The Determinants of Carbon Footprint: Role of Agriculture

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Abstract

The global food system, from fertilizer production to food packaging, is responsible for one-third of all human-caused greenhouse gas emissions. On average, carbon footprint represents more than 50% of the total ecological footprint in the world. Carbon footprint is said to be a widely accepted indicator of GHG intensity, originating from different economic activities. Due to its important role in raising awareness of global warming, scientists and policymakers also use it as a management tool. However, the application of carbon footprint on the agricultural sector is still limited in the literature. The aim of the paper is to explore what agriculture-specific factors influence the carbon footprint at a global level. This research investigates the determinants of the carbon footprint on a global sample, considering the role of agriculture and trade for a period of 1961-2013. Data are derived from the Global Footprint Network and the World Bank databases. The sample includes a panel dataset of 133 countries and 53 years’ period. A feasible generalized least squares estimator is applied to the sample in order to estimate the regression model, along with panel tests. Results show that carbon footprint is stimulated by economic development and agricultural production (arable land, agricultural machinery, fertilizer use). Furthermore, agricultural trade has a positive impact on the carbon footprint. By contrast, the growth of carbon footprint is negatively related to the higher share of rural population and agricultural development.

Keywords

carbon footprint, agriculture, trade, panel regression, global sample

Introduction

According to scientists, agriculture is one of the major contributors to climate change. One-third of our greenhouse gas emissions come from agriculture (Gilbert 2012). Agricultural greenhouse gas (GHG) emissions are mainly composed of methane and nitrous oxide. Furthermore, agriculture uses 11 percent of the Earth’s land surface for crop production (FAO 2003). It also makes use of 70 percent of all water surface (FAO 2011). The global food system, from fertilizer manufacture to food storage and packaging, is responsible for up to one-third of all human-caused greenhouse gas emissions (Gilbert 2012).
The ecological footprint measures a country’s use of cropland, forests, grazing land and fishing grounds for providing resources and absorbing carbon dioxide from burning fossil fuels (Global Footprint Network, 2018). On average, carbon footprint represents more than 50% of the total ecological footprint in the world. Carbon footprint is thought to be a widely accepted indicator of GHG intensity, originating from different economic activities. Due to its important role in raising awareness of global warming, scientists and policymakers also use it as a management tool.

However, investigating determinants of the carbon footprint on the agricultural sector is still limited in the literature. Therefore, it is important to explore what agriculture-specific factors influence the carbon footprint. The research analyses determinants of the carbon footprint on a global sample, focusing on the role of economic development, agricultural production and agricultural trade between 1961 and 2013. The applied data are derived from the Global Footprint Network (2018), the World Bank (2018a) WITS and World Bank (2018b) World Development Indicator databases. The sample includes a panel dataset of 133 countries and 53 years’ period.

**Theoretical background**

Two main approach exits on estimating GHG emission: consumption-based and production-based approach (Mózner 2013). The domestic emission inventories are based on a production-based approach while consumption-based approach claims that countries are responsible for emissions generated elsewhere due to its consumption (Peters 2008, Mózner 2013).

Several scientific studies have been published on the measurement and modelling of GHG emissions at macro level. Many income and non-income factors were identified as key drivers of emission. Key drivers of global GHG emissions are populations growth, trends in demographic structure (urbanisation), consumption expenditure, transport infrastructure, production methods, waste management, and energy systems (IPCC 2014, p 4.). Non-income factors such as geography, diet, and lifestyle also affect per capita emission or carbon footprints (GAIA, 2012; Corsten et al., 2013).

The literature presents contradicting results relating to whether population growth in rich or poor countries contributes more to increasing GHG emissions. Poumanyvong and Kaneko (2010) measured elasticities ranging from 1.12 (high-income) to 1.23 (middle-income) to 1.75 (low-income) countries, while Jorgenson and Clark (2010) find a value of 1.65 for developed and 1.27 for developing groups of countries.

Agriculture already uses 11 percent of the world’s land surface for crop production. It also exploits 70 percent of all water withdrawn from aquifers, streams, and lakes. Agricultural policies have primarily benefited farmers with productive land and access to water, bypassing the majority of small-scale producers, who are still locked in a poverty trap of high vulnerability, land degradation and climatic uncertainty (FAO 2011, p. 25).

In the last decades, the calculation and use of carbon footprint become more widespread. The carbon footprint is often used for the amount of carbon being emitted by economic activity. The carbon footprint is also an important component of the ecological footprint since it is a competing demand for biologically productive space (Global Footprint Network, 2018).

