Short communication

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Agriculture-specific determinants of carbon footprint

The global food system, from fertiliser production to food packaging, is responsible for approximately one-third of all human-caused greenhouse gas emissions. The ecological footprint captures the ecological assets that a population needs to produce, the natural resources it consumes, and to absorb its waste. The carbon footprint as the main component represents more than 50% of the total ecological footprint. 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 for estimating environmental pollution. In contrast, the application of carbon footprint on the agricultural sector is still limited in the literature. The paper aims to explore what agriculture-specific factors influence the carbon footprint at a global level based on 1961-2013 data. The study employs feasible generalized least squares estimator along with panel unit root tests. Results show that carbon footprint is stimulated by economic development and agricultural production (arable land, agricultural machinery, fertilizer use), and in addition, agricultural exporting 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, determinants, trade

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Introduction

According to environmental scientists, agriculture is one of the major contributors to climate change. Approximately one-third of the greenhouse gas emissions (GHG) come from agriculture (Gilbert, 2012). It is already well known that agricultural GHG emissions are mainly composed of methane and nitrous oxide. Furthermore, agriculture uses approximately 11 per cent of the Earth's land surface for crop production and makes use of 70 per cent of all water surface (FAO, 2003; FAO, 2011). The global food system, ranging from fertiliser manufacture to food storage and packaging, is responsible for up to one-third of all human-caused GHG emissions (Gilbert, 2012).

Environmental pollution is generally captured at a national level by measuring ecological and carbon footprints in environmental economics. 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). The carbon footprint represents more than 50% of the total ecological footprint in many countries of the world. Furthermore, the carbon footprint is supposed to be a widely accepted indicator of GHG intensity, originating from different economic activities. Due to its increasing importance, scientists and policymakers also use it as a management tool.

Investigating the determinants of carbon footprint on the agricultural sector at product level has already been addressed by the literature, though analyses at the country level are still limited in the empirical literature, especially from a global perspective. Therefore, the paper analyses the determinants of carbon footprint on a global sample, focusing on the role of economic development, agricultural production, agricultural development and agricultural trade (export) between 1961 and 2013.

The paper is structured as follows: the subsequent section discusses the theoretical framework of the study. Section 3 presents the methodology and econometric specification. Section 4 illustrates the development of the ecological and carbon footprint, followed by the results. The final section concludes.

Theoretical framework

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

Several scientific studies have been published on the measurement of GHG emissions at the macro level. In recent years, many income and non-income factors were identified as key drivers of emission (IPCC, 2014), such as population growth, trends in demographic structure (urbanisation), consumption expenditure, transport infrastructure, production methods, waste management and energy systems. Various non-income factors can be also mentioned such as geography, diet, and lifestyle, which also affect per capita emission of 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), 1.23 (middle-income) to 1.75 (low-income) countries, while Jorgenson and Clark (2010) find a value of 1.65 for developed countries and 1.27 for developing countries.

In the previous decades, the calculation and use of carbon footprint has become more widespread. The carbon footprint is often used for determining 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). Due to its important role in raising awareness of environmental degradation, scientists and policymakers also use it as a management tool for measuring the environmental effect of different countries.

However, it should be noticed that the carbon footprint is strongly correlated with consumption expenditure. The consumption-based emissions are more closely associated with GDP than with territorial emissions (IPCC, 2014). 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 agriculture and agricultural production, technology, population, etc. might influence carbon footprints of the economies in different ways. China with its highest population and production level is one of the major contributors to the global 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. 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).

Most of the carbon footprint studies are focusing on certain geographical area and product-level data. Muthu (2014) revealed that among the three main Chinese crops, rice has the biggest carbon footprint, followed by wheat and maize sectors. According to a study conducted on livestock of pig meat in Flanders by the carbon footprint method, 1 kg of pig meat creates a carbon footprint of 5.7 kg CO2 equivalent. At the farm level, fodders 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.

Hypotheses and econometric specifications

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 (1955) supposed that the distribution of income becomes more unequal at the early stages of a country's income growth, then the distribution ultimately moves back toward greater equality as economic growth continues. The further developed curve called 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 the willingness to enhance environmental quality (Munasinghe, 1999). The inverted U-shaped association between economic growth and environmental degradation is known as the Kuznets curve. The first hypothesis attempt to tests the EKC on carbon footprint:

H1: An inverted U-shaped relationship exists between economic growth and the development of countries' carbon footprint at a global level.

