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Avoidable food losses and associated production-phase greenhouse gas emissions arising from application of cosmetic standards to fresh fruit and vegetables in Europe and the UK

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ABSTRACT

The use of aesthetics for classifying and accepting fresh food for sale and consumption is built into food quality standards and regulations of the European Union. The food distribution sector in Europe and the UK is oligopolistic in nature; a small number of supermarket chains control a large market share. The influence of these 'multiples' enables them to impose additional proprietary 'quality' criteria. Produce that doesn't meet these standards may be lost from the food supply chain, never seeing a supermarket shelf – it may not get past the supplier, or even leave the farm. Here, for the first time, we estimate the quantity of food loss and waste of fresh fruit and vegetables arising from cosmetic standards in Europe and UK, and its associated greenhouse gas (GHG) emissions. We find few direct measurements of such losses, resulting in large uncertainties for key commodities. In the context of these uncertainties, we estimate avoidable FLW from on-farm cosmetic grade-outs of up to 4500 kt yr^{-1} in the UK and 51,500 kt yr^{-1} in the European Economic Area (EEA). Our estimates suggest over a third of total farm production is lost for aesthetic reasons, which equates to as much as 970 kt CO_2e (UK) and 22,500 kt CO_2e (EEA) of embedded production-phase GHG emissions annually. Examining the issue from the perspective of markets, suppliers, and consumers we establish there is an over-emphasis on superficial qualities (i.e. cosmetic appearance) of fresh produce, which leads to its unnecessary loss and waste. Using an illustrative case study, we provide potential avenues to mitigate these losses and the associated GHG emissions.

1. Introduction

Food loss and waste (FLW) is one of the great scourges of our time. In excess of 10% of global population is chronically hungry (FAO et al., 2017, p. 5), yet we lose or waste about a third of all food meant for human consumption at some point in the food supply chain (FSC) (Gustavsson et al., 2011). Producing food accounts for 10–12% of global greenhouse gas (GHG) emissions, primarily nitrous oxide (N_2O) from crop production and methane (CH_4) from meat and dairy production (Smith et al., 2014, pp. 822–824). Food waste alone may account for up to 16% of environmental impact of the agri-food chain (Scherhaufer et al., 2018). In addition to global food security and nutrition challenges, producing food that does not serve its purpose of feeding the populace has potentially avoidable climate-cost emissions embedded within it.

There are many drivers of FLW, from the technological to the social (Canali et al., 2016). Amongst them in the agricultural production phase are 'aesthetic imperfection' and 'overplanting' of produce (Parfitt et al., 2010; Teuber and Jensen, 2016, p. 34). These two drivers are linked – farmers must meet their contractual obligations to deliver specified tonnage of produce that meets particular standards (Beretta et al., 2013; Halloran et al., 2014). A proportion of yield is expected not to meet cosmetic criteria and thus may not easily be sold, and possibly not even harvested (Garrone et al., 2014). Cosmetic requirements are an important component of 'quality' standards for fresh fruit and vegetables (FFV) produced and sold in the global North – a greater number of prescribed elements apply to the appearance of FFV than to

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nutritional or food-safety characteristics (Porter et al., 2018). Produce deemed of too low a quality to enter the food supply chain may take several different non-food routes. It is typically ploughed back into fields, composted, landfilled, used as animal feed, or as anaerobic digestion feedstock (Beretta et al., 2013; Jeannequin et al., 2015; Redlingshöfer et al., 2017).

Reporting of on-farm FLW data by producers is not required by EU regulations – prior to harvest it is not considered to be food (European Parliament and Council, 2002, Art. 2). Discourse on food waste at the production stage has typically focused on accidental loss, such as from natural hazards and disease (Gille, 2012). In contrast, there is a dearth of studies quantifying avoidable food loss due to cosmetic standards and its embedded greenhouse gas emissions. Estimates at this life cycle stage are usually based upon a small number of studies carried out on just a few crops and applied to entire regions (Gustavsson et al., 2011), although others are more locally focused (Franke et al., 2016; Hartikainen et al., 2018). Some studies omit losses in the production phase entirely due to uncertainties (Monier et al., 2010). The few reported losses from failure to meet cosmetic criteria are wide and quite uncertain. The limited evidence of on-farm food losses due to aesthetics suggests upwards of 40% of harvested FFV produce can be lost from the food supply chain at this stage alone (Bloom, 2011, p. 96; Davis et al., 2011, p. 19; Stuart, 2009, p. 102). Recently, a more focused investigation in Germany and the Netherlands, utilising farmer self-assessed losses due to cosmetics, confirmed anecdotal evidence that wastage varies greatly by product, with 'typical' levels of about 20% (de Hooge et al., 2018).