Carbon footprint is thought to be a widely accepted indicator of GHG intensity, originating from different economic activities (Global Footprint Network, 2018). Due to its important role in raising awareness of global warming, scientists and policymakers also use it as a management tool for measuring the environmental effect of different countries.
On the one hand, it should be mentioned that carbon footprint is strongly correlated with consumption expenditure. The consumption-based emissions are more closely associated with GDP than with territorial emissions (IPCC 2014, p 4.). The consumption-based framework assigns the emissions released through the supply chain of goods and services consumed within a nation irrespective of their territorial origin. The difference in inventories calculated based on the different frameworks are also the emissions embodied in trade (Peters and Hertwich, 2008; Bows and Barrett, 2010). Different countries and agricultural sectors have diverse carbon footprints. Country size, the importance of agricultural production, technology, population etc. might influence carbon footprints of the economies in different ways.

Regarding geographical aspects, China with its highest population and production level is one of the major contributors to carbon footprint and climate change. In China, the carbon footprint of crop production represents 8% of the nation’s total emissions and two-thirds of the agricultural footprint are of agrochemical origin (55 % of Nitrogen fertilization). Moreover, irrigation and energy consumption contributes to 22% on average, whereas plastic film and machinery management contributes less than 10 % of the total carbon footprint in crop production (Muthu, 2014). Muthu (2014) revealed that among the three main Chinese crops, rice has the biggest carbon footprint, followed by wheat and maize sectors. Moreover, among vegetable crops, Chinese cabbage has the strongest carbon footprint whereas water spinach the lowest.

According to a study conducted on livestock of pig meat in Flanders by the carbon footprint method, 1kg of pig meat creates a carbon footprint of 5.7 kg CO2 equivalent. Production and transport of purchased foders then after production and usage of manure (composed of 88% of methane and 12% of nitrogen) are the higher part of overall carbon footprint (respectively 54% and 24%). At the farm level, foders were responsible for more than two-thirds of the carbon footprint (Muthu, 2014).

Comparing carbon footprints between different animal meat productions, beef has the biggest carbon footprint, followed by pork (Dyer et al., 2008, Desjardins et al., 2014). In dairy production, Desjardins et al. (2014) demonstrated that powders have the largest carbon footprint among dairy products, followed by butter and cheese in the example of Canada.

In sum, according to food products ranking based on their carbon footprint, the meat is in the first place, followed by cheese and eggs, while fruits and vegetables have the lowest carbon footprint. Thus, applying these results to diet types, red meat consumers have two-time higher carbon footprint than a vegetarian (Green Eatz, 2018).

A global level application of carbon footprint on the agricultural sector employing an econometric model is still limited in the environmental economics literature. Thus, it is important to measure the agriculture-specific factors influencing carbon footprint at a global level focusing on its different activities.

**Evolution of Carbon footprint**

On the demand side, the ecological footprint measures a country’s use of lands, forests, and fishing grounds for providing resources and absorbing carbon dioxide from burning fossil fuels. On the supply side, biocapacity measures how much biologically productive area is available in the World to regenerate these resources and services. The Global Footprint Network (2018) data breaks down the ecological footprint by these surface areas for nearly 150 countries from 1961 to 2013 (Figure 1). These statistics indicate that carbon footprint has the highest share in the ecological footprint of the world (more than 50%), followed by cropland, forest and grazing land.
Statistics show that the USA, China, Russia, Japan and Germany had the highest carbon footprint between 1961 and 2013 (Figure 2). It suggests that countries with high population and strong industrial or agricultural sector are responsible for the highest footprint in the World.

Source: own composition based on Global Footprint Network (2018)
Methods

On the consumption side, developed, high income, and populated countries might have a larger demand for food products (consume more meat and processed food product) that might generate a larger carbon footprint. Ang (2007) revealed a positive relationship between per capita GDP and per capita CO2 emission. Kuznets supposed that the distribution of income becomes more unequal at early stages of income growth but that the distribution ultimately moves back toward greater equality as economic growth continues (Kuznets 1955). The further developed Kuznets curve (environmental Kuznets curve, EKC) suggests that as development and industrialization progress, environmental damage increases due to greater use of natural resources, later, in the post-industrial stage, cleaner technologies appear with willingness to enhance environmental quality (Munasinghe, 1999) This inverted U-shaped relationship between economic growth and environmental degradation known as Kuznets curve. The environmental Kuznets curve has become a standard feature in the technical literature of environmental policy (Grossman and Krueger 1991). The first hypothesis tests the EKC on carbon footprint:

**H1:** It is an inverted U-shaped relationship between economic growth and the evolution of countries’ carbon footprint.