A higher scale of agricultural production needs more arable land and agricultural equipment; it also uses more fertilizer. This certainly increases environmental degradation (Foley *et al.*, 2011; Baccini *et al.*, 2012; Grace *et al.*, 2014; Henders *et al.*, 2015) and in turn, stimulates a country's carbon footprint.

H2: A higher scale of agricultural production (agricultural machinery, fertilizer use, arable land) leads to reductions in the carbon footprint.

Agricultural development is supposed to decrease agricultural CO_2 emissions by using environmentally friendly technologies, in line with Balogh and Jámbor (2017). Thus, the carbon footprint is also expected to decline in line with the progress of agricultural development at the global level.

H3: Agricultural development (agriculture value-added) via technological efficiency encourages the reduction of carbon footprint.

Globalization has considerably enhanced the trade in animal feed and processed meat products (Kearney, 2010), reducing the environmental burden (Balogh and Jámbor 2017) and decreasing countries' carbon footprint via technological advance.

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

There is a significant trade-off between resource use and the consumption habits of the rural and urban population. Sethi (2017) suggest that a country's degree of urbanization also influences its carbon emissions and that cities and their spatial development contribute significantly to global warming through higher GHG emission. Thus, a country with a higher proportion of rural population (and thus, a lower urban population) might indicate a more limited carbon footprint compared to a country that is more urban in make-up.

H5: The higher the rural population (expressed as a percentage of the total population) is, the lower the carbon footprint is.

The applied econometric model aims to estimate the main determinants of carbon footprint in agriculture in the world. 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 52 years' period (1961-2013) representing the world economy. Descriptive statistics are available in the Appendix. In this study, the following equation is estimated for modelling carbon footprint:

$$\begin{aligned} \ln\_Carbonfootprint_{it} &= \beta_0 + \beta_1 \ln\_GDPPC_{it} + \\ &+ \beta_2 \ln\_(GDPPC)^2_{it} + \beta_3 \ln\_Tractors_{it} + \beta_4 Arableland_{it} + \\ &+ \beta_5 Agrvadded_{it} + \beta_6 \ln\_Agrexportq_{it} + \beta_7 Ruralpop_{it} + \\ &+ \beta_8 \ln\_Fertilizer_{it} + \varepsilon_{it} \end{aligned} \quad (1)$$

where i denotes the country t the given time.

In equation (1), the carbon footprint as a dependent variable is expressed in global hectares in logarithm form. The economic development is represented by GDP per capita, in PPP at current international US dollars (ln_*GDPPC*) and its squared term (ln_$(GDPPC)^2$. Agricultural development is measured by agriculture value-added in percentage of GDP (Agrvadded). Fertilizer consumption (kilograms per hectare of arable land), arable land area in the share of total land area (Arableland), and agricultural machinery (tractors per 100 square km of arable land) denote agricultural productivity. The rural population is expressed as the share of the total population (in per cent). Finally, agricultural trade is expressed as agricultural export in quantity (in kilograms).

A feasible generalized least squares estimator (xtgls) is applied to the sample to estimate the panel regression, along with panel unit root tests (Table 1). To avoid multicollinearity, different models were estimated with different composition of explanatory variables. Panel unit root tests suggested by Maddala and Wu (1999) and Pesaran (2007) were used to check the stationarity of applied variables. The test results indicate that dependent variables are stationary (rejection of the hypothesis of non-stationarity), i.e. variable does not have unit-roots. Descriptive statistics of the variables used are summarised in Table 2.

Table 1: Results of panel unit root tests.

Maddala and Wu (1999) Panel Unit Root test (MW)					
Specification without trend			**Specification with trend**		
Variable	lags	p-value	Variable	lags	p-value
ln_*Carbonfootprint*	0	0.000	ln_*Carbonfootprint*	0	0.000
ln_*Carbonfootprint*	1	0.000	ln_*Carbonfootprint*	1	0.021
ln_*Carbonfootprint*	2	0.000	ln_*Carbonfootprint*	2	0.322
Pesaran (2007) Panel Unit Root Test (CIPS)					
Specification without trend			**Specification with trend**		
Variable	lags	p-value	Variable	lags	p-value
ln_*Carbonfootprint*	0	0.000	ln_*Carbonfootprint*	0	0.000
ln_*Carbonfootprint*	1	0.000	ln_*Carbonfootprint*	1	0.624
ln_*Carbonfootprint*	2	0.008	ln_*Carbonfootprint*	2	1.000

Source: own calculations based on sample data.

