	Emissions from transport of fruits and vegetables from the storage (warehouse) in the UK to the	Calculation based on heavy-duty vehicle transport emissions of the fruit and vegetables from storage
60			

retailer's sale point by heavy-duty vehicles. (warehouse) in the UK to the retailer's sales point.

**Notes:** Detail of these calculations can be provided on request. All final values of variables are in tonnes of CO<sub>2</sub>e.

**Table V.** Key Factor Variables and Dependent Variable

Variable (As presented in the model)	Description of Variable	Calculation and Source of Data Collection
CO <sub>2</sub> e (CO <sub>2</sub> )	UK Carbon dioxide emissions from all sectors.	Office for National Statistics (2017)
Growers' Field (GF)	This is the emissions from the summation of land use, synthetic fertilisers, manure applied, crop residues, organic soil and burning residues emissions.	Based on the summation of emissions from land use, synthetic fertilisers, manure applied, crop residues, organic soil and burning residues from FAOSTAT (2017).
Inland Logistics outside the UK (ILUK)	This is emissions from the summation on-farm transportation, storage of fruits and vegetables (in overseas) and port logistics.	Based on the summation of emissions from on-farm transportation, overseas storage and port logistics from FAOSTAT (2017).
Transportation (Transportation)	This is transport emissions of fruits and vegetables from all the selected countries to the UK. It is the sum of variable road, air, rail and sea.	Based on the summation of emissions from all modes of transportation particularly by road (heavy-duty vehicles), air (planes), sea and rail. Calculation method adopted from Edwards-Jones <i>et al.</i> (2008) and Elhedhli and Merrick (2012)
Sales and Distribution (SD)	This is the emissions from delivery to retailer's warehouses, storage for distribution and distribution to retailer's shops. It is sum of the variables delivery, storage for distribution and distribution.	Author's calculation by addition of Delivery, Storage and Distribution emissions. Calculation method adopted from Edwards-Jones <i>et al.</i> (2008) and Elhedhli and Merrick (2012)

**Notes:** Based on Author's calculation. All final values of variables are in tonnes of CO<sub>2</sub>e.

### 3.3 Model

**3.3.1 Multiple Linear Regression (MLR).** To estimate the key factors, a multiple linear regression model is used for the panel data constructed using Eviews software (Thomsen *et al.*, 2010). By estimating a function for the key factors of CO<sub>2</sub>e in the framework, the model is expressed as:

$$\ln CO_2 = \beta_0 + \ln GF + \ln ILUK + \ln TRANSPORTATION + \ln SD + \epsilon_i \quad \dots \text{equation 1}$$

where  $\ln CO_2$ , the dependent variable is the log of UK carbon dioxide emissions.  $\beta_0$  is the constant.  $\ln GF$  is the log of Growers' Field;  $\ln ILUK$  is the log of Inland Logistics outside the UK;  $\ln TRANSPORTATION$  is the log of Transportation; and  $\ln SD$  is the log of Sales and Distribution.  $\epsilon_i$  is the error term. This study takes the natural logarithm of all the variables to correct all highly skewed variables into more approximately normal ones, to remove heteroskedasticity, and to handle an event of non-linearity relationship between dependent variable and explanatory variables (Lady, 2005).

By estimating a function for all the activities (inputs) of key factors of CO<sub>2</sub>e in the framework, the model is expressed as

$$\ln CO_2 = \beta_0 + \ln LANDUSE + \ln SF + \ln MA + \ln CR + \ln OS + \ln BR + \ln OFT + \ln OVS + \ln PL + \ln HdV + \ln Plane + \ln Train + \ln Transoceanic + \ln DV + \ln Sfd + \ln Distr + \epsilon_i \quad \dots \dots \text{equation 2}$$

This model is adapted from the work of Aydin (2015) that uses MLR to determine key factors of energy-related CO<sub>2</sub>e in Turkey. A computerised software, Eviews Version 6.0 (Thomsen *et al.*, 2010) is used to analyse the key factors and all inputs of CO<sub>2</sub>e in the UK FSC.

**3.3.2 Stochastic Frontier Analysis (SFA).** SFA exists for estimating a model of technical efficiency scores. We assume technical efficiency (TE) which is an output-oriented measure (Coelli *et al.*, 1998). This means the maximum output can be attained, given a set of inputs. The estimates, standard errors and mean efficiency are calculated using the stochastic production functional model (Meeusen and van Den Broeck, 1977). This method is used to assess whether the key factors as a set of inputs can significantly identify UK CO<sub>2</sub>e. This will help direct corrective measures and interventions towards the identified significant key factors of CO<sub>2</sub>e in the UK FSC. Under SFA, there are common functional forms in the literature – i.e. Quadratic, Translog function and Cobb-Douglas productions functions. This study uses the Cobb-Douglas Stochastic Frontier model due to the simple nature linearising with application of logarithms, providing a better functional form to estimate efficiency (Martins *et al.*, 2012).

Therefore, the Cobb-Douglas stochastic frontier production model is estimated as:

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln GF_{it} + \beta_2 \ln ILUK_{it} + \beta_3 \ln Transportation_{it} + \beta_4 \ln SD_{it} + v_{it} - U_{it} \quad \dots \dots \text{equation 3}$$

where the subscripts *i* and *t* represent the *i*th selected countries (sample) and the year of observation respectively, and *i*=1, 2, .....*n*; *t*=1, 2, .....*n*; CO<sub>2</sub><sub>*it*</sub> represents UK CO<sub>2</sub>e; ILUK<sub>*it*</sub> represents Inland Logistics outside the UK; Transportation<sub>*it*</sub> represents Transportation; and SD<sub>*it*</sub> represents Sales and Distribution. “ln” represents the natural logarithm. where the Technical efficiency is defined as:

$$TE_{it} = \frac{Y_{it}}{Y_{it}^*} = \frac{f(X_{it}\beta)\exp(V_{it}-U_{it})}{f(X_{it}\beta)\exp(V_{it})} = \exp(-U_{it}) \quad \dots \dots \text{equation 4}$$

where *U*<sub>*it*</sub> is the specifications of inefficiency. The model is estimated using a computer program, Frontier 4.1 suggested by Coelli (1996) to calculate the Maximum Likelihood Estimates (MLE) for the parameters of the Cobb-Douglas stochastic frontier production model.

#### 4.0. Empirical Results and Analysis

##### 4.1. Identifying the key factors of CO<sub>2</sub>e in UK food supply chains

Hausman test investigates the preferred model between random effects and fixed effects estimator. When fixed effects estimator is preferred it means the null hypothesis is rejected. Fixed effects estimator has the benefit of capturing any effects that vary over time but are common across the whole panel data. Table VI presents the results of the fixed effects estimator as a preferred model by Hausman test (Hausman, 1978) after estimating equation 1 for the key factors of CO<sub>2</sub>e. The R-squared value of 0.585 explains that 58.5% of the variation in the log of CO<sub>2</sub>e can be explained by this model.

The results in Table VI show that Growers' Field and Inland Logistics outside the UK are not significant. This may be due to the complexity of the capture of overseas data and differences in measurement approach used by ONS and FAOSTAT. Nevertheless, the findings of other key factors such as Transportation and Sales and Distribution are significant. The results reveal that an additional increase in import by the modes of Transportation of fresh food predicts an increase in the UK CO<sub>2</sub>e by 10 tonnes of CO<sub>2</sub>e at 5% significance level. This is due to the burning of fossil fuel and long-distance travel of fresh food from global supply to the UK. This result is consistent with the work of Defra (2013) that a significant proportion of overall UK CO<sub>2</sub>e is contributed by food transportation. Previous research by Marriott (2005) estimated CO<sub>2</sub>e associated with transportation of fresh fruits and vegetables from EU and non-EU countries, highlighting that a significant portion of CO<sub>2</sub>e are generated from the transport of fruits and vegetables. Also, Defra estimated tomatoes transport emissions to be 0.1 CO<sub>2</sub>e per tonne of tomatoes from Spain to the UK (Garnett, 2006). While we were considering the global supply of fresh fruits and vegetables to the UK, we could evince increased

importation and changes in modes of transportation over the period of the last decade. This study reveals transportation emissions of 10 CO<sub>2</sub>e per tonne of fresh fruits and vegetables to the UK.

In addition, this study finds an inverse relationship between Sales and Distribution emissions and UK CO<sub>2</sub>e. Thus, the results reveal that a decrease of UK CO<sub>2</sub>e of 1.3 tonnes of CO<sub>2</sub>e from Sales and Distribution per a tonne of fresh fruits and vegetables from global supply, *ceteris paribus*. It is statistically significant at the 1% level. This is due to the efficiency processes and measures used in the supply chain in the UK. The result is consistent with Hulthén and Gadde's (2009) emphasis that modified distribution facilities (e.g., trucks and distribution centres), when efficiently utilised, can reduce fuel consumption and CO<sub>2</sub>e.

**Table VI.** Key Factors of Carbon Dioxide Emissions

Variable	Coefficient
Growers' field	-0.000(0.001)
Inland Logistics outside the UK	0.003(0.004)
Transportation	0.100** (0.009)
Sales and Distribution	-0.013*** (0.005)
Summary Statistics:	
Observation	400
R-squared	0.585
Adjusted R-squared	0.577
Prob(F-statistic)	0.007
<b>Notes:</b> ***p<0.01, **p<0.05 and *p<0.1. The standard errors are the values in the parentheses. Prob (F-statistic) showing the overall significant predicative capacity of the model.	

#### 4.2. Identifying the significant inputs (activities) of Key Factors of CO<sub>2</sub>e

Using the model defined by equation 2, this study finds the existence of multicollinearity. Multicollinearity test is carried to remove coefficient estimates that have high dependence upon the correlation between the dependent and other predictor variables (He *et al.*, 2018). Therefore, log of plane which has high coefficient is removed from equation 2 to estimate for inputs (activities) of key factors of CO<sub>2</sub>e. From Table VII, fixed effects estimator is the preferred model by a Hausman test. The R-squared value of 0.631 explains that 63.1% of the variation in log of CO<sub>2</sub>e can be explained by this model. The results of all inputs (activities) of key factors of CO<sub>2</sub>e from MLR are presented in Table VII.

The results reveal that land use is statistically significant at 1%, implying that an additional use of foreign land for fruits and vegetables produce to the UK will increase predicted UK CO<sub>2</sub>e by 6.3 tonnes, *ceteris paribus*. This is consistent with the findings of Audsley *et al.* (2010) that explain that a proportion of CO<sub>2</sub>e from global land use changes are attributable to the UK food supply chain.