The higher scale of agricultural production needs more arable land and agricultural equipment as well as uses more fertilizer that definitely increases environmental pollution (Foley et al. 2011; Baccini et al. 2012; Grace et al. 2014; Henders et al. 2015) that stimulates carbon footprint.

**H2** Higher scale of agricultural production (agricultural machinery, fertilizer use, arable land) boosts carbon footprint.

Agricultural development is supposed to decrease CO2 emission by using environmentally friendly technologies, in line with Balogh and Jambor (2017). Thus, the carbon footprint is also expected to decline with the progress of agricultural development at the global level.

**H3:** Agricultural development (agriculture value added) via technological efficiency encourage to reduce carbon footprint.

Globalization has considerably enhanced the trade of animal feed and processed meat products (Kearney, 2010), stimulating environmental pollution (Balogh and Jambor 2017) and enlarging carbon footprint.

**H4:** Agricultural trade has a positive impact on the carbon footprint by stimulating food production and transport.

There is a significant trade-off between mass resource use and consumption habits of the rural and urban population. Puppim de Oliveira and Sethi (2017) suggest that a country’s degree of urbanization also determines its carbon emissions. Sethi (2017) added that cities and their spatial development contribute significantly to global warming through GHG emission. Thus, the higher share of the rural population (lower urban population) indicates limited carbon footprints compared to the urban one.

**H5:** The higher the rural population (% of total population) is, the lower the carbon footprints are.
The applied econometric model aims to estimate the main determinants of carbon footprint in agriculture. Data are derived from the Global Footprint Network (2018), the World Bank (2018a, 2018b) World Integrated Trade Solutions (WITS), and World Development Indicator (WDI) databases. The sample includes a panel dataset of 133 countries and 53 years’ period (1961-2013) representing the world economy. Descriptive statistics and panel tests are available in Appendix. In this study the following equation is estimated for modelling carbon footprint:

\[
\ln_{Carbonfootprint_i} = \beta_0 + \beta_1 \ln_{GDPPC_i} + \beta_2 \ln_{(GDPPC)^2_i} + \beta_3 \ln_{Tractors_i} + \beta_4 \text{Arableland}_i + \beta_5 \text{Agrvadded}_i + \beta_6 \ln_{Agrexportq_i} + \beta_7 \text{Ruralpop}_i + \beta_8 \ln_{Fertilizer}_i + \varepsilon_i
\]

where \( i \) denotes the country and \( t \) the time.

In the equation, the carbon footprint as dependent variable is expressed in global hectares in logarithm form. The economic development is represented by GDP per capita, in PPP at current international USD (\( \ln_{GDPPC} \)) and its squared term (\( \ln_{(GDPPC)^2} \)). Agricultural development is measured by agriculture value added in percent of GDP (Agrvadded). Fertilizer consumption (kilograms per hectare of arable land), arable land area in share of total land area (Arableland), and agricultural machinery (tractors per 100 sq. km of arable land) denote agricultural productivity. The rural population is expressed in share of the total population (in percent). Finally, agricultural trade is embodied as agricultural export in quantity in kg.

A feasible generalized least squares estimator (\( xtgls \)) is applied to the sample in order to estimate the panel regression, along with panel unit root tests (Appendix). In order to avoid multicollinearity, different models were estimated with different composition of explanatory variables.

**Results**

The unit root tests for carbon footprint reject the hypothesis of non-stationarity (the null hypothesis for Maddala and Wu (1999), and Pesaran (2007) CIPS tests that series is I(1)) see Appendix).

In all estimated models (Table 1), explanatory variables are significant at 1% level. The regression results indicate that carbon footprint is stimulated by countries’ income in the developing period of economic growth (GDP per capita) then turns to decrees in the developed phase, confirming H1 (EKC hypothesis).

Furthermore, agricultural production variables (agricultural machinery, fertilizer use) are positively associated with a carbon footprint in line with the H2 hypothesis (production-based emission approach).

An inverse effect is revealed between agricultural development and carbon footprint, hence H3 has to be also accepted. This result confirms that agricultural development provides better technology, thereby helping to reduce resource use and environmental pollution via environment-friendly technologies at global level.

