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Apples to kangaroos: A framework for developing internationally comparable carbon emission factors for crop and livestock products

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ABSTRACT

Consumption-based greenhouse gas accounting, which encompasses emissions from a nation's domestic final consumption as well as emissions embodied in imports, is gaining favor in the climate change literature for its effectiveness and consideration of equity. Unfortunately, the calculation of emissions embodied in the trade of agricultural food products is hindered by a lack of consistent and comparable emission factors.

Food import quantities for every country are readily available through the United Nations Food and Agriculture Organization. Unfortunately, the carbon emission factors necessary to calculate the embodied emissions in imported foods are largely unavailable or unreliable for many countries. On top of this, different methodologies for determining carbon emission factors provide varying estimates based on different assumptions. The differences in these assumptions and methodologies can mean that attempts to compare and combine emissions based on factors from different countries become less of a comparison of apples-to-apples and more of an apples-to-oranges or even apples-to-kangaroos exercise.

This study proposes a method to combine the Food and Agriculture Organization's available greenhouse gas data, production data, and agricultural yields and scaling it against benchmarks in the literature to estimate a time-series of crop and livestock carbon emission factors that are internally consistent within the Food and Agriculture Organization's data set and comparable from nation to nation. The framework provided is then used to produce a sample set of carbon emission factors for Chinese agricultural import suppliers to determine the embodied greenhouse gases in China's food imports.

1. Introduction

Estimates of agriculture's contribution to total global greenhouse gas (GHG) emissions range from 10% to 32% (Bellarby et al., 2014). The United Nations (UN) has reported that agricultural GHG emissions have doubled in the last 50 years, with the potential to increase another 30% by 2050 (Tubiello et al., 2014). The United Nations Food and Agriculture Organization (FAO) provides national estimates of GHG for agricultural activities for countries around the globe as well as the quantity of foods traded between countries. Because the GHGs provided are for agricultural sources and activities rather than foods, however, determining the GHGs associated with the production of a traded food product, or its embodied emissions, is a non-trivial task. The carbon emission factors (CEFs) that are necessary to calculate the embodied emissions in imported foods are largely unavailable or unreliable for many countries (FAOSTAT, 2015). These emissions embodied in imports are combined with a nation's domestic final consumption in consumption-based GHG accounting, which is gaining favor in the climate change literature for its effectiveness and consideration of equity (Bergmann, 2013; Davis and Caldeira, 2010; Feng et al., 2013; Liu, 2015; Wiedmann et al., 2011; Zhang et al., 2013). Unfortunately, the calculation of emissions embodied in the trade of agricultural food products is hindered by a lack of consistent and comparable emission factors.

On top of this, different methodologies for determining CEFs provide varying estimates based on different assumptions. The differences in these assumptions and methodologies can mean that attempts to compare and combine emissions based on factors from different countries become less of a comparison of apples-to-apples and more of an apples-to-oranges or even apples-to-kangaroos exercise.

With recognition of the importance of consumption-based GHG accounting and acknowledgment of the role that agriculture and

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food play in global GHG emissions, how then can embodied emissions in food imports and exports be adequately determined? The FAO provides annual crop and livestock production figures for nations around the world as well as agriculture and food import/export data and GHGs associated with crops and livestock at a national level. The production and trade data is product-based, typically measured in tonnes of crops or head of livestock. The agricultural GHGs for a given nation, however, are categorized by activities using Intergovernmental Panel on Climate Change (IPCC) guidelines rather than specifically by product. For crops, this means rather than listing emissions associated with fruit, vegetable, or cereal production in a country, data is given for the nation's GHGs associated with fertilizer application, crop residue burning, or energy use. This proves to be problematic for calculating the embodied emissions in trade as activity-based GHG emissions cannot easily be translated into product-specific emissions. For livestock, the FAO's GHG data includes emissions from enteric fermentation and manure management for a variety of livestock types but fail to account for the indirect emissions from sources such as land use conversion, which is the emission of greenhouse gases resulting from human-induced land use change and forestry activities, and livestock feed, which comprise a majority of the contribution of GHGs for non-ruminants.

This study proposes a method to combine the FAO's available GHG and production data and scaling it against benchmarks in the literature to imply a time-series of crop and livestock CEFs that are internally consistent and comparable from nation to nation. This paper is structured as follows: the need for internally consistent, international, time series data is described in Section 2 (Literature Review) with regard to what data is available now through the FAO and the literature. Section 3 (Material and Methods) provides a framework for using the existing FAO data to produce consistent, comparable data across nations and an extended timeframe. Section 4 (Results) presents how the framework provided is used to produce a sample set of CEFs for Chinese agricultural import suppliers to determine the embodied GHGs in China's food imports. Section 5 (Discussion) addresses the advantages, shortcomings, and applicability of the methodology and the conclusion and implications of our findings are presented in Section 6 (Conclusion).