An inverse relationship is found for fruits and vegetables produced by organic soil and crop residues left on the soil. Both inputs of farm produce are statistically significant at 5%. It indicates that an additional use of organic soil farming for producing fruits and vegetables has the ability to decrease UK CO<sub>2</sub>e by 4.1 tonnes. This is consistent with the work of Schahczenski and Hill (2009) which explains that organic agriculture has the ability to reduce CO<sub>2</sub>e. Similar to organic soil farming, the results show that farming by crop residues on soils is expected to decrease UK CO<sub>2</sub>e by 2.4 tonnes of carbon dioxide emissions, holding all other explanatory variables fixed. This result is consistent with the work of Mangalassery *et al.* (2014); who discuss that adopting zero tillage systems such as crop residue cover plays a significant role in reducing CO<sub>2</sub>e. Other farm produce emissions inputs such as synthetic fertilisers, manure applied and burning crop residues are found not statistically significant.

On-farm transportation and port logistics (inputs of the key factor, Inland Logistics outside the UK) are not found significant. On the other hand, overseas storage indicates a positive relationship with UK CO<sub>2</sub>e. Statistically, it shows that additional storage of fruits and vegetables at the overseas storage facilities increases the UK FSC CO<sub>2</sub>e by 6.2 tonnes, at a 1% significance level. This is consistent with the literature of Garnett (2006).

Results from different modes of transportation are very interesting. The findings reveal that road transport is significant, at the 10% level. The explanation for this can be that an additional transportation increase by road (heavy-duty vehicles) will increase UK CO<sub>2</sub>e by 11 tonnes, *ceteris paribus*. CO<sub>2</sub>e associated with road transport is greater than other modes of transportation CO<sub>2</sub>e (Defra, 2013). This finding is consistent with

findings from Greene and Plotkin (2011) that show that heavy-duty vehicles have the highest of the freight transportation and are increasing faster than other modes of transport, accounting for about 60%.

Sea transport is significant at 10%. The findings show that imports by additional sea transport (transoceanic) will increase UK CO<sub>2</sub>e by 2.9 tonnes of CO<sub>2</sub>e. This indicates a positive relationship between UK CO<sub>2</sub>e and sea transport. The results are consistent with the study of Cadarso *et al.* (2010) that explained that significant proportion of overall CO<sub>2</sub>e is contributed by international freight transport emissions such as transoceanic traffic.

On rail transport, this paper finds rail transport significant at 1%, and also predicts a possible reduction in CO<sub>2</sub>e by using improved rail transportation. The result indicates that additional journey by rail transport from the overseas countries to the UK offers the possibility of reducing CO<sub>2</sub>e by 7.8 tonnes of CO<sub>2</sub>e. This is consistent with the literature of Jones (2002) that discusses that shift to more energy-efficient modes of transport such as rail transport that reduces transport-related energy consumption, leading to CO<sub>2</sub>e reduction.

Moreover, Delivery and Distribution inputs of Sales and Distribution are found non-significant. This may be due to the fact that major inputs such as packaging, retailer's storage and waste are not included in the key factors. Another reason can be attributed to the use of one retailer's storage and distribution centre (e.g., Tesco) for the calculation. In addition, the proximity or measurement used for the logistics and distribution CO<sub>2</sub>e in the UK may not be appropriate. Thus, other inputs mainly associated with logistics and distribution such as storage and use of fuel are excluded from the inputs. Nevertheless, the results show that storage for distribution of the imported fruits and vegetables is statistically significant. It shows that UK CO<sub>2</sub>e can increase by 4.2 tonnes of CO<sub>2</sub>e from a storage facility provided for the fruits and vegetables. This is consistent with the work of Garnett (2011) that stresses that the fruit and vegetable sector does rely on cold storage. Adding that, cold storage provides a significant contribution to the UK's carbon dioxide emissions.

Therefore, the inputs of key factors that significantly contribute to CO<sub>2</sub>e in the UK FSC are road transport, land use, overseas storage, storage for distribution and sea transport. Furthermore, organic soil and crop residues farming are other inputs that significantly reduce CO<sub>2</sub>e in the UK FSC. Further, the key factors that significantly contribute to CO<sub>2</sub>e in the UK FSC are identified as Transportation and Distribution. Figure 2 presents ranking of significant key factors that contribute to CO<sub>2</sub>e in the UK FSC.

While some results of this study are consistent with the literature (e.g., Cadarso *et al.*, 2010), we also have a few new findings that contribute to the existing literature. First, our results strongly recommend that 'improving Sales and Distribution activities can reduce CO<sub>2</sub>e in the UK FSC'. Second, our findings suggest that foreign land use, crop residue farming practices, organic farming practices, sea and rail transport contribute to CO<sub>2</sub>e in the UK FSC.

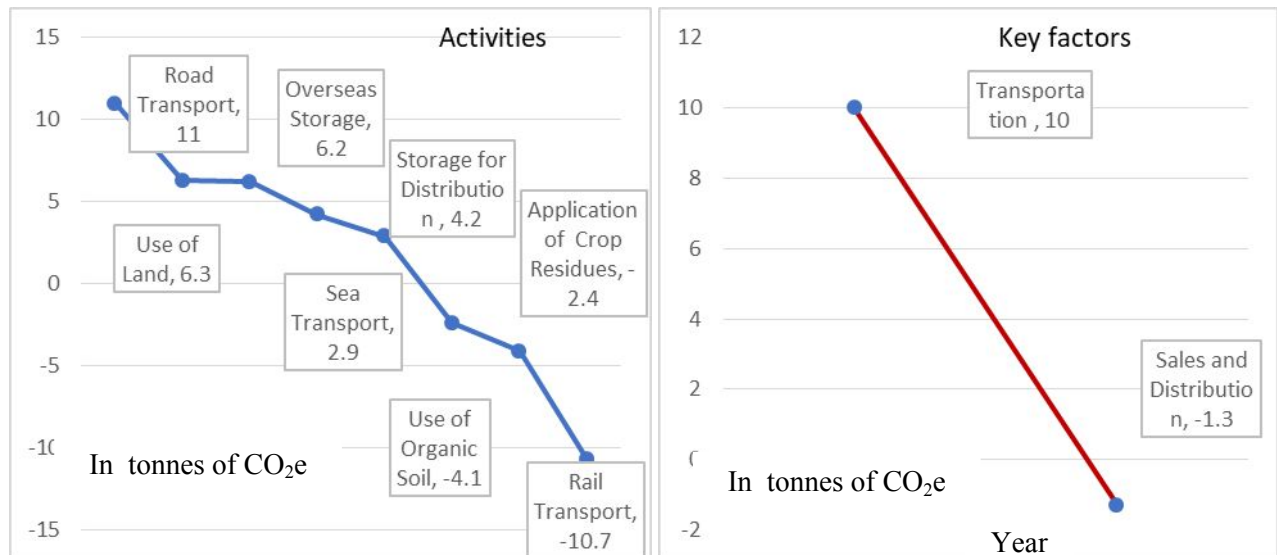
**Table VII.** Inputs (Activities) of Key Factors of CO<sub>2</sub>e

Variable	Coefficient
Land use	0.063*** (0.020)
Synthetic Fertilisers	0.002(0.014)
Manure Applied	0.003(0.018)
Crop Residues Applied	-0.024**(0.012)
Organic Soil	-0.041**(0.016)
Burning Residues	0.008(0.013)
On-farm Transportation	20.553(12.666)
Overseas Storage	0.062***(0.016)
Port Logistics	-8.208(4.800)
Road Transport	0.110*(0.065)
Rail Transport	-0.107*** (0.066)
Sea Transport	0.029*(0.018)
Delivery	-12.444(7.880)
Storage for Distribution	0.042***(0.014)
Distribution	0.046(0.068)

## Summary Statistics

1	Observation	400
2		
3	R-squared	0.631
4	Adjusted R-squared	0.551
5		
6	Prob(F-statistic)	0.000

7 **Notes:** \*\*\* $p < 0.01$ , \*\* $p < 0.05$  and \* $p < 0.1$ . The standard errors are the values in the parentheses. Prob (F-  
 8 statistic) showing the overall significant predicative capacity of the model.  
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29 **Figure 2.** Ranking of significant inputs (activities) and key factors that contribute to CO<sub>2</sub> emissions in UK food  
 30 supply chains.  
 31

#### 32 4.3. Efficiency of the key factors in determining CO<sub>2</sub>e in UK food supply chains

33 Maximum Likelihood Estimates (MLE) of the coefficients of the stochastic frontier model is significantly  
 34 better and preferred estimation model to Ordinary Least Squares (Coelli et al., 1998). Table VIII presents  
 35 results of MLE of Cobb-Douglas Stochastic Frontier Model defined by equation 3. The results from MLE of  
 36 Stochastic Frontier Analysis reveal all key factors (Growers' Field, Inland Logistics outside the UK,  
 37 Transportation, and Sales and Distribution) are significant. This implies that the key factors are technically  
 38 efficient to determine an increase or a decrease of the CO<sub>2</sub>e in the UK FSC (the output variable). Moreover,  
 39 the mean efficiency of the key factors from the observation sample is estimated as 74.52%. Therefore, the  
 40 study reveals that the key factors used by the study can efficiently predict CO<sub>2</sub>e in the UK FSC by 74.52%.  
 41 This is consistent with the literature of Garnett (2011) and de Ruiter *et al.* (2016) that explain that significant  
 42 amounts of CO<sub>2</sub>e are generated by the entire FSC. The existing inefficiency, which is 25.48%, can be referred  
 43 to as activities (input variables) such as use of energy, packaging, retailer's storage, household storage and  
 44 waste which were not included in the key factors (in the data) due to their complexity. This can be explained in  
 45 line with the work of Garnett (2006) which explains that some inputs (such as waste) are highly significant,  
 46 and that CO<sub>2</sub>e produced during harvesting, storage and transported should be accounted for. Also, Tassou *et*  
 47 *al.*'s. (2014) research highlights significant CO<sub>2</sub>e generated throughout the FSC, e.g., storage and waste. The  
 48 sum of beta is less than 1, showing a decreasing return to scale. This evidence is in line with falling trends of  
 49 UK CO<sub>2</sub>e reported by OECD (2019) and ONS (2017). Despite an increase in the import of food, UK CO<sub>2</sub>e  
 50 generated by the FSC processes including Growers' Field and Transportation has not proportionally increased.  
 51

52 Further, the results reveal that Sales and Distribution which is positive and significant with high coefficient  
 53 has the potential to have a greater effect on the output variable, CO<sub>2</sub>e (see Table VIII). This finding confirms  
 54 the MLR results of this study in line with Hulthén and Gadde (2009). It further explains that improved  
 55 logistics including modifying distribution facilities (e.g., trucks and distribution centres efficiently utilised)  
 56 can reduce fuel consumption and CO<sub>2</sub>e.  
 57

58 The minimum efficiency is 63.55% while the maximum is 79.39%. In general, high technical efficiency  
 59 was recorded for the total observations from 1990 to 2014. This shows that FSC professionals, researchers and  
 60 other major stakeholders can rely on the findings of this study to initiate more practical measures directed  
 towards the identified key factors of CO<sub>2</sub>e as a more reliable CO<sub>2</sub>e mitigation strategy to significantly  
 contribute to the UK's vision of CO<sub>2</sub> reduction emissions by 80% in 2050.

