Journal of Cleaner Production xxx (2015) 1–14

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Linking national food production to global supply chain impacts for the energy-climate challenge: the cases of the EU-27 and Turkey

Murat Kucukvar*, Hamidreza Samadi

Department of Industrial Engineering, Istanbul Sehir University, Istanbul, 34662, Turkey

ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form
9 August 2015
Accepted 29 August 2015
Available online xxx

Keywords:
Multi region input–output analysis
Production layer decomposition analysis
Energy-climate challenge
Food supply chains
EU-27
Turkey

ABSTRACT

Although the food industry has a significant impact on the European economy and society, its contribution to energy consumption and global climate challenge is also considerably high compared to other manufacturing industries. However, the global energy and carbon impacts of European food production are not addressed sufficiently. With this motivation, this research aims to advance the body of knowledge on carbon and energy footprint analysis of food industries in the 27 member states of the European Union and Turkey. We employed a time series multi-region input–output analysis to analyze the carbon and energy footprints of food manufacturing industries. As a global multi-region input–output database, this research used the World Input–Output Database, which provides a time-series of world input–output tables for 40 countries worldwide covering 1440 economic sectors. The results from this study indicate that Germany, France and Spain have the largest food production-related energy footprint. All European countries have upstream suppliers as the dominant contributors of their total energy consumption, except for Romania, for which onsite impacts are dominant. Furthermore, the largest share of carbon emissions related to Turkish food manufacturing is found in Turkey's geographical boundary, whereas more than 50% of the total energy footprint of Turkey's food manufacturing industry is located in various regions outside of Turkey, including the rest of the world and particularly United States and the European Union. The findings show that upstream supply chains are responsible for over 90% of carbon emissions, while direct emissions and those from the first three-layers of food manufacturing supply chains are found to be responsible for approximately 80% of total carbon emissions.

1. Introduction

The energy-climate challenge has become a heavily discussed topic in the European Commission, especially now that the world is in the midst of several economic, social, environmental, and political problems fueled by lack of energy security and steeply rising carbon emissions (European Commission, 2003). Unfortunately, the current footprints of human and industrial activities continue to grow in an unsustainable manner, resulting in severe global environmental issues including, but not limited to, global climate change and energy resource depletion. Consequently, the current situation necessitates a detailed analysis of global supply-chain-linked environmental footprints with respect to both consumption and production (Hoekstra and Wiedmann, 2014). While the world as a whole is facing serious socio-economic and environmental problems due to overconsumption and/or overproduction, European economies are likewise not yet on the right track, and have been largely dependent on fossil energy resources for decades, making them still vulnerable to rising energy prices and raw material supply shortages. In 2009, a majority of the manufacturing industries in Europe experienced dramatic declines (up to 20%) in total production outputs, resulting in an increasing unemployment trend (European Commission, 2010). To minimize the EU's energy and resource dependence on eastern nations and make European economic trends more sustainable, a resource-efficient manufacturing is identified within the Europe's 2020 strategic development plan as follows (European Commission, 2011a):

> *"find new ways to reduce inputs, minimize waste, improve management of resource stocks, change consumption patterns, optimize production processes, management and business methods, and improve logistics".*

The food production sector is considered to be one of the major contributors to the carbon and energy footprints of our ecosystem,

* Corresponding author.
E-mail address: muratkucukvar@sehir.edu.tr (M. Kucukvar).

http://dx.doi.org/10.1016/j.jclepro.2015.08.117
0959-6526/© 2015 Elsevier Ltd. All rights reserved.

and therefore there is a dire need for fundamental paradigm changes in the way that food is produced, processed, and distributed, so as to achieve sustainable development and food security (FAO, 2010). Among the European manufacturing sectors, the food industry is one of the largest and most important industries and responsible for the largest shares of both economic value contribution and natural resource consumption (Food Drink Europe, 2014). In 2010, food consumption and production were identified as being responsible for 20–30% of environmental impacts in Europe, including climate change and energy resource depletion (Aronsson et al., 2014). Food production in Europe continues to put pressure on the carrying capacity of regional and global communities. For instance, changing land use, land degradation, and dependence on fossil fuel resources are altogether approximately attributed to one-quarter of total greenhouse gas (GHG) emissions. Hence, to achieve a resource-efficient European socio-economic system through smart, carbon-neutral, and sustainable industrial growth, the food sector is highlighted as priority area calling for (European Commission, 2011b):

> *"incentives for healthier and more sustainable production and consumption of food and to halve the disposal of edible food waste in the EU by 2020".*

