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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 4,500 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.

HIGHLIGHTS (3-5 bullets, max 85 characters per bullet)

- Application of cosmetic standards has resulted in substantial avoidable food losses
- Many actors across the agri-food chain enforce these standards upon farmers
- The embedded emissions of lost sub-optimal food in the EEA is as much as 22.5 Mt CO_2e yr^{-1}
- Quantity of avoidable on-farm losses remains uncertain due to a lack of coverage
- We propose several avenues to mitigate on-farm food loss and its embedded emissions

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KEYWORDS (up to 6)

climate change mitigation; food supply chain; cosmetic standards; fresh fruit and vegetables; embedded emissions; food loss and waste

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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) – a greater number of prescribed elements apply to the appearance of FFV than to 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 Organization'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.

Eq 1

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

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 EEA and 0.88 for the UK. That is, 14% and 12% of the respective recorded harvests for the EEA and UK is not intended for human consumption and thus do not have cosmetic standards applied to them.

Eq 2

$$AF_k = 1 - \left(\frac{Seed_k + Other\ Uses_k}{Production_k} \right)$$

Where, for crop *j* in region *k* (the EEA or UK) for the period 2009-2013: *AF* is proportion of the FFV crop not intended for consumption by humans; *Production* is the amount of crop (in kt); *Seed* is the amount directly used to propagate a future harvest (in kt); and *Other Uses* is the amount intended for any other non-food purposes (in kt).

Finally, we estimate the production-phase embedded emissions (*Em*) using the 'minimum, 'maximum', and 'average' peer-reviewed crop and region-specific cradle-to-farm-gate emission factors (*EFs*) detailed previously. These factors are applied to the three grade-out *Loss* estimates ('minimum, 'maximum', and 'average') from Eq 1 for each FFV crop in the EEA and UK (Eq 3). The result is a 3x3 scenario matrix of total EEA and UK, and specific FFV crop *Em* estimates.

Eq 3

$$Em_{j,k,s} = \sum Loss_{j,k,s} * EF_{j,k,s}$$

Where: Em is the quantity (in kt CO_2e) of GHG emissions of crop j in country k for scenario s; $Loss$ (in kt) is food loss for crop j in region k from Eq 1, and; EF is the emission factor (in kt CO_2e kt^{-1}) for crop j in country k for scenario s. Summary data is provided in Table 1.

Table 1. Summary of data used to estimate range of on-farm cosmetic grade-outs of FFV. *Harvested Production* for potatoes is adjusted for its allocation factor from Eq 2. Fully referenced tables for Loss Factors and Emissions Factors are provided in Supplementary Information (Tables SI1 and SI2).

		Harvested Production (kt)	Loss Factor (%)			Emissions Factor (kt CO_2e kt^{-1})		
Crop	Region		Min	Central	Max	Min	Central	Max
Apple	UK	208	5	15	25	0.11	0.21	0.32
	Europe	9,309	1	10	25	0.03	0.17	0.43
Broccoli + Cauliflower	UK	152	3	12	20	0.29	1.12	1.94
	Europe	2,341	3	12	20	0.29	1.26	2.22
Cabbage	UK	231	8	22	40	0.22	0.22	0.22
	Europe	3,821	8	22	40	0.22	0.35	0.48
Carrot	UK	724	24	31	50	0.05	0.20	0.35
	Europe	5,663	10	23	50	0.02	0.17	0.50
Lettuce	UK	107	5	26	50	1.00	1.39	1.78
	Europe	2,285	5	24	50	0.26	1.01	1.78
Onion	UK	390	9	15	20	0.07	0.22	0.37
	Europe	6,623	8	17	33	0.04	0.23	0.48
Pear	UK	24	10	11	12	0.32	0.32	0.32
	Europe	2,231	10	11	12	0.20	0.32	0.43
Potato	UK	4,888	3	19	40	0.17	0.22	0.26
	Europe	48,729	3	14	40	0.09	0.19	0.51
Strawberry	UK	118	1	12	35	0.80	0.94	1.27
	Europe	1,311	1	10	35	0.30	0.78	1.27
Tomato	UK	97	7	7	7	2.07	4.34	9.40
	Europe	6,969	1	3	7	0.11	1.59	9.40

2.2 Results

2.2.1 Cosmetic losses

The Eurostat-recorded harvest quantity for FFV in the EEA and UK in 2016 is 89,300 kt and 6900 kt, respectively. Estimated on-farm grade-out losses of FFV in the EEA range from 3700 kt to 51,500 kt and from 470 kt to 4500 kt for the UK in 2016 (see Supplementary Information). Thus, the range of losses for cosmetic reasons is 4 – 58% and 7 – 65% of recorded *Harvested Production* in the EEA and UK, with an 'central' estimate of 17% and 25%. As indicated in Section 2.1, *Harvested Production* from the

Eurostat database does not include grade-out losses. Adding the losses back gives total actual FFV farm production intended for human consumption of 93,000 – 141,000 kt for the EEA, and 7400 – 11,500 kt for the UK. The estimated range of on-farm cosmetic grade-out losses relative to total farm production in the EEA and UK is 4 – 37% and 6 – 39%, respectively, with a 'central' value of 14% for the EEA and 20% for the UK.