2. Literature Review

As countries are increasingly called to account for their GHG emissions, questions have been raised in recent years as to who is responsible for emissions. Under the United Nations Framework Convention on Climate Change, nations account only for GHG emissions produced within their borders. This method, production-based accounting, potentially understates or overstates the emissions associated with a nation's consumption as it ignores the GHG emissions associated with imports and exports, the emissions embodied in trade. Under consumption-based accounting, however, the consumption-based emissions are found to be production emissions less the emissions embodied in exports plus the emissions embodied in imports (Davis and Caldeira, 2010). While considerable work has been done using consumption-based accounting to analyze emissions associated with industry sectors on a larger scale, or in energy and manufacturing, the embodied emissions in food and agricultural trade has been largely relegated to a single sector in these analyses (Hawkins et al., 2015). To gain an understanding of the effects of the embodied emissions in food and agriculture, a greater level of disaggregation is necessary.

The IPCC 2006 Guidelines for National Greenhouse Gas Inventories recommend a production-based accounting method in which emissions are calculated by multiplying activity data by an emissions factor. The key GHGs of concern by the IPCC in agriculture are CH_4, N_2O, and CO_2. CH_4 is produced from enteric fermentation in livestock, manure management, rice cultivation, and the burning of savannah and crop residues. N_2O is also generated through manure management and the burning of savannah and crop residues, but is also produced by microbial processes in soils as nitrogen is added to soils through synthetic fertilizers, animal waste, crop residues, biological fixation, or other organic nitrogen additions. CO_2's contribution to agricultural GHGs is associated with the energy used for electricity and fuel use, such as planting, tilling, harvesting, and water management activities. Further detail on the processes and factors included in the IPCC's GHG calculations may be found in the Volume 4, Agriculture, Forestry, and Other Land Use, of the 2006 Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). These are all considered direct emissions associated with agricultural production. The IPCC's guidelines for agricultural emissions do not include the indirect generation of GHGs from the production of inputs such as fertilizers, pesticides, and animal feed (Lin et al., 2014).

Herrero et al. (2011) highlight the importance of providing the climate change community and policy makers with accurate estimates of emissions and the links between agriculture and climate. Though they focus specifically on livestock, their conclusions are equally applicable to food production as a whole. Determining reliable GHG emission figures for agriculture is necessary to understand its role compared to other industries and emission sources. Reliable GHG figures are necessary for identifying to reduce GHGs while still providing employment and food for the global population. Consequently, the emissions estimates must be consistent and comparable over a range of nations.

As countries' GHG accounts and inventories do not conveniently break down their agricultural emissions in ways that easily allow the calculation of the emissions embodied in food imports and exports, other methods to disaggregate the emissions must be found. The production-based emission calculation can be rearranged to divide emissions by activity data to provide an implied emission factor (IPCC, 2006). The methodologies for measuring emissions activities as well as determining emission factors, however, remains unsettled due to opacity in the collection, reporting, and validation of data for different national and international agencies and organizations around the world (Guan et al., 2012). The FAO's trade numbers provide the activity data by breaking down countries' imports and exports into detailed annual accounts of different food products (FAOSTAT, 2015). The other element necessary along with the FAO's trade numbers, however are the emission factors – multipliers or coefficients, to show how the production of one ton of apples or 2000 head of cattle have generated a certain amount of carbon dioxide-equivalent (CO_2-e) emissions.

Crucial for the use of the FAO's trade numbers in this endeavour, which are verified for their coverage and comparability through a multi-layered quality assurance system, is that these CEFs are similarly comprehensive and consistent, as is described in the Good Practice Guidance for national emission inventories (IPCC, 2006). FAO data is collected and collated from national statistical agencies or other international organizations through forms and questionnaires. As with other international organizations like the International Monetary Fund or the Organization for Economic Co-operation and Development, the quality of the FAO's data is largely dependent on the quality of data collected by individual countries and organizations. Under the FAO's quality assurance framework, statistical outputs are assessed and validated on a regular basis, errors are measured and documented, methods for preventing and reducing errors are in place and implemented, and the revision policy is made publicly available. Additionally, a section of the FAO's quality assurance framework is dedicated to the