1.1. Sustainable supply chain management and life-cycle assessment

While resource extraction and food production take place in some parts of the word, manufacturing, redistribution, and consumption occur in different parts of the world (Wiedmann et al., 2011). Hence, to be able to analyze supply chain sustainability and promote sustainable production policies for the European food industry, international supply chains needs to be captured (Chaabane et al., 2012). On the other hand, current sustainable supply chain management understanding prioritizes the social, environmental, and economic goals of an individual company for improving long-term economic performance of the company and its supply chains (Carter and Rogers, 2008). While it is appropriate from an individual company's perspective, when the entire supply chain network and its integration with environmental sustainability are considered, a broader understanding is necessary. In the literature, most of the studies addressing issues related to supply chain sustainability and resource-efficiency have narrow boundaries and focus on a specific phase of supply chain such as transportation and logistics (Cholette and Venkat, 2009; Egilmez and Park, 2014; Soysal et al., 2012) and inventory management (Bouchery et al., 2012; Hua et al., 2011). Although analyzing different segment of supply chains are necessary and can be beneficial for corporate level supply chain management efforts (Benjaafar et al., 2013), some studies indicated that these segments have very small impact compared to upstream supply chain impacts (Egilmez et al., 2014). Hence, mapping the energy and carbon hotspots for food production throughout global supply chain can guide policy makers, industry stakeholders, and researchers to canalize the efforts to the right domains.

A proper analysis of the global impacts of the food manufacturing sector and its associated supply chain(s) becomes necessary for regional and international policy making to achieve sustainable food production. To realize EU's sustainable food manufacturing targets for minimizing energy use and GHG emissions, the sustainability impacts of food industry must be analyzed from a supply chain perspective. Over the last decade, the concept of sustainable supply chain management has become a topic of considerable interest worldwide, and is also widely discussed in regional policy making (Acquaye et al., 2011; Ahi and Searcy, 2013; Beske and Seuring, 2014). The necessity of systems thinking in sustainable supply chain management is immediately apparent due to the fact that a wide range of environmental impacts arises from various parts of the supply chains of the food manufacturing sectors (Roth et al., 2008; Smith, 2008; Yakovleva, 2007). To understand the environmental impacts of production, including food products, life-cycle assessment (LCA) and environmentally extended input–output analysis (EE-IOA) are two of the main methods used in many projects, including 'Environmental Impacts of Products of the European Union' (Huppes et al., 2006; Tukker and Jansen, 2006; Tukker et al., 2011). The Coordination Action for innovation in Life Cycle Analysis for Sustainability (CALCAS) is funded by the 6th Framework Programme of the European Commission, and has also highlighted the importance of using process-based LCA (P-LCA) and EE-IOA in micro and macro-level environmental decision making for production and consumption (Heijungs et al., 2010; Weidema et al., 2009; Onat et al., 2014a).

LCA models are widely used to calculate the energy and carbon footprints of the food production sector over its entire life cycle (Cellura et al., 2012a; Soussana, 2014; Van der Werf et al., 2013). LCA is capable of analyzing the energy and carbon impacts of product life cycles in what is commonly known as a cradle to grave analysis, including the raw material extraction/processing, production, transportation, use, and end-of-life phases (De Benedetto and Klemeš, 2009; Rebitzer et al., 2004; Rivera et al., 2014). In the literature reviewed for this study, several studies were found that applied the LCA method to the life-cycle impacts of food products such as dairy and milk (Berlin and Sonesson, 2008; Flysjö et al., 2011), beef (Cederberg and Mattsson, 2000; Nguyen et al., 2010), fish (fisheries) (Pelletier et al., 2009; Ziegler and Valentinsson, 2008), rice and/or wheat (Meisterling et al., 2009; Röös et al., 2011), and potatoes and/or tomatoes (Cellura et al., 2012b; Roy et al., 2008).

1.2. Input–output analysis: single and multi-region models

While P-LCA is good for quantifying direct environmental impacts, it does not account for the contribution of all upstream supplier impacts related to the processing, manufacturing, and/or distribution of products (Egilmez et al., 2013; Onat et al., 2014b,c; Mäenpää and Siikavirta, 2007). Many LCA studies on food sustainability have covered a limited range of indirect impacts, particularly in terms of energy and carbon footprint analyses. However, in most cases where such a process-based analysis is applied, it usually tends to consider only direct impacts by neglecting the upstream (production, transportation, and/or distribution) impacts of the food production sector (Weber and Matthews, 2008). Earlier studies on the direct and upstream energy and carbon footprint impacts of different food manufacturing sectors also showed that the P-LCA method suffers from significant truncation errors, which can be on the order of 50% or higher (Egilmez et al., 2014; Wood et al., 2006). To address this gap, the EE-IOA method is widely used for quantifying the environmental impacts of products and/or processes, and is capable of quantifying the overall environmental impacts of production or consumption while considering the role of extended supply chains (Jungbluth et al., 2011; Kucukvar et al., 2014a,b; Virtanen et al., 2011).

Several studies used a single-region EE-IOA in order to estimate the carbon and energy impacts of food products and production/distribution sectors. For example, Wood et al. (2006) conducted a comparative environmental LCA of organic and conventional farming in Australia in terms of energy use and carbon footprint impacts. The EE-IOA was used in order to fully account for indirect resource inputs from all upstream production stages. In another study, a hybrid LCA model combining EE-IOA and P-LCA was used to