Both Transportation and Sales and Distribution are positive and have significant coefficients suggesting the importance of logistics in contributing to CO<sub>2</sub>e in the UK FSC. This confirms the estimate of MLR (see Table VI) which reveals similar results.

**Table VIII.** Maximum Likelihood Estimates of Cobb-Douglas Stochastic Frontier Production Model

Variable	Parameter	Coefficient
Constant	$\beta_0$	-178.811*** (0.986)
Growers' Field	$\beta_1$	-0.106** (0.002)
Inland Logistics outside the UK	$\beta_2$	-152.467*** (0.734)
Transportation	$\beta_3$	37.569*** (0.146)
Sales and Distribution	$\beta_3$	114.974*** (0.684)
Sigma-Squared	$\Sigma$	4.339 (3.659)
Gamma	$\Gamma$	1.000*** (0)
Log likelihood function		-685.146
LR test of the one-sided error		1618.042

**Notes:** \*\*\*p<0.01, \*\*p<0.05 and \*p<0.1. The standard errors are the values in the parentheses.

## 5. Discussions and Implications

Following analysis and findings of this paper, it is clear that logistical services within the country for local distribution and third-party logistics (3PL) operators outside the sourcing country can improve logistics performance and also enhance the FSC effectiveness by reducing CO<sub>2</sub>e. This will involve exploring more feasible technological, operations-related, policy and legal-related measures.

### 5.1. Technological and operation-related measures

Improving efficiency is one of the technological and operation-related measures. This may include the use of solar, biogas, wind or hydrogen fuel cells as power plants. Most of the large ships are powered by power plants on the water which is associated with large amounts of CO<sub>2</sub>e. So, a shift to more efficient energy sources such as biogas-fuelled ships can enhance in CO<sub>2</sub>e reduction in the FSC. Further, onboard energy management, smart voyage planning and hull and propeller optimisation in sea transport are additional efficient operational measures that can reduce CO<sub>2</sub>e. In addition, businesses operations can shift to rail transport, particularly for inter-city transport and long distances transport, due to high CO<sub>2</sub>e associated with heavy-duty vehicles transport. Alternatively, transport mode shift from usual heavy-duty vehicles to hybrid electric vehicles can significantly reduce transport-generated CO<sub>2</sub>e (Fontaras *et al.*, 2008). Furthermore, fuel-efficient driving and driving operations can reduce fuel consumption and CO<sub>2</sub>e in the atmosphere (Ishii *et al.*, 2008). With regards to that, heavy-duty vehicle drivers and staff can gain appropriate training and skills development in fuel-efficient driving and driving operations. **Otherwise, using rail transport is more environmentally friendly and also helps enhance sustainable FSC. The rail transport is one of the common choices as it is energy-efficient, improves environmental performance, and reduces CO<sub>2</sub>e (Lammgard, 2012).**

Also, improving storage energy systems can be one technological and operation-related measure that managers or businesses can explore. This includes the use of light-emitting diode lighting, innovative technologies and trailing edge in refrigeration, ventilation and heating equipment. Managers or businesses can increase the use of renewable energy such as biomass and biomass boilers. Using waste products for energy, plants and animal materials can also significantly reduce CO<sub>2</sub>e (Thornley *et al.*, 2015). Tassou *et al.* (2014) argue that proper training for staff on behavioural changes in energy use is very important. Alternatively, the study of Sanchez-Rodrigues *et al.* (2014) can be utilised. Sanchez-Rodrigues *et al.*'s (2014) research stresses that shifting freight from road to rail in container movements between ports and inland destinations in the UK will reduce CO<sub>2</sub>e. Additionally, rerouting containers away from usual large ports in the UK Southeast and making use of the North-west and Northern ports for the distribution of imports can reduce CO<sub>2</sub>e. Nonetheless, the use of rerouting technique, practices and principles of decarbonisation of logistics can be used (McKinnon and Piecyk, 2012). For example, managers can set CO<sub>2</sub> emission reduction targets in logistics operations by



redefining logistics emissions targets and applying this initiative to the entire logistics operations in respect of the carbon trade-offs that exist between all logistical operations and services.

### 5.2. Policy and legal-related measures

Maintaining environmentally sustainable business objectives is a big challenge for global operators. Many companies around the globe are progressing towards incorporating green practices including green supply chain management and green logistics (Ahi and Searcy, 2013). These initiatives can enable businesses to achieve environmental sustainability goals that consider CO<sub>2</sub>e reduction targets. In addition to that FSC businesses can ensure that suppliers or stakeholders share similar greener objectives or goals. This will enable control or reduction of CO<sub>2</sub>e in various processes/services by the logistical services and 3PL operators.

Moreover, other major stakeholders such as the governments, advocates, institutions, the third sector and researchers can create and promote certain initiatives to contribute to CO<sub>2</sub>e reduction in the FSC. First, in the Kyoto Protocol, plane and transoceanic transport are not included (Saunders and Hayes, 2007). Advocates and governments can suggest the inclusion of these significant emissions factors (hotspots) to the Kyoto Protocol. This will enable governments to apply more stringent policy mechanisms to achieving CO<sub>2</sub> emission targets in sea and airplane transportation. Additionally, governments can adopt or encourage policies such as mobility management programmes, urban redevelopment, privatisation and public-private partnerships to enhance better transportation systems and infrastructure to continuously reduce CO<sub>2</sub>e from food trade.

Second, logistics and supply chains managers from emerging economies can integrate low-carbon policies and practices into their operations which could become the organisation's competitive advantage while contributing to a more sustainable society. Integrating low-carbon policies and measures involves planning, implementation and maintaining carbon efficiency of business activities and processes. The practices should entail low-carbon products, low-carbon production and low-carbon logistics (de Sousa Jabbour *et al.*, 2019).

Moreover, retailers can stress the importance of buying organic foods to advance sustainable FSCs. Notwithstanding that, Barrett *et al.* (2013) argue that a strong consumption-based policy research approach would enable the UK to improve sustainable consumption and production policies. This would create sustainability roadmap that can be easily followed by all stakeholders (including farmers, logistics businesses, retailers and customers) to reducing CO<sub>2</sub>e. This can be facilitated by first measuring the supply-side and demand-side indicators of consumption of fruits and vegetables empirically, considering all players to have better assessment and allocate appropriate policies to help achieve targets. To achieve this, institutions, researchers and experts can collaborate to enhance consistency, robustness and reliability of approaches and methods for CO<sub>2</sub>e reduction. Furthermore, Sundarakani *et al.*'s (2010) suggestions can be adopted by businesses and FSC players to enhance mitigation of the CO<sub>2</sub>e across the food supply chain, through the following: (I) adding rates of carbon emission to criteria for supplier selection; (II) design FSC with CO<sub>2</sub>e in mind concurrently; (III) design green buying and supplying policies; (IV) use innovations in logistics services to reduce CO<sub>2</sub>e; (V) design distribution strategies that promote recycling at the end of consumption; (VI) create substantial awareness among consumers on CO<sub>2</sub>e.

Importantly, Lang and Schoen (2016) question why the UK import apples or pears which could be grown locally. Efforts should be channelled towards intensifying locally produced fresh food, while solely importing the fresh food that cannot be grown in the UK e.g., mangoes and pineapples. Although UK locally produced fruits (e.g., apples and pears) are more sustainable and generate significantly less waste than importation of tropical fruits (Hendry *et al.*, 2019), the entire supply chain culminates in CO<sub>2</sub> emissions. Global warming could also be affecting the UK local production of fruits, so innovative measures and practices can be implemented to expand the growing season of locally grown fruits which will have better environmental benefits. This discussion provides insights into technological and operations-related and policy and legal-related measures as a fast-track approach to reducing CO<sub>2</sub>e in the UK FSC. In addition, other measures and initiatives that can be explored to mitigate CO<sub>2</sub>e are suggested – e.g., use of biomass energy and carbon sequestration. In addition, the findings and analysis can help other countries to rethink the impact of CO<sub>2</sub>e on their food trade and promote local production. In addition, while key activities, e.g., food waste, were not captured in the study, future researchers can consider food waste assessment of a specific food category from different regions and also could compare this with locally produced ones.

## 6. Conclusions

This paper uses multivariate approaches (multiple linear regression and stochastic frontier analysis) to analyse ONS and FAO data covering the period from 1990 to 2014 to identify key factors of CO<sub>2</sub>e in the UK food supply chains. The re-defined LCA tool applied is an all-inclusive assessment, which covers the entire food supply chain starting from overseas sources.

This study finds that Transportation and Sales and Distribution are the two key factors of CO<sub>2</sub>e in the UK FSC by the regression approach. Additionally, SFA results confirm that the key factors are sufficient to predict an increase or decrease in CO<sub>2</sub>e in the UK FSC. This paper contributes to the existing literature and fills an

empirical gap, by identifying that Sales and Distribution decreases the UK CO<sub>2</sub>e by 1.3 tonnes of CO<sub>2</sub>e, through improved technological approaches used in logistical services, sales, and distribution in the UK. This paper also supports previous studies by McKinnon and Piecyk (2012) and Defra (2013) that estimated that transportation contributes a significant amount of CO<sub>2</sub>e in the UK FSC. Further, the SFA reveals the key factors that can efficiently predict CO<sub>2</sub>e in the UK FSC by 74.52%. The inefficiency that exists can be explained by the inputs of the key factors that are not included in data collection – e.g., use of energy, packaging and waste.

Analysis from the **two multivariate methods (MLR and SFA)** clarifies that interventional, realistic and practical measures can be directly explored identifying key factors as a more reliable mitigation approach to reducing CO<sub>2</sub>e in the UK FSC.

