Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain

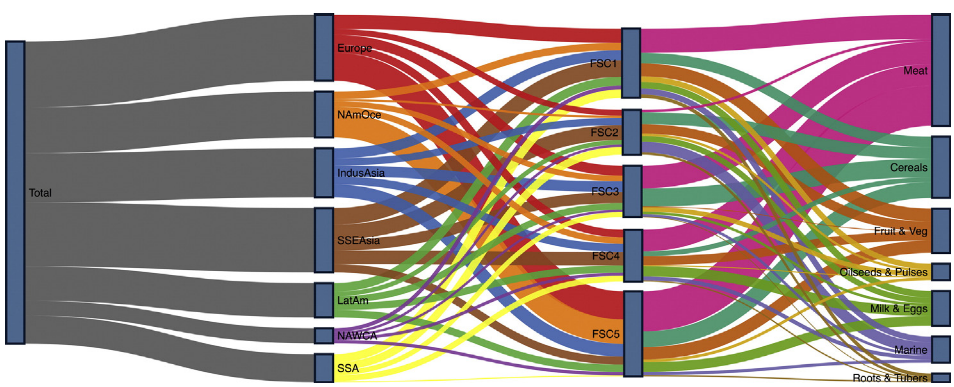
Stephen D. Porter [a,*], David S. Reay [a], Peter Higgins [b], Elizabeth Bomberg [c]

[a] School of GeoSciences, University of Edinburgh, Edinburgh EH8 9XP, UK
[b] Moray House School of Education, University of Edinburgh, Edinburgh EH8 9JX, UK
[c] School of Social & Political Science, University of Edinburgh, Edinburgh EH8 9LD, UK

HIGHLIGHTS

- The evolution of GHG emissions from food for human use that is lost or wasted is not well understood.
- Embedded GHG emissions from food supply chain losses are estimated for each of the past 50 years.
- GHG emissions from loss and waste in staple goods, such as cereals, is similar in magnitude as meat.
- Globally per capita food wastage is rising, but levelling/declining in developed regions.
- A growing population in developing regions is increasing food wastage and associated emissions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 June 2016
Received in revised form 30 June 2016
Accepted 6 July 2016
Available online xxxx

Dr. D. Barcelo

Keywords:
Food waste
GHG emissions
Climate change
Emission factor
Loss factor
Supply chain

ABSTRACT

Research on loss & waste of food meant for human consumption (FLW) and its environmental impact typically focuses on a single or small number of commodities in a specific location and point in time. However, it is unclear how trends in global FLW and potential for climate impact have evolved. Here, by utilising the Food and Agriculture Organization's food balance sheet data, we expand upon existing literature. Firstly, we provide a differentiated (by commodity, country and supply chain stage) bottom-up approach; secondly, we conduct a 50-year longitudinal analysis of global FLW and its production-phase greenhouse gas (GHG) emissions; and thirdly, we trace food wastage and its associated emissions through the entire food supply chain. Between 1961 and 2011 the annual amount of FLW by mass grew a factor of three – from 540 Mt to 1.6 Gt; associated production-phase (GHG) emissions more than tripled (from 680 Mt to 2.2 Gt CO_2e). A 44% increase in global average per capita FLW emissions was also identified – from 225 kg CO_2e in 1961 to 323 kg CO_2e in 2011. The regional weighting within this global average changing markedly over time; in 1961 developed countries accounted for 48% of FLW and less than a quarter (24%) in 2011. The largest increases in FLW-associated GHG emissions were from developing economies, specifically China and Latin America – primarily from increasing losses in fruit and vegetables. Over the period examined, cumulatively such emissions added almost 68 Gt CO_2e to the atmospheric GHG stock; an amount the rough equivalent of two years of emissions from all anthropogenic sources at present rates. Building

* Corresponding author.
E-mail address: Stephen.Porter@ed.ac.uk (S.D. Porter).

http://dx.doi.org/10.1016/j.scitotenv.2016.07.041

up from the most granular data available, this study highlights the growth in the climate burden of FLW emissions, and thus the need to improve efficiency in food supply chains to mitigate future emissions.

1. Introduction

Since at least the 1970s, reducing post-harvest losses of food was identified as an element integral to supporting a growing population, particularly in developing countries (Hall, 1970; Bourne, 1977; GAO, 1977). However, the issue of food wastage – food produced for human consumption that is ultimately not eaten – has of late become a topical issue, especially for governments who have appreciated the financial and climate change implications. For example, in the UK, the Department for Environment, Food & Rural Affairs' review of waste policies applicable in England included specific mention of the priority of dealing with food waste, in addition to those related to commercial refuse and industrial waste (Defra, 2011). They estimated food waste accounted for half of landfill GHG emissions – roughly 40% of such waste was directed to landfills at the time. However, this perspective only related to the consumer stage of the food supply chain (FSC). In contrast, the European Commission's proposed directive on waste (European Commission, 2015) directly recognised that FLW may occur at any stage of the FSC. As drafted, this directive will require Member States to implement and monitor preventive measures to reduce waste generation, though it is not yet in force.