Agricultural trade (represented by agricultural export quantity) have a positive impact on carbon footprint (Table 1), proving H4 in line with the finding of Ang (2009), Chebbi et al. (2011), Sharma (2011), Shahbaz and Leitao (2013) as well as Balogh and Jambor (2017).

By contrast, the carbon footprint is negatively related to the higher share of rural population in the total population (H5).
These model results confirm the positive significant effect of agricultural activities on the carbon footprint. Last but not least, besides measuring and calculating the determinants of carbon footprint, it is necessary to have results and explanations on how to reduce it in agriculture. Thus, relevant knowledge should be shared on new agricultural practices, and sustainable innovations, as well as the financial access to new sustainable technologies, should be enhanced (Thornton, 2012). It is an especially important duty for the least developed countries in Asia and Africa.

After highlighting the different factors of carbon footprint in agriculture, the protection and maintenance of forest cover, good management practice of rangelands, fodders grasses and pastoral systems have to be developed and improved (FAO, 2011) in every countries and region. Furthermore, it will be necessary to do the same for agricultural practices such as the installation of crop rotations, intercropping and cover cropping or integration of agroforestry and other perennial species (FAO, 2017). Extensive agriculture uses more environmentally friendly technologies and produces less carbon footprint.

The two 'hot spots' of GHG emissions in livestock farm are for fodders production and manure usage. Within farms, its changes could be realised and have real impacts on GHG decrease. Hortenhuber et al. (2011) revealed that in European dairy cattle farms, the substitution of 50 % of soy meal by local products would have created a diminution of 26 % of GHG emissions. It is emphasizing the importance of short supply chain in reducing environmental pollution.

With regard to the emission of nitrogen origin, legumes implementation, such as fava beans, chickpeas, and lentils, a solution can be to revitalize the soil and to use fewer fertilizers. In fact,
these species have nitrogen-fixing properties, that is to say, atmospheric nitrogen becomes usable for these crops, thanks to them (Thornton, 2012).

**Discussion**

The study analysed the determinants of carbon footprint in the agricultural sector employing panel econometrics at a global level for a period of 1961 and 2013. The results revealed that carbon footprint was highly associated with economic development in the earlier phase of development, later, after a turning point, it tended to decrees (EKC hypothesis). Moreover, agricultural production is positively associated with an increase of carbon footprint, in line with the production-based emission approach. Agricultural trade has a positive impact on carbon footprint, fostering the growth of carbon footprint. Finally, the carbon footprint is negatively related to the higher share of the rural population as well as the higher level of agricultural development at the world level. On the other hand, it is also important to provide policy implications for decision-makers on how to reduce the carbon footprint in agriculture. Such solutions could be: relevant knowledge sharing on sustainable innovations and agricultural practices. Furthermore, the protection and maintenance of forest cover, the better management of rangelands, fodders grasses and pastoral systems can also play a key role in reducing carbon footprint. Shifting plants to nitrogen-fixing properties such as fava beans, chickpeas and lentils can be a tool to revitalize the soil.

**Acknowledgement**

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**References**


Appendix

Descriptive statistics of variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs.</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Min</th>
<th>Max</th>
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</thead>
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<td>15.28</td>
<td>2.41</td>
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<td>ln_GDPPC</td>
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<td>2.08</td>
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<td>ln_(GDPPC)^2</td>
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<td>17.25</td>
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<td>ln_Tractors</td>
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<td>2.43</td>
<td>-5.44</td>
<td>8.79</td>
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<tr>
<td>Arableland</td>
<td>628</td>
<td>16.52</td>
<td>14.25</td>
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<td>Agrvadded</td>
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<td>15.69</td>
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<td>ln_Agexport</td>
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<td>21.23</td>
<td>2.41</td>
<td>6.79</td>
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<td>ln_Agrimport</td>
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<td>21.76</td>
<td>1.79</td>
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<td>Ruralpop</td>
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<td>23.63</td>
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<td>1.89</td>
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<td>9.71</td>
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</tbody>
</table>

Source: own calculation based on sample data

Result of unit root tests

Maddala and Wu (1999) Panel Unit Root test (MW)

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<th>Variable</th>
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<th>p-value</th>
<th>Variable</th>
<th>lags</th>
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Pesaran (2007) Panel Unit Root test (CIPS)

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<th>Variable</th>
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<td>ln_Carbonfootprint</td>
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Source: own calculation based on sample data