While supply chain actors, e.g., retailers, can continue to increased use of carbon labelling and carbon foot printing as backdoor measures to educate consumers on low-carbon products, we suggest more technological and operations-related measures and feasible policy and legal-related measures. These can serve as vital mitigating measures for a significant amount of CO<sub>2</sub>e generated by the UK FSC. These measures include maintaining greener objectives across the FSC network, improving efficiency in the use of logistics and storage facilities, integration of low-carbon policies and practices into operation, and adopting governmental policies such as privatisation and urban redevelopment to enhance better transportation systems and infrastructure.

### 6.1 Key contributions

Our study makes three critical contributions to the literature and practice. First, we re-define LCA as an all-inclusive assessment tool which entails measuring environmental and other related impacts (mainly CO<sub>2</sub>e) starting from overseas sources. To achieve a complete picture of LCA, all activities generating CO<sub>2</sub>e in the supply chains in their entirety need to be measured and included in the LCA. This assessment approach has been missing in the extant literature of social sciences. To the best of our knowledge, if any attempt is made by previous studies, the LCA would only consider a few aspects or activities within the supply chain, e.g., transportation and waste. We suggest re-defined LCA tool to be considered as a holistic approach tool starting from overseas sources.

Second, our methodological approach that considered the use of multivariate methods (regression and stochastic frontier analysis) to analyse the secondary data is somewhat novel and it makes a solid contribution. This approach suggests an advanced, more robust measurement of determining CO<sub>2</sub>e within the supply chains. Knowing that we have solid background on and justification for the CO<sub>2</sub>e estimated, we can initiate appropriate sustainable policies and measures to enhance sustainable food supply chains. This approach has not been explored widely in the past and this can also be extended to other areas of study.

Third, our findings are unique and make empirical contributions to the current literature. While studies are yet to estimate efficiency of the activities in determining CO<sub>2</sub>e, our paper represents a solid piece work to suggest the step forward. It also helps readers in operations and supply chain management to understand key factors that can be properly channelled to enhance sustainability and support extra global competitive edge. We have also properly aligned the findings with policies and measures for both businesses and governments. We believe these are unique and deserve attention.

### 6.2. Limitations and research opportunities

This study has some limitations. The first limitation is related to the theoretical perspective. It is important to align the research with organisational theories to help develop theoretical contributions and insights into different organisational theories, e.g., ecological modernisation theory and resource-based view. As our paper is focusing on the CO<sub>2</sub>e aspect of sustainability, the scientific and ecological management sides of the FSC are not considered. Some of the established theories of operations management such as the resource-based view and stakeholder theory may help to relate available organisational resources efficiently to reduce CO<sub>2</sub>e and may also help to involve the import/export businesses to control carbon emissions through strict measures. Future research can consider this theoretical aspect of the study. Second, data that we collected did not cover current years; they only covered 1990 to 2014. This is due to large amounts of missing data in the dataset pertaining to 2015-2017 at the time of our data collection. This is mainly because of limited availability of data for the sample countries and the selected fruits and vegetables of the sample countries. Likewise, important activities such as food waste and packaging were excluded in the re-defined LCA of the UK food supply chains due to complexity of data and estimation, and the lack of availability of data. Further studies can collect data from different online sources, e.g., UN Comtrade (International Trade Statistics Database) to complement ONS and FAOSTAT data. Moreover, researchers can consider food waste assessment of specific food categories from different regions and also compare these with locally produced ones. In addition, this study finds Growers' field data non-significant due to different activities (variables) comprising these data. Therefore, future researchers can adopt different mathematical calculations (e.g., Differential equations and Cauchy-Riemann equations) for estimation of Growers' Field data.

Further studies can consider research opportunities in Sustainability Impact Assessment (SIA) of the UK FSC. This can provide more insights into the impact of activities of the supply chains that contribute to CO<sub>2</sub>e in the UK FSC. Other researchers can also consider technological inclusion in FSC.

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# Key factors of Carbon footprint in the UK food supply chains: A new perspective of life cycle assessment

## Response to reviewers' comments

### Reviewer: 1

Recommendation: Minor Revision

Comments:

IJOPM-0 6-2019-0478

Reducing UK's Carbon Footprint in Food Supply Chains

This paper uses existing Carbon Footprint Data from countries exporting to the UK (Fruit and Vegetables) to determine the key factors in the supply chain that are driving or reducing emissions. Having worked with food and carbon footprint analysis, I know how challenging it is to get good numbers for this work. Rather than calculated CO<sub>2</sub> emissions for each kind of fruit and vegetable supply chain from various exporters to the UK, the authors instead use a representative sample of specific fruit and vegetable items from key export countries for their analysis. They then apply Multilinear Regression analysis and Stochastic Frontier Analysis to determine the average effects of various activities in the supply chain. Overall, this is a well done study and makes a contribution not only in terms of method but additionally in terms of looking at the issues around continuing to import and a large proportion of the U.K.'s fruit and vegetables from other countries which is clearly a problematic issue not only in the U.K. But also for many countries around the world that rely on imports more than within country production like the U.S. and Japan. Also China is increasing its imports of many food products which isn't really reflected in the time period of this study.

So, while I think the paper is generally in very good shape. I have suggestions for improving the paper that would make it more acceptable for publication. Most of these comments are for clarifications so the paper is more understandable to those readers who do not work with CO<sub>2</sub> emissions and footprint analysis.

### Response:

We would like to thank this reviewer for positive and constructive comments. We appreciate the suggestions made by this reviewer. We have tried to accommodate all the suggestions and feedback from this reviewer in our new modified version of the article. The current version of the paper enhanced with all possible suggestions and it is thoroughly proof-read to ensure a high level of readability.

First, the introduction and literature review areas are fine (see specific grammatical or clarification of sentences issues following the main review.

### Response:

We would like to thank this reviewer for acknowledging our work in the introduction and literature review. We have done a thorough proof-reading with support of a native speaker.

I had to read through the paper a few times to understand why the particular methodology was used to connect stages of the supply chain to the overall CO<sub>2</sub> emissions. Because of this methodology, several issues end up being neglected such as food waste, packaging, etc. As a result, it would be important to spend more time in the front end of the methodology section explaining why you had to use this approach (regression and stochastic frontier analysis) and also cite the papers that have also used this approach.

**Response:** We do agree that the methodology section can be strengthened. In the revised article we have included a new paragraph on the methodologies to highlight specific methods that we



used in the article, namely regression and stochastic frontier analysis, and their importance in data analysis and results. See the first paragraph in page 6, before section 3.1 (under methodology and conceptualisation section), we have included the rationale of choosing regression and stochastic frontier analysis and also referred a few relevant articles that have followed such approaches. Please note, linear programming method is modified to multivariate approaches in our research.

We agree and appreciate the views of the reviewer on inclusion of issues associated with the supply chain such as food waste, packaging and energy use for machines. As we have limited data on global supply chain emissions from online sources, we tried to make a strong explorative data analysis with the available data on land usage, storage, transportation and distribution. Choosing multivariate data analysis approaches (such as regression and stochastic frontier analysis) helped us to explore and make sense of sample data in hand. With such approaches we were able to study the available data to determine the patterns and test hypotheses (the conceptual framework of key factors of CO<sub>2</sub>e) for circumstantial evidences.

As you can see from the dearth of articles on carbon footprint it in IJOPM, the journal has struggled to include papers on this subject so do a solid job explaining how this method differs from other LCA type of studies and why it is appropriate in this particular case.

**Response:**

We appreciate this reviewer's observation of our research distinctive contributions to IJOPM. We have revised the article to accommodate this important suggestion. See page 3 second paragraph (before Research Questions), we have revised the paragraph to reflect this change.

Second, I found it hard to believe that animal product imports are not generating more CO<sub>2</sub> than fruit and vegetables. Can you include a table that shows estimates of the different food categories to support why you chose to use fruit and vegetables?

**Response:**

We agree that animal product imports generate significant CO<sub>2</sub>e in the food supply chain. It is important to note that our study is focused on fresh fruits and vegetables. To provide clarity and insights into fruits and vegetables CO<sub>2</sub>e compared to different food categories, we have included a new table in page -2.

Page 2, Table I shows greenhouse gases emissions (mainly CO<sub>2</sub>e) associated with food categories production and typical western diet.

In addition, page 2 first paragraph of the revised version provides a detail explanation for our choice of fruits and vegetables supply chain compared to other food categories.

To reflect inclusion of the Table I, we modified the numbering of the tables in the modified version of the article. The current version of the paper is enhanced with appropriately numbered tables and figures.

Third, the discussion (contribution, limitations and opportunities for future research) could be expanded; it seems to have been neglected relative to the rest of the paper. For example, many other countries could benefit from this kind of analysis and one could use other big food categories to see how they might be different from produce. Also, certain aspects have been neglected in this study as you mention (food waste, packaging, etc.). So how might you get at this area? Some fruit and vegetables are more subject to perishability, damage, and waste (for example, only part of the whole item is actually edible) and tropical fruits are one of most popular import items yet have lots of waste elements. The amount of waste in a specific category could be significantly more for a banana versus a locally produced apple. Waste dramatically increases the net CO<sub>2</sub> emissions from particular items. So future research really

needs to address some of these neglected issues. Also, please think of other implications not only for businesses but for government policy since these are key areas for contributions.

Finally, end by stressing the contributions of the paper and a conclusion paragraph.

**Response:**

We appreciate the reviewer for his/her positive comments on expanding the discussion section of this paper. The following modifications have been made to incorporate the suggestion from the reviewer.

Page 1 of the modified version - practical implications incorporated policy implications and adaptation of efficient energy. Page 16, Section 5.2, has new paragraph on how policies and government regulations in other countries can make positive impacts in their food trade and promote local production.

As correctly pointed by the reviewer, food waste was not captured in the study. However, future researchers can consider assessment of specific category of food waste from different regions. Section 6 is now having a separate heading on limitations and research opportunities.

**Details**

Pg. 1, line 60: What do you mean by widely displaced overseas?

**Response:**

We have revised the sentence to correct the grammatical error. See page 2, the last phrase has been revised to “generated from overseas operations”.

This modification also reflected in similar phrase used in page 6 in the Table II.

Pg. 2, line 38: followed by a review of

Pg. 2, line 38: This is the first place that we learn that you will only focus on fruit and veg, can you introduce this early and state why this is a particularly important area? (Note: this is not just for the UK, but many many counties suffer from high CO2 emissions from that same kind of imports, essentially the developed world are importing fruit and veg from the developing world).

**Response:**

We thank this reviewer for this observation. See page 2 first paragraph, we have made modification to accommodate this suggestion, particularly introducing the focus of the study and why fruits and vegetables import study is an important area of research.