The subject of this paper is identifying – using a whole-system approach – where FLW occurs and its associated production-phase only GHG emissions (in CO_2 equivalents – CO_2e). We aim to estimate the magnitude of GHG emissions arising from FLW across and within the whole of the global FSC from a bottom-up perspective. To do so, we focus on what we term the production-phase emissions – those emissions embedded in food due only to domestic agricultural practices. We acknowledge that additional emissions will arise through the FSC as food is stored, transported and processed, and how any final resulting waste is managed. However, as we explain in Methods section, these additional FLW-related emissions occurring 'beyond the farm-gate' have been omitted from our analysis.

The UN's most recent medium-variant estimate of the global human population in 2050 is 9.6bn (versus 7.2bn currently). This is an increase of 33% from 2013 estimated levels, almost all of which is projected to come from developing countries (UNDESA, 2015). Concurrent economic development should be expected, with the fastest growth rates from developing countries. Despite recent variations, World Bank Group (2016) forecasts of GDP growth to 2018 for high income countries will be less than half that of developing countries (1.6–2.1% versus 4.3–5.3% per annum, with rather higher rates projected for India and China, in the region of 7–8% pa).

As wealth increases, there is a tendency for diets to shift away from cereals to a diet more similar to that in developed nations, often containing higher levels of fats, sugars and animal products (Drewnowski, 2000; Pradhan et al., 2013). Whilst cereals provide about half of the global calorie supply, there can be large differences between developing and developed nations. For example, cereals provide up to 70% of calories in some African countries versus approximately 30% in the UK. Meat consumption in developing countries as a whole has quadrupled since 1963, and by almost a full order of magnitude in China (Kearney, 2010). Such a shift may be a cause of concern from a climate change perspective. The higher level of embedded GHG emissions per tonne of meat, versus other sources of nutrition (e.g. 19.4–39.1 t CO_2e t^{-1} beef versus 1.4–5.2 t CO_2e t^{-1} rice; Table 1) magnifies the climate change impact of food waste.

As a sector, agriculture contributes 10–12% of global annual GHG emissions. This is the equivalent of 5–5.8 Gt CO_2e y^{-1}, roughly 70% of which arise from how soils are managed and the raising of dairy and meat cattle (Smith et al., 2014). The combination of feeding an additional 2.4bn people by 2050, together with a shift to more emission-intensive diets, is likely to put further strain on the global climate via increased production-phase GHG emissions (Pradhan et al., 2013; Hallström et al., 2015). Given its magnitude, current estimates of FLW indicate this lost food is equivalent to that required to meet global demand in 2050 (FAO, 2013a). FLW therefore represents a prime target for addressing the challenges both of climate change and of food security.

The food supply chain (FSC; see Fig. 1) is a system that cuts across several sectors (i.e. agriculture, transport, industrial processes, retail, waste, land use) involving various stakeholders. The FSC is also transnational – to illustrate, the UK imports more than 50% of the food consumed domestically from many different countries (de Ruiter et al., 2016). These horizontal characteristics of the food industry complicate its examination and evaluation as a system from a top-down approach – one where emissions from seemingly distinct and separate economic industries are apportioned across a horizontal system. Our approach here is bottom-up; building up the picture of food loss and waste step-by-step from the most granular level available – food commodities by country. The chosen boundary for associated GHG emissions is the farm-gate (see Methods section for further details on the rationale). We are concerned with the embedded production-phase emissions from FLW – those from agricultural production – and attribute them to specific commodities, countries and FSC stages.

Studies into food supply chain losses have typically focused on a particular country or local region and a small subset of commodities over very short periods of time. Two of the earliest, Wenlock and Buss (1977) and Wenlock et al. (1980), examined losses at the UK household level (FSC5) and estimated wastage to be about 5% of food brought into the home. Some thirty-five years later, Quested et al. (2013) used a similar method of household surveys with the addition of weighing food waste from refuse, and estimated UK household food wastage to be in the region of 22%. In the U.S. Kantor et al. (1997) estimated wastage from the downstream part of the FSC (specifically, retailers, food service and consumers) to be about 27%, similar to the figure of 29% estimated a decade later by Buzby and Hyman (2012). However, as discussed below, only relatively recently have FSC inefficiencies been broadened beyond a commodity-country focus and framed in a climate change perspective.

Monier et al. (2010) explored FLW for the EU-27 in 2006 (the 27 member states of the EU at that time) from the farm-gate onwards, including end-of-life. Specifically excluding losses on the farm during production or harvest, they concluded that households and food manufacturing had the largest proportion of total losses (42% and 39%, respectively). Their estimate of total wastage of all food in that year (i.e. including that portion not usually consumed such as fruit and vegetable peelings and animal carcasses) at the EU-27 level was 89 Mt, or 179 kg per capita. Bräutigam et al. (2014), however, was unable to replicate these results. Using the approach of Gustavsson et al. (2011), they estimated per capita food wastage in the EU-27 to be 60% higher (288 kg).

The first study to quantify food loss and waste at a global scale, Gustavsson et al. (2011), did so for the year 2007 based upon data from the Food and Agriculture Organization of the United Nations (FAO) Food Balance Sheets (FBS). They concluded roughly one-third of food produced for human consumption (equivalent to 1.3 Gt y^{-1} globally) is lost or wasted at some point between the farm and the consumer. A follow-up technical paper applied GHG emission factors to these

Please cite this article as: Porter, S.D., et al., A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.07.041