Here, we extend the discourse by viewing food loss and its embedded GHG emissions through the lens of aesthetics. Cosmetics-centred 'quality' criteria derived from physical characteristics of attractiveness alone are imposed on many food producers by down-stream actors (such as regulators, retailers, and consumers). These criteria may stem from in-built consumer preferences, with other actors reacting in response (EU FUSIONS, 2014). Produce that is excluded from the food supply chain (FSC) through not meeting such aesthetic 'standards' can be regarded as avoidable waste. Likewise, greenhouse gas emissions associated with the production of this wasted food can be deemed avoidable, with changes in aesthetic classifications having the potential for emissions mitigation.

In the following, we provide what we believe to be the first estimation of production-phase embedded emissions of fresh fruit and vegetables lost from the food supply chain due to application of cosmetic standards. We then argue a complex and interactive system exists that encourages food waste and is perpetuated by all actors in the typical agri-food chain. As we will show, these actors include governments (via regulations of minimum 'quality standards'), supermarket multiples (via the power to impose private voluntary standards), and consumers (via learned expectations). Finally, we supplement this analysis and argument with a case study of an atypical farming operation within the Central Belt of Scotland to illustrate potential pathways to prevent cosmetic standard-driven FLW.

2. Estimations of EEA and UK grade-out losses and embedded emissions

2.1. Methods

The geographic areas of focus are the European Economic Area (EEA) and the UK. The EEA is comprised of the EU Member States as well as Iceland, Norway, and Switzerland. These three countries are all members of the EU's 'single market', and are thus bound by the same regulations on food produce as EU Member States. Only EEA and UK FFV crops with at least one published on-farm cosmetic grade-out loss factor (*LF*) and corresponding cradle-to-farm-gate emission factor (*EF*) are included in this analysis. The factors are taken from the underlying sources referred to by Porter et al. (2016), plus additional, more recent, sources from peer-reviewed literature and reputable grey-literature sources. The keywords "carbon footprint" and "life cycle analysis" together with "UK" and "Europe" were used to search the Scopus, ScienceDirect and Web of Science databases for peer-reviewed emissions factors published since 2016. Citation tracking was subsequently used to identify potential grey literature using the same filtering criteria. In addition, the official French database of agriculture emissions, ADEME (2017), was included. The resulting literature was further filtered to include only those with emissions factor data in CO_2 for the production stage, or had sufficient detail included to make this conversion, for fresh fruit and vegetables. Full details of sources and values for both *LF* and *EF* variables are contained within Supplementary Information Tables 1 and 2

The estimates we used for regional EEA on-farm grade-out FFV loss factors (*LF*s) and their production-phase embedded emission factors (*EF*s) are crop-specific from any EEA country. In the UK, all but two crops have a country-specific *LF*; for pears and cabbages, the respective EEA factors are used as proxies. *LF*s may be reported as a range or as a single estimate; *EF*s are typically reported as a single point estimate. The absolute minimum and maximum estimates are identified for each crop's *LF* and *EF* for the EEA and also within the UK sub-set. We also make a central estimate of the *LF* for each crop by averaging the mid-points of ranges and the single estimates. Alternatively, the central estimate of the *EF*s is an average of all reported estimates for each crop within the EEA as a whole and also for the UK specifically. We present these as 'min', 'max', and 'central' in Section 2.2. Data for FFV production for the year 2016 was sourced from the eurostat (n.d.) database. Non-food use data was obtained from the United Nation's Food and Agriculture Organisation's (FAO) Food Balance Sheet database (FAOSTAT, n.d.); see Table 1.

We estimate the mass of on-farm cosmetic grade-out losses with the model shown in Eq (1). We use the Eurostat database for FFV crop production in the EEA as a whole and the UK specifically. Most FFV crops have a single entry for *Harvested Production*; this value is used. However, tomatoes, apples, and pears, have two entries for *Harvested Production*. For these three crops, we use the quantity indicated as 'for fresh consumption' in the Eurostat database; cosmetic criteria are not applied to that proportion of these crops intended 'for processing' from the outset. FFV graded-out on-farm does not enter the food chain and therefore is not included in *Harvested Production* data (Redlingshöfer et al., 2017). We adjust for this in the denominator term of Eq (1).

$$Loss_s = \sum \left(\frac{Harvested\ Production_{j,k} * AF_{j,k} * LF_{j,k,s}}{1 - LF_{j,k,s}} \right) \tag{1}$$

Where: *Loss* is the total food loss in scenario *s* from on-farm cosmetic grade-outs (in kt); *Harvested Production* is the mass (in kt) of food crop *j* in country *k*, (where *k* is either the UK or EEA); *AF* is the allocation factor of crop *j* in region *k* (Eq (2)); *LF* is the loss factor (in %) for crop *j*, in country *k*, under scenario *s* (minimum, maximum, average).

Some portion of a crop may be intended for seed or other use, but not recorded in Eurostat as such. To adjust for the non-food uses, we create a weighted-average allocation factor (*AF*) for each FFV crop. We use annual FAO data for the most recent five-year period available (2009–2013), as shown in Eq (2). The only FFV crop affected is potatoes – where the *AF* is calculated as 0.86 for the