Pg. 3, line 38: Here you start the line indicating the upcoming material is more recent, but in fact 2012 is not that recent. Can you find more recent citations? If not, I would suggest changing the wording.

**Response:**

We thank this reviewer for the excellent observation. We have changed the sentence in page 3. We have thoroughly proof-read the article to enhance readability.

Pg. 9, section 3.3: The formatting of all the equations doesn't look right. Perhaps it was the conversation to a pdf but consider creating more space around the equations and lining them up better for clarity.

**Response:**

We thank this reviewer for the keen observation. Yes, we agree that equations 1 and 2 are not properly formatted on the pdf. We have improved the line spaces and justification to prove better formatting. We are happy to make any further changes in the formatting at the time of printing, if required. For example, we can give equations in jpeg format or Latex.

Please see pages 10 and 11 in the revised version. All four equations are provided as separate equations with adequate line spacing.

$$\ln CO_2 = \beta_0 + \ln GF + \ln ILUK + \ln TRANSPORTATION + \ln SD + \epsilon_i \quad \dots \text{equation 1}$$

$$\ln CO_2 = \beta_0 + \ln LANDUSE + \ln SF + \ln MA + \ln CR + \ln OS + \ln BR + \ln OFT + \ln OVS + \ln PL + \ln HdV + \ln Plane + \ln Train + \ln Transoceanic + \ln DV + \ln SfD + \ln Distr + \epsilon_i \quad \dots \text{equation 2}$$

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln GF_{it} + \beta_2 \ln ILUK_{it} + \beta_3 \ln Transportation_{it} + \beta_4 \ln SD_{it} + v_{it} - U_{it} \quad \dots \text{equation 3}$$

$$TE_{it} = \frac{Y_{it}}{Y_{it}^*} = \frac{f(X_{it}\beta)\exp(V_{it}-U_{it})}{f(X_{it}\beta)\exp(V_{it})} = \exp(-U_{it}) \quad \dots \text{equation 4}$$

Pg. 10, line 16: The growers field data would be another very important to get CO2 emission data. You should consider how this might be estimated in the future as it was presumed non-significant based on poor data (5)?

**Response**

We appreciate this reviewer's comment on the need to stress the usefulness of growers' field data. We have provided suggestions at the limitation and research opportunities section (Section 6.2) for future study.

Pg. 10, line 59: The word estimate should be plural here I think. Pg. 11, line 27: Vehicles should be plural here.

**Response:**

We thank you for this comment. See page 12, the second paragraph for the revised sentence starting with "Multicollinearity test is carried to remove coefficient estimates that have high dependence...".

See page 12, the last paragraph, the word "vehicle" is accordingly changed to plural.

Now we have thoroughly proof-read the article to avoid such minor errors. We hope that the revised version is free from errors and typos.

Pg. 11, line 50: Soil transport? Is this supposed to be land transport?

**Response:**

Sorry for this error. It must be sea transport. The revised version is free from this error.

Pg. 11, line 56 and 57: This sentence needs improvement so that the reader can interpret what you are trying to say.

**Response:**

We have modified this sentence in page 13 as follows:

While some results of this study are consistent in line with the literature (e.g. Cadarso et al., 2010), we also have a few new findings that contribute to the existing literature. First, our results strongly recommend that 'improving Sales and Distribution activities can reduce CO2e in the UK FSC'.

Pg. 14, line 9: This seems like an opportunity to again indicate that use of rail rather than trucking might be more appropriate.

**Response:**

We agree with this reviewer's comment. The use of rail is more environmentally friendly. We have included a sentence to stress the relevance of the use of rail transport instead of trucking.

See page 15, Section 5.1, "Otherwise, using rail transport is more environmentally friendly and also help enhancing sustainable FSC. The rail transport is one of the common choices as it is energy efficient, improves environmental performance and reduces CO2e (Lammgard, 2012)"

Pg. 14, line 27: the phrase maintaining "business greener objectives" doesn't make sense. Can you clarify what you are trying to say here? Something to the effect of continuously improving sustainability performance? Pg. 14, line 25: Should be CO2 emission reduction

Pg. 14, line 37: Inclusion of

Pg. 14, line 39: Should be third parties

Pg. 14, line 44: This needs to be reworded. Are you implying that retailers need to stress the importance of buying organic foods to reduce carbon footprints?

Pg. 14, line 46: By this what? Please spell out what you are talking about.

Pg. 14, Line 55: Can you be clear about what it means to develop novelty?

Pg. 14, line 57: Preface with One might ask "why does the UK...."

**Response:** We modified the section 5.2 in page 16 to reflect all suggested changes. We have double checked this section to ensure quality.

Pg. 14, bottom of page: Here it would be important to note that many UK products (apples, pears, etc) are significantly less perishable and thus less waste which compounds the CO2 emissions of importing tropical fruits.

**Response:**

We appreciate your suggestion on emphasising on the impact of UK products and import of tropical fruits on CO2e. In the revised version in page 16 before Section 6, we emphasised the point to encourage locally produced food in the UK and innovative measures that spearhead local production, which is more sustainable and significantly less waste.

Pg. 15. Another point that should not be lost is that global warming is increasing the ability of the U.K to grow fruits (i.e. grapes) and potentially other vegetables that have traditionally been imported.

**Response:**

We addressed this comment in Page 16, paragraph 5 (before Section 6). "Though global warming could be affecting UK local production of fruits in the UK, innovative measures and practices can be implemented..."

Pg. 15, line 19: This beginning sentence does not make sense. It is probably missing some words.

**Response:** The revised version has incorporated changes.

Pg. 15, line 23: "Maintaining greener objectives" means what?

**Response:**

This is modified in the revised version as 'maintaining environmentally sustainable business objectives' (see page 16, section 5.2)

Pg. 15, line 29-31: This paragraph needs to be clarified and expanded. Also, please add a conclusion paragraph.

**Response:**

We thank you for this comment. The revised version has Section 6 Conclusions, Section 6.1. Key contributions and section 6.2 Limitations and research opportunities

Additional Questions:

1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes, the paper does a nice job at looking at the fruit and vegetable supply chain importation issues ranted to CO2 emissions with an interesting empirical approach.

**Response:**

We would like to thank this reviewer for the encouraging comments.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: As far as I can tell, the authors have used appropriate literature to support their study. In a couple instances, I have asked for more current citations.

**Response:**

We would like to thank this reviewer for the positive and constructive comments. We appreciate the suggestions made by this reviewer and we have made all relevant modifications. The current version of the paper is thoroughly proof-read with support of a native speaker.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: The paper has an appropriate methodology but I have suggested that the authors spend more time justifying why they used their approach rather than a more detailed LCA analysis of specific (biggest volume) fruit and vegetables imported into the UK.

**Response:**

We thank this reviewer for the encouraging and constructive comments. We appreciate the suggestions made by this reviewer. We have clarified the methodological approaches used. The current version of the article communicates better justification of the methodology and its contribution to the literature and the journal.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: The results are very clear and the tables/figures support the text. The conclusion section seems to have received the least amount of attention, so the authors need to work on expanding the discussion, limitations, and conclusion.

**Response:**

We are grateful for this reviewer's encouraging comment on the results and presentation of the tables/figures. We have accommodated all the suggestions on the conclusion section and appropriate expansion and modification are incorporated. The current version of the paper enhanced with all possible suggestions (on the discussion, limitations, and conclusion) and it is thoroughly proof-read.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of

knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: This section should be expanded more. There are many implications for improving not only business but government policies that would support the use of better transportation mechanisms and infrastructure to continuously reduce the emissions from food trade.

**Response:**

We appreciate the excellent observation of this reviewer. We have tried to accommodate all the suggestions and feedback from this reviewer in our new modified version. The current version is expanded and enhanced with all relevant implications for improving government infrastructure and transportation policies that can massively reduce carbon emissions along supply chains.

See pages 15-16, Section 5.2 Policy and legal-related measures

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the fields and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: The paper has a number of unclear sentences and incorrect word use/grammatical errors. I have indicated the areas where I see issues but it would help to do a solid edit before submitting the paper again.

**Response:**

We are grateful for the reviewer's comments. We also proof-read the article thoroughly with support of a native speaker.

**Reviewer:2**

Recommendation: Major Revision

Comments:

Dear authors, first of all, thank you for the opportunity of reading your manuscript 'Reducing UK's Carbon footprint in food supply chains'. Indeed, food supply chains generate considerable impacts on the environment. Learning from the UK case adds to the current body of knowledge. As I see merit in your research, I also feel the manuscript can be developed further, mainly in terms of the organisational theories capable of supporting your analysis, and in terms of the real originality of your work. I hope you will find my comments useful in order to achieve an improved version of your manuscript.

**Response:**

We thank this reviewer for his/her encouraging words. We have tried to accommodate all the suggestions and feedback from this reviewer to develop the manuscript. The current version of the paper has enhanced quality by incorporating most of the suggestions and feedback from the reviewers. We have also proof-read the article thoroughly with support of a native speaker.

**GENERAL SUGGESTIONS:**

- the manuscript does not have any organisational theory as supporting theory. Would it be relevant to have it?
- research results cover a period of secondary data from 1990-2014, which is quite in the past. It should be justified and added as limitation. This is not a flaw if recognised as limitation, but I concerned.
- latest references are missing. It seems like the paper was produced around 2014/15. This is not wrong, but please consider latest references from IJOPM and top sustainability journals

1 - Have you identified 'factors' of supply chains or 'activities' of supply chains? Also, you  
2 have not covered all food supply chain of the UK, but a fraction of the fruits and vegetables  
3 supply chain from selected suppliers. This should be clear from the start

4 **Response:**

5 We thank this reviewer for the positive feedback and constructive criticism. We made the  
6 following modifications to accommodate the suggestions.

7  
8  
9 This research was conducted in 2017 and we used the data available at that time. Some of the  
10 data was not complete and hence we were forced to omit those data. This is one of the  
11 limitations of this study. However, we have wisely used the available dataset to arrive at  
12 managerial decision making on sustainably related issues. We have included further  
13 explanation in a new section 6.2 in page 17.

14  
15  
16 We have included a few latest articles in relation to our topic of research from IJOPM and also  
17 from other journals such as IJPR. See page 4 second paragraph and page 5 first paragraph. We  
18 have highlighted the articles that we considered in the modified version; this is in the reference  
19 list in pages 17-22.