Table 2: Descriptive statistics of variables.

Variable	Observations	Mean	Standard Deviation	Min	Max
ln_*Carbon*	6,429	15.28	2.41	4.93	21.98
ln_*GDPPC*	2,928	24.90	2.08	19.21	30.45
ln_$(GDPPC)^2$	2,928	49.80	4.15	38.41	60.90
ln_*Tractors*	4,191	3.88	2.43	-5.44	8.79
Arableland	628	16.52	14.25	0.55	73.39
Agrvadded	4,327	19.68	15.69	0.04	74.27
ln_*Agrexport*	2,308	21.23	2.41	6.79	27.67
Ruralpop	6,356	52.85	23.63	0.00	97.35
ln_*Fertilizer*	1,445	4.01	1.89	-7.76	9.71

Source: own calculations

Results

In all estimated models (1-4), explanatory variables are significant at 1% (Table 3). The regression results indicate that carbon footprint is stimulated by countries' income in the developing period of economic growth (GDP per capita), but then begins to decrease in the developed phase, confirming H1 (the 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 reduces footprint by providing better technology, thereby helping to reduce resource use and environmental pollution via environment-friendly technologies at a global level.

Agricultural trade (represented by agricultural export quantity) have a positive impact on carbon footprint, proving H4 in line with the findings of Ang (2009), Chebbi *et al.* (2011) and Balogh and Jambor (2017).

By contrast, the carbon footprint is negatively related to the higher share of the rural population in the total population (H5).

These results confirm the positive and significant effects of agricultural components on the carbon footprint. Last but not least, besides measuring and calculating the determinants of carbon footprint, it is necessary to have explanations on how to reduce the carbon footprint 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 country and region.

Furthermore, it will be necessary to do the same for agricultural practices such as the installation of crop rotations,

Table 3: Regression results.

VARIABLES	(1) ln_Carbonfootprint	(2) ln_Carbonfootprint	(3) ln_Carbonfootprint	(4) ln_Carbonfootprint
ln*GDPPC*	0.9150***	0.9160***	0.9120***	0.9060***
	(0.0110)	(0.0116)	(0.0114)	(0.0101)
ln(*GDPPC*)^2	-0.1730***	-0.0484***	-0.0946***	0.0282***
	(0.0164)	(0.0132)	(0.0154)	(0.0076)
ln_*Tractors*	0.1100***	0.1170***	0.1190***	
	(0.0125)	(0.0123)	(0.0121)	
Arableland	0.0130***	0.0117***	0.0117***	0.0078***
	(0.0009)	(0.0009)	(0.0009)	(0.0009)
Agrvadded	-0.0277***			
	(0.0028)			
ln_*Agrexport*	0.0723***	0.0919***	0.0868***	0.0501***
	(0.0094)	(0.0096)	(0.0095)	(0.0086)
Ruralpop			-0.0069***	
			(0.0012)	
ln_*Fertilizer*				0.0338***
				(0.0095)
Constant	-5.629***	-8.650***	-7.331***	-8.5790***
	(0.330)	(0.214)	(0.318)	(0.1710)
Observations	843	917	917	1,309
Number of countries	82	90	90	117

Note: Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: own calculations.

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 key components of GHG emissions in livestock farming 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 emphasises the importance of short supply chain in reducing environmental pollution.

Concerning 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. These species have nitrogen-fixing properties, therefore, the atmospheric nitrogen becomes usable for these crops (Thornton, 2012).

Conclusion

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, than later, after a turning point, it tended to decrease (confirming the EKC hypothesis). Moreover, agricultural production is positively associated with an increase in carbon footprint, in line with the production-based emission approach.

Agricultural export has a positive impact on carbon footprint, by stimulating the production and transport of goods as well as by 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 revitalise the soil.

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