20  
21  
22 We agree that our paper has not included any theory to support our arguments. It may be ideal  
23 to use organisational theories; however, we feel this research on UK Carbon footprint with  
24 LCA is somewhat new to business and social sciences and it will need in-depth research to  
25 establish a strong theory to create a sustainable approach in reducing CO<sub>2</sub>e in Food supply  
26 chains. Using some of the established theories of operations management such as resource-  
27 based view and stakeholders' theory may help to relate available resources efficiently to reduce  
28 CO<sub>2</sub>e and also help to involve the import/export businesses to control carbon emissions  
29 through strict measures. We will consider this in our future work. This is further explained in  
30 the limitations in section 6.2.

31  
32  
33 1) TITLE: The current title is a bit misleading, because when you use the term 'reducing'  
34 in 'Reducing UK's Carbon footprint in food supply chain' it seems that your manuscript will  
35 explore how companies in the food supply chain did reduce their emissions. However, your  
36 paper is much more about identifying key elements in the UK food supply chain, is not it? In  
37 this context, I would suggest the following title: 'Identification of key factors of carbon  
38 emissions in food supply chains in the United Kingdom: life cycle assessment perspective' or  
39 something similar to this.

40  
41 **Response:**

42 We have considered this suggestion and modified the title as follows: Key factors of Carbon  
43 footprint in the UK food supply chains: A new perspective of life cycle assessment

44  
45  
46 2) ABSTRACT: you use secondary data obtained from ONS and FAOSTAT. However,  
47 what is the timeline of the data set you have?

48 **Response:**

49 We have made changes in the abstract to reflect this suggestion. The timeline for the dataset  
50 1990-2014 is included. We also explained this further in the page 6 under Section 3.

51  
52  
53 3) ABSTRACT and the entire text: can you really affirm 'Transportation and  
54 Sales/Distribution are the two key factors'? I mean, are 'transportation' and  
55 'sales/distribution' really 'factors' or are they operations management activities? Please,  
56 think about it.

57 **Response:**

58 We thank this reviewer for this comment. Our conceptual framework first captured all activities  
59 within the food supply chains of the overseas countries who export to the UK. Following extant  
60 literature review, we noted the activates among others include land use, synthetic fertilisers

1 use, application of manure, organic soil farming, burning of crop residues, on-farm  
2 transportation, overseas storage, port logistics, road transport, sea transport, air transport, rail  
3 transport, delivery, storage and distribution. To enhance implementation of sustainable policies  
4 and measures within specific areas of the food supply chains, we grouped all the activities into  
5 areas of operations and supply chain management activities which we refer to as the “key  
6 factors”. Thus, Growers field, Inland logistics, Transportation and Sales and Distribution were  
7 considered for this study.

8 Page 3, para -2 reflects the changes made in the revised version.

9  
10 4) ABSTRACT and Introduction: Regarding originality, we know that LCA is a new tool  
11 in operations management, however, in environmental sciences, it a consolidated tool. For  
12 example, journals such as International Journal of Life Cycle Assessment, Journal of Cleaner  
13 Production, among others, publish dozens of papers applying LCA to production chains. In this  
14 context, please, highlight the uniqueness of your paper. It is well known that transportation  
15 logistics is very much responsible for considerable amount of CO2 emissions. But I am sure  
16 your research has something unusual, unique, different from others to be highlighted.

17 **Response:**

18 We thank this reviewer for the constructive comments. A new section 6.1 in page 17 included  
19 contributions of this study.

20  
21  
22  
23 5) KEYWORDS: I would like to suggest ‘low carbon operations’ and ‘low carbon  
24 economy’ as potential keywords

25 **Response:**

26 We thank you for this comment. ‘Low carbon operations’ is added as one of the key words.

27  
28  
29  
30 6) INTRODUCTION: Once again, the objective of the paper is to understand ‘factors’  
31 while I very much believe that you have understood ‘operations and supply chains activities’  
32 which generate more CO2. Is this ‘factors’ or ‘activities’?

33 **Response:**

34 We thank the reviewer for the excellent observation and positive comment. We have provided  
35 clarity on the “factors” and “activities” presented in the paper and how they are related with  
36 operations and supply chain activities.

37 See modifications in page 3, para -1.

38  
39  
40 7) INTRODUCTION: this sentence would benefit from references/citations: ‘Drawing  
41 from existing studies...’

42 **Response:**

43 We thank you for this comment. We have made modification that provide in-text citations. See  
44 page 3 third paragraph for the changes.

45  
46  
47 “Drawing from existing studies (Pretty *et al.*, 2005; Smith *et al.*, 2007), a conceptual framework is  
48 developed to enable identification of all the stages of FSC from outside (exporting countries) to the UK.”

49  
50 8) RESEARCH RESULTS: I really see value in this result ‘SFA results confirm that the  
51 key factors are sufficient to predict an increase or decrease in CO2 emissions in the UK food  
52 supply chains.’ I would suggest putting it as one of the main contributions of your work

53 **Response:**

54 We thank you for this positive and encouraging comment. We have made the following  
55 modifications:

56  
57  
58 In page 1, in the abstract, we have highlighted this “In addition, the SFA results confirm that  
59 the key factors are sufficient to predict an increase or decrease in CO2 emissions in the UK  
60 food supply chains.”



Page 14, Section 4.3, we have included the changes as follows: “This implies that the key factors are technically efficient to determine an increase or decrease of the CO<sub>2</sub>e in UK FSC (the output variable).”

Page 16, Section 6, has reflected the changes as follows: “Additionally, SFA results confirm that the key factors are sufficient to predict an increase or decrease in CO<sub>2</sub> emissions in the UK food supply chains. This paper contributes to the existing literature...”

9) Literature review is not update. There are policy documents and reports that are quite new, but in terms of academic literature, authors could add latest papers. I will mention some of them:

<https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1002%2Fbse.1832&data=01%7C01%7Cusha.ramanathan%40ntu.ac.uk%7C9132ac198f13488c277308d7bc8817c9%7C8acbc2c5c8ed42c78169ba438a0dbe2f%7C0&sdata=nAaOgd8c bB7hmO9qX2aU60yrDYc3KkpyvllV%2Fw9MV1I%3D&reserved=0>

<https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1080%2F00207543.2017.1421790&data=01%7C01%7Cusha.ramanathan%40ntu.ac.uk%7C9132ac198f13488c277308d7bc8817c9%7C8acbc2c5c8ed42c78169ba438a0dbe2f%7C0&sdata=eOfcxq9v7GYj3QXvmbItI0Wv1qiZjNSHKAaggSbox7Bk%3D&reserved=0>

#### **Response:**

We have read and included the review article (de Sousa Jabbour *et al.*, 2019) as suggested by this reviewer in the modified version. We have also included a few more new articles to add value to our research work. Now our review is up to 2019 and this includes a rich academic literature such as Schoenherr *et al.* (2015), Pullman and Wikoff (2017), Poore and Nemecek (2018), Porter *et al.* (2018) and Hendry *et al.* (2019).

See page 4 and page 5 for some of the latest journals included to accommodate this suggestion. We also have a number of current top journals included throughout the article in the modified version. We believe that the revised version is updated with the latest literature.

10) SECTION 2.1: The figures/facts/numbers about waste in food supply chains are quite outdated. You bring data from 2014, 2015, and I was wondering if you could please add something more recent.

#### **Response:**

Revised version of the paper has included more recent facts and figures throughout the article. We do understand the importance of using recent data, but we had limitation when this research was conducted in 2017 and we used the data available at that time. Some of the data was not complete and hence we were forced to omit those data. This is one of the limitations of this study. However, we have wisely used the available dataset to arrive at managerial decision making on sustainably related issues. We have included further explanation in the new section 6.2, page 17.

11) SECTION 3.1: At this stage, it is clear that your work does not use any organisational theory – such as the stakeholders’ theory – or ecological modernisation – to support your theoretical/framework choices. While this is not a flaw of your paper, my understanding is that IJOPM is journal, which aims to develop theory further. Please think about it... would it be a limitation of your research?

#### **Response:**

We thank the reviewer for this comment. We address this as one of the main limitations of the paper. See page 17, section 6.2 (limitations and research opportunities). We suggest that further study can extend the paper and help develop theoretical contributions and insights into different

organisational theories such as ecological modernisation theory and resource-based view theory.

12) SECTION 3.2: It is surprising that your data refers to ‘secondary data collected from FAOSTAT (2017) and ONS (2017) covering 1990 to 2014’. Anyway, data is quite old, and it should be provided clear justification and limitation. Indeed, if the manuscript is published in 2020/2021, research results will be quite old.

**Response:**

We thank this reviewer for this observation and comment. Data was capped to 2014 due to large amount of missing data for most countries and the activities for 2015 to 2019 was not complete. Microdata of this kind take longer time for researchers e.g. FAO to update to current years. However, we address this as a limitation of the paper. See page 17, section 6.2 (limitations and research opportunities).

13) SECTION 5: implications for theory, practitioners, and policy makers are too general. It would be great if authors create subsections for each beneficiary of this paper. Also, a clear section about limitations should be provided. This paper has significant implications for supply chain and logistics managers, and thus lessons learned for these professionals could be added. Most of the countries that supply to the UK food sector (as per your research) are from emerging economies. Any specific implication/guideline for them?

I hope authors will find comments useful, and I thus suggest that the manuscript could be revised before publication. Good luck!

**Response:**

We thank this reviewer for the constructive and positive comments. We have tried to accommodate all suggestions in the modified version. We have added a new section for policy and legal-related measures, please see Section 5.2, page-15 and 16.

“Second, logistics and supply chains managers from emerging economies can integrate low-carbon policies and practices into their operations which could become the organisation’s competitive advantage while contributing to more sustainable society. Integrating low-carbon policies and measures involve planning, implementation and maintaining carbon efficiency of business activities and processes. The practices should entail low-carbon products, low-carbon production and low-carbon logistics (de Sousa Jabbour *et al.*, 2019)”.

**Additional Questions:**

1. Originality: Does the paper contain new and significant information adequate to justify publication?: Please, see detailed comments in 'Comments to the Authors'. I am concerned that used secondary data covers from 1990 to 2014.

**Response:**

We thank the reviewer for this comment. We have responded to this comment earlier. We have provided appropriate modifications in the paper.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: A number of latest references in low carbon operations are not cited. Please update them. Please, see detailed comments in 'Comments to the Authors'.

**Response:**

We have modified the article in line with this comment. We have a number of current top journals included throughout the modifications. For example, de Sousa Jabbour *et al.* (2019) from International Journal of Production Research. Please see page 18-22.

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3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: There is no clear organisational theory used as supporting theory. Please, see detailed comments in 'Comments to the Authors'.

**Response:**

We have provided further justification and clarity for methodological approaches used for this research in page 6 under Section 3. We also addressed missing organisational theories as limitation of the research and provided suggestions for future study, in page -17 under Section 6.2.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Yes, they are. Please, see detailed comments in 'Comments to the Authors'.

**Response:**

We thank the reviewer for this encouraging comment. We have addressed all concerns related to this comment. We have included new sub-sections under Section 6. Section 6.1 Key contributions and Section 6.2 Limitations and research opportunities.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: It can be improved further. Please, see detailed comments in 'Comments to the Authors'.

**Response:**

The current version of the paper is enhanced with expanded implications for research and practice. We have responded to these comments in the previous questions.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the fields and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Please, sometimes there is overusing of acronyms in abstract and title.

**Response:**

We thank this reviewer for his/her positive and constructive comments. The current version of the paper has been thoroughly proof-read to ensure its language and structure.

# Key factors of Carbon footprint in the UK food supply chains: A new perspective of life cycle assessment

**Table I.** GHG emissions (in CO<sub>2</sub>e) associated with food categories production and typical western diet

Greenhouse gas (GHG) emissions for food categories production (weighted) in the UK including import from EU and outside EU		Contribution of different food categories to diet-related GHG emissions (CO <sub>2</sub> e)	
Food Category	GHG emissions (kgCO <sub>2</sub> e/kg)	Food Category	Per cent of GHG emissions (CO <sub>2</sub> e) in typical western diet
<b>Meat</b>	35.9	Meat, Beans, Fish, and Other non-dairy proteins	57
<b>Fruits and Vegetables</b>	1.6	Fruits and Vegetables	11
<b>Milk</b>	1.8	Milk and Dairy	14
<b>Poultry Meat</b>	5.4	Bread, Potato, Pasta, Rice and Other starchy foods	6
<b>Rice</b>	3.9	Food and Drinks (High in Sugar and/or Fat)	5
<b>Fish</b>	5.4	Other Miscellaneous Foods e.g., Alcohol, Sources and Hot drinks	7
<b>Tea</b>	1.9		
<b>Wheat/Oats</b>	1.0		
<b>Sugar</b>	0.1		

**Source:** Adapted from Scarborough *et al.* (2014) and FCRN (2015)

**Table II.** Studies on activities of UK food supply chains and its related CO<sub>2</sub>e implications.

Study	Findings
Jones (2002)	CO <sub>2</sub> e associated with supply of fresh food to the UK consumers transported by trucks or planes is greater than rail.
<b>Marriott (2005)</b>	Significant portion of CO <sub>2</sub> e is associated with fresh food import from EU and non-EU countries. Majority of this CO <sub>2</sub> e is caused by food transport.
<b>Garnett (2006)</b>	CO <sub>2</sub> e are generated throughout the life cycle hotspots of FSC. The hotspots include transportation, storage and waste.
<b>Saunders <i>et al.</i> (2006)</b>	CO <sub>2</sub> e per tonne of apples produced in the UK are higher than in the New Zealand due to higher use of energy.
McKinnon and Piecyk (2012)	Significant amount of CO <sub>2</sub> e produced from transport operations.
<b>Hulthén and Gadde (2009)</b>	Modified distribution facilities (e.g., trucks and distribution centres) efficiently utilised can reduce fuel consumption and CO <sub>2</sub> e.
<i>Audsley et al.</i> (2010)	A significant proportion of CO <sub>2</sub> e (101 Mt CO <sub>2</sub> -equivalent emissions) from global land use change attributable to the UK FSC.
<b>Garnett (2011)</b>	FSC produces CO <sub>2</sub> -equivalent emissions at all stages in its life cycle, starting from the farming process and its inputs, through to manufacturing, refrigeration, distribution, retailing, food preparation and waste disposal. Evidence shows that in addition to technological mitigation, there is need to shift patterns of consumption.
<b>Defra (2013)</b>	176 Mt of CO <sub>2</sub> -equivalent is generated within the UK domestic food sector in 2011 and significant amount is generated from food transport.
<i>Mangalassery et al.</i> (2014)	Adopting zero tillage systems such as crop residue cover play significant role in reducing CO <sub>2</sub> e.
<i>Tassou et al.</i> (2014)	FSC is responsible for 176Mt CO <sub>2</sub> e emissions while food waste counts for 15Mt CO <sub>2</sub> -equivalent emissions. CO <sub>2</sub> e are generated throughout the FSC, e.g., agriculture, manufacturing, domestic operations, storage, transport, retail and catering.
<i>de Ruiter et al.</i> (2016)	The UK is increasingly reliant on outsourcing countries and the CO <sub>2</sub> e associated with the FSC is increasingly generated from overseas operations.

**Table III:** Selected Countries, Fruit and Vegetables, Farming Community, Storage Facility Centre, Days of Storage and Ports for Export

Country	Selected Fruit and Vegetables	Selected Farmland/Farming Community	Storage Facility Centres	Days of Storage	Export Centres/Ports
China	Banana Pepper	Guangdong	Guangdong Fruit, Vegetable and Non-staple Food Company.	3	Port of Shenzhen Guangzhou Baiyun International Airport, Guangdong Sheng, China
Colombia	Banana Pineapple	Colanta SA company Farmland, Girón, Santander, Colombia	Storage Facility, Colanta, 66, Girón, Santander, Colombia	3	Barranquilla Port El Dorado International Airport
Costa Rica	Melons Banana	Limón Central	Almacen Villalazo, Limón, Siquirres, Costa Rica	3	Port of Puerto Limon Limon International Airport
Spain	Grapes Lettuce	Province of Murcia	Moving and Storage La Seda, Mudanzas y Guardamuebles La Seda	3	Noatum Container Terminal Valencia, Port of Madrid Ciudad Real Airport
France	Apple Tomatoes	D'aucy	D'aucy, Prince de Bretagne	3	Nantes Saint-Nazaire Port Lann Bihoue Airport
Ghana	Banana Pineapple	Nyanyano, Kasoa, Central, Ghana	Jei River Farms Awutu	3	Tema Ports and Harbours Kotoka International Airport, Accra
India	Mango Banana	Sericulture Maharashtra	Cold Chain Solution of India	3	JSW Jaigart Port Chhatrapati Shivaji International Airport
South Africa	Apple Pears	Elgin, Southern Africa	Interpaarl Logistics	3	Transnet Port Terminals - Cape Town Cape Town International Airport

**Note:** Three (3) days is the estimated days for storage based on the work of UNL (2017) that suggests safe standard for storing fruits and vegetables

**Table IV.** Selected Activities of the UK FSC (Input Variables)

Variable (As presented in the model)	Description of Variable	Authors' Calculation and Source of Data Collection [multiple sources; but main source: FAOSTAT (2017)]
Land use (Land use)	This is the emissions produced by the use of cropland and land use change by the country	Calculation based on cropland emissions.
Synthetic Fertilisers (SF)	This is the emissions produced by the use of synthetic fertilisers in a country for agricultural activities.	Calculation based on synthetic fertilisers emissions.
Manure Applied (MA)	This is emissions produced by applying manures on agricultural soils by farmers.	Calculation based on manure applied to soils emissions
Crop Residues Applied (CR)	This is emissions from crop residues and pasture renewal left on agricultural lands by farmers.	Calculation based on crop residues on soils.
Organic Soil (OS)	This is emissions from cultivated organic soils under cropland.	Calculation based on organic soil cropland emissions.
Burning Residues (BR)	This is the emissions produced by the combustion of a portion of crop residues burnt on farming fields.	Calculation based on burning residue emissions.
On-farm transportation (OFT)	This is emissions from use of heavy-duty vehicles for transportation of fruits and vegetables from farmland to the overseas storage as a proxy for farm produce logistics.	Calculation based on heavy-duty transport emissions (as a proxy) for fuel and machinery use for transporting fruit and vegetables.
Overseas storage (OVS)	This is the emissions from storage of fruits and vegetables from overseas at the warehouses before transporting it to the port for export.	Calculation based on storage emissions provided by Wakeland <i>et al.</i> (2012) and work of UNL (2017).
Port logistics (PL)	This is emissions from the transport of fruits and vegetables from the warehouse to the ports (either the airport or cargo port or train station).	Calculation based on distance from the overseas storage and emissions by heavy-duty vehicle transport of the fruits and vegetables.
Road (Hdv)	This is emissions from road (heavy-duty) transport of fruits and vegetables from home grown country to the UK.	Calculation based on distance from between the cities (home grown country capital and London, considering the location of the port) and emission by heavy-duty vehicle transport.
Air (Plane)	This is emissions from air (plane) transport from fruits and vegetables from home grown country to the UK.	Calculation based on the air travel distance from between the cities (home grown country airport nearest to overseas storage and Heathrow airport) and emission by plane transport.
Rail (Train)	This is emissions from train transport of fruits and vegetables	Calculation based on the travel distance from between the cities

1		from home grown country to the UK	(home grown country rail station nearest to overseas storage and St. Pancras Station) and emission by train transport.
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6	Sea	This is emissions from sea	Calculation based on the travel
7	(Transoceanic)	(transoceanic) transport of fruits	distance from between the cities
8		and vegetables from home grown	(home grown country cargo port
9		country to the UK.	station nearest to overseas storage
10			and London Port) and emission by
11			train transport.
12			
13	Delivery	This is emissions from transport of	Calculation based on the travel
14	(DV)	fruits and vegetables from the port	distance from the port in London to
15		by heavy-duty vehicles to	the retailer's large storage
16		warehouses of retailers in the UK.	(warehouse) using Tesco Groceries
17			Warehouse (as the storage point) and
18			emission by heavy-duty vehicle
19			transport.
20			
21	Storage for Distribution	This is emissions from storage of	Calculation based on storage
22	(SfD)	fruits and vegetables at the	emissions provided by Wakeland <i>et</i>
23		warehouse before transported to	<i>al.</i> (2012) and work of UNL (2017).
24		sales point warehouse.	
25			
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27	Distribution	Emissions from transport of fruits	Calculation based on heavy-duty
28	(Distr)	and vegetables from the storage	vehicle transport emissions of the
29		(warehouse) in the UK to the	fruit and vegetables from storage
30		retailer's sale point by heavy-duty	(warehouse) in the UK to the
31		vehicles.	retailer's sales point.
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**Notes:** Detail of these calculations can be provided on request. All final values of variables are in tonnes of CO<sub>2</sub>e.



**Table V.** Key Factor Variables and Dependent Variable

Variable (As presented in the model)	Description of Variable	Calculation and Source of Data Collection
CO <sub>2</sub> e (CO <sub>2</sub> )	UK Carbon dioxide emissions from all sectors.	Office for National Statistics (2017)
Growers' Field (GF)	This is the emissions from the summation of land use, synthetic fertilisers, manure applied, crop residues, organic soil and burning residues emissions.	Based on the summation of emissions from land use, synthetic fertilisers, manure applied, crop residues, organic soil and burning residues from FAOSTAT (2017).
Inland Logistics outside the UK (ILUK)	This is emissions from the summation on-farm transportation, storage of fruits and vegetables (in overseas) and port logistics.	Based on the summation of emissions from on-farm transportation, overseas storage and port logistics from FAOSTAT (2017).
Transportation (Transportation)	This is transport emissions of fruits and vegetables from all the selected countries to the UK. It is the sum of variable road, air, rail and sea.	Based on the summation of emissions from all modes of transportation particularly by road (heavy-duty vehicles), air (planes), sea and rail. Calculation method adopted from Edwards-Jones <i>et al.</i> (2008) and Elhedhli and Merrick (2012)
Sales and Distribution (SD)	This is the emissions from delivery to retailer's warehouses, storage for distribution and distribution to retailer's shops. It is sum of the variables delivery, storage for distribution and distribution.	Author's calculation by addition of Delivery, Storage and Distribution emissions. Calculation method adopted from Edwards-Jones <i>et al.</i> (2008) and Elhedhli and Merrick (2012)

**Notes:** Based on Author's calculation. All final values of variables are in tonnes of CO<sub>2</sub>e.

**Table VI.** Key Factors of Carbon Dioxide Emissions

Variable	Coefficient
Growers' field	-0.000(0.001)
Inland Logistics outside the UK	0.003(0.004)
Transportation	0.100** (0.009)
Sales and Distribution	-0.013*** (0.005)
Summary Statistics:	
Observation	400
R-squared	0.585
Adjusted R-squared	0.577
Prob(F-statistic)	0.007
<b>Notes:</b> *** $p < 0.01$ , ** $p < 0.05$ and * $p < 0.1$ . The standard errors are the values in the parentheses. Prob (F-statistic) showing the overall significant predicative capacity of the model.	

**Table VII.** Inputs (Activities) of Key Factors of CO<sub>2</sub>e

Variable	Coefficient
Land use	0.063*** (0.020)
Synthetic Fertilisers	0.002(0.014)
Manure Applied	0.003(0.018)
Crop Residues Applied	-0.024**(0.012)
Organic Soil	-0.041**(0.016)
Burning Residues	0.008(0.013)
On-farm Transportation	20.553(12.666)
Overseas Storage	0.062*** (0.016)
Port Logistics	-8.208(4.800)
Road Transport	0.110*(0.065)
Rail Transport	-0.107*** (0.066)
Sea Transport	0.029*(0.018)
Delivery	-12.444(7.880)
Storage for Distribution	0.042*** (0.014)
Distribution	0.046(0.068)
Summary Statistics	
Observation	400
R-squared	0.631
Adjusted R-squared	0.551
Prob(F-statistic)	0.000

**Notes:** \*\*\*p<0.01, \*\*p<0.05 and \*p<0.1. The standard errors are the values in the parentheses. Prob (F-statistic) showing the overall significant predicative capacity of the model.

**Table VIII.** Maximum Likelihood Estimates of Cobb-Douglas Stochastic Frontier Production Model

Variable	Parameter	Coefficient
Constant	$\beta_0$	-178.811*** (0.986)
Growers' Field	$\beta_1$	-0.106** (0.002)
Inland Logistics outside the UK	$\beta_2$	-152.467*** (0.734)
Transportation	$\beta_3$	37.569*** (0.146)
Sales and Distribution	$\beta_3$	114.974*** (0.684)
Sigma-Squared	$\Sigma$	4.339 (3.659)
Gamma	$\Gamma$	1.000*** (0)
Log likelihood function		-685.146
LR test of the one-sided error		1618.042

**Notes:** \*\*\* $p < 0.01$ , \*\* $p < 0.05$  and \* $p < 0.1$ . The standard errors are the values in the parentheses.

# Key factors of Carbon footprint in the UK food supply chains: A new perspective of life cycle assessment

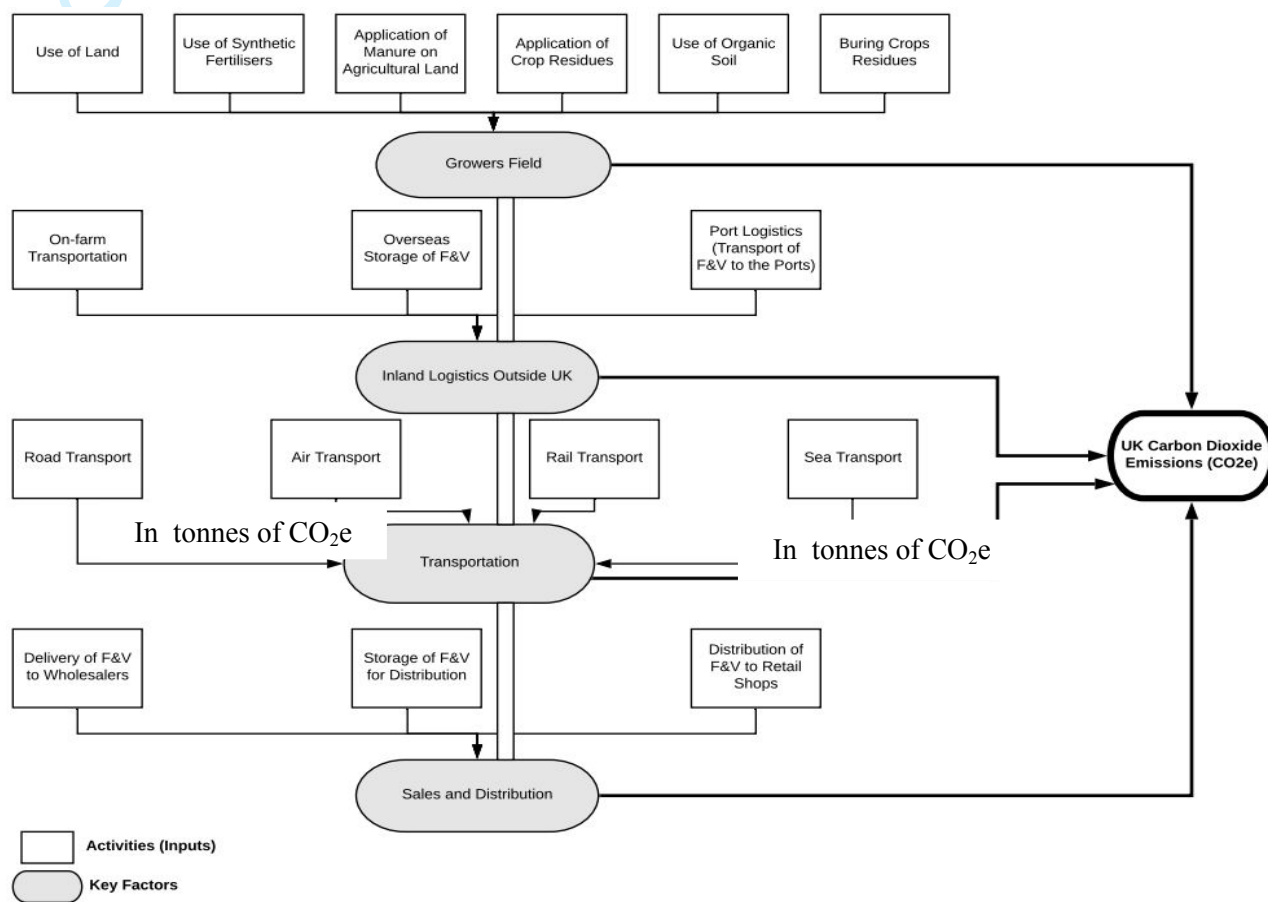


Figure 1. A conceptual framework of CO<sub>2</sub>e in the UK FSC

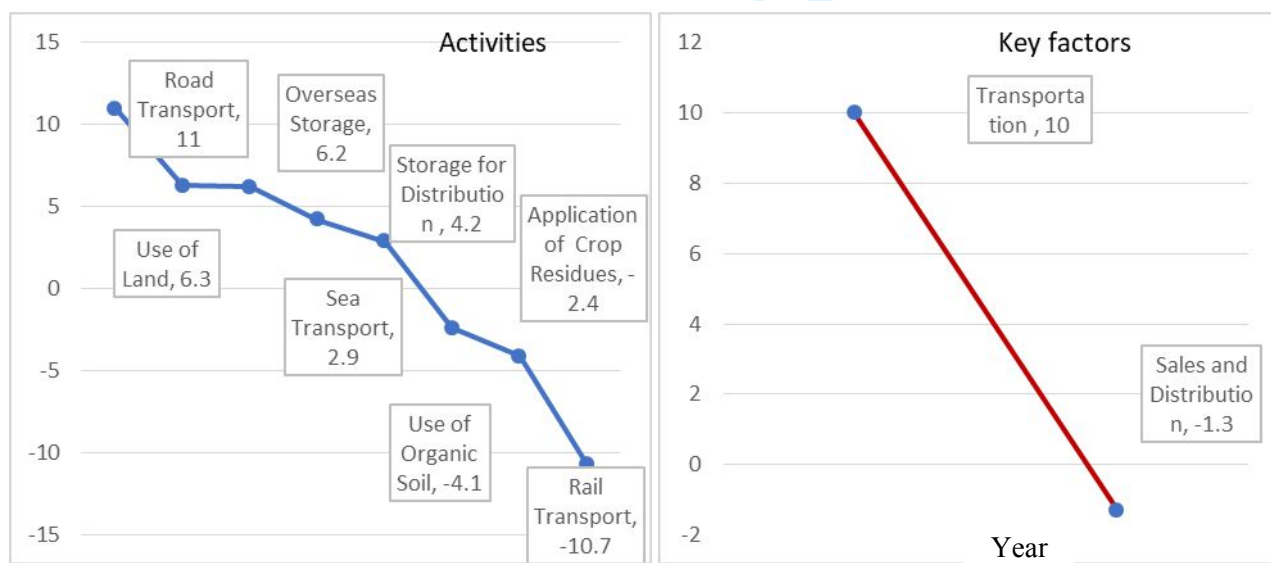


Figure 2. Ranking of significant inputs (activities) and key factors that contribute to CO<sub>2</sub> emissions in UK food supply chains.