In the UK, cosmetic grade-out losses are dominated by potatoes and carrots (Figure 1a). This is a function of their importance as an agricultural crop – potatoes were 70% of the UK FFV harvest by mass in 2016, whilst carrots were 10%. They also have higher minimum, maximum, and central cosmetic grade-out *LF*s relative to other crops. Together, these two crops account for 81 – 88% of grade-out losses by mass. This is equivalent to 380 – 4000 kt of losses, with a 'central' value of 1500 kt. Onions and cabbage, the third and fourth most important crop group for UK farming (just under 10% combined total), deliver just 6 – 13% of grade-out losses (250 – 880 kt, 'central' estimate of 390 kt).

Total grade-out losses for FFV within the EEA are estimated to range from 3700 kt to 51,500 kt. Similar to the UK, potatoes dominate cosmetic-related losses in the EEA, accounting for 41 – 63% of all grade-outs by mass (1500 – 32,500 kt, 'central' estimate of 7900 kt) from 55% of recorded production volume. Carrots, onions, and brassicas, are key hotspots of grade-out losses in the remaining 45% of the harvest (Figure 1b). Together, these latter three crop groups account for FFV losses of 1600 kt – 12,100 kt ('central' value of 4400 kt), equivalent to 23 – 44% of EEA on-farm grade-out losses. (See Supplementary Information for details.)

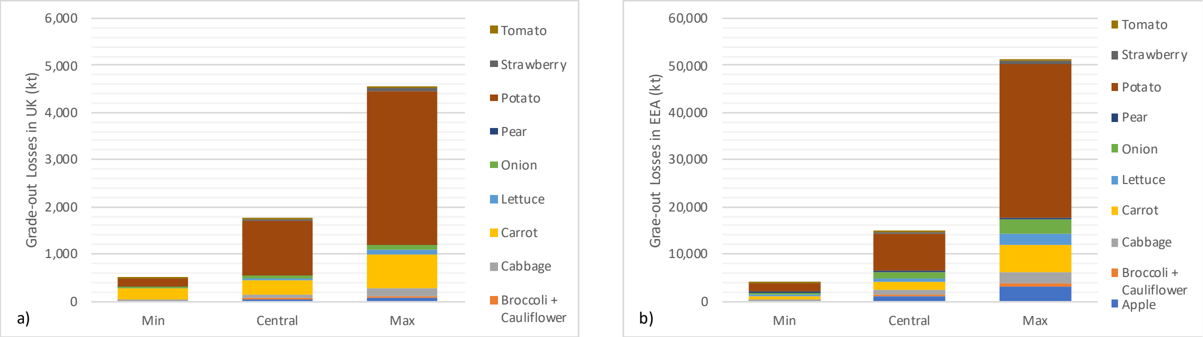

Figure 1. Grade-out losses (in kt) in 2016 in; a) the UK, and b) the EEA of the different FFV crops, applying the minimum, maximum, and 'central' *LF* estimates to recorded *Harvested Production* in Table 1 (i.e. the output of Eq 1).

2.2.2 Embedded emissions of cosmetic losses

Applying three *EF* values (minimum, maximum, and 'central' estimates) for each *Loss* scenario generates nine 'scenarios' of embedded production-phase GHG emissions. The absolute and proportional emissions of three scenarios for FFV in the UK and EEA are shown in Figure 2. They are the output of Eq 3 using the Min-Min, Central-Central, and Max-Max combination of *Loss* from Eq 1and *EF* values from Table 1. Relative importance of crops and their production-phase emissions is evident when comparing the UK with the EEA at large. Total embedded production-phase GHG emissions of food loss due to cosmetic criteria in the UK range from about 60 kt CO_2e in a 'minimum' scenario to 970 kt CO_2e in a 'maximum' scenario, with a 'central' estimate of 380 kt CO_2e. At the EEA level, total production-phase embedded GHG emissions range from about 340 kt CO_2e to almost

22,500 kt CO_2e, with an 'central' estimate of about 3600 kt CO_2e (details of all scenarios are in Table SI 4). To put these latter figures in context, they are up to roughly 5% of the 426,000 kt CO_2e of GHG emissions attributed to the European agriculture sector in 2015 (Eurostat, 2017).

In the UK, the highest levels of embedded emissions from grade-out losses are from potatoes, carrots, and brassicas; together they account for 55 – 77% of the total. Potatoes have a relatively narrow range of UK-specific *EF* estimates (0.17 – 0.26 t CO_2e t^{-1}), typically at or near the lowest factor value for FFV crops. Even so, because of the high production volume and grade-out losses of potatoes, this crop is apportioned the highest level of embedded emissions. Our estimates of these emissions for the UK potato crop range from 25 to 510 kt CO_2e, with a central estimate of 200 kt CO_2e (or 19 – 67% of the total for the UK). Embedded emissions in grade-out losses of carrots and brassicas range from 14 – 210 kt CO_2e, or 10 – 36% of the UK total. The range of absolute and proportionate emissions of carrots and brassicas reflects the higher level of uncertainty in the *EF* literature of these crops relative to others, particularly potatoes.

Trends at the EEA region level are similar to those for the UK specifically. Potatoes are also the most important in terms of magnitude of embedded GHG emissions in all nine scenarios for the EEA. This one crop accounts for roughly one- to two-thirds of these emissions (or, 130 – 9900 kt CO_2e) with a 'central' scenario estimate of 36% (1300 kt CO_2e). Brassicas and root vegetables (carrots and onions) together account for 19 – 35% of embedded emissions ('central' of 30%), or 120 – 4200 kt CO_2e ('central' estimate of 1100 kt CO_2e; see Supplementary Information for detailed breakdown by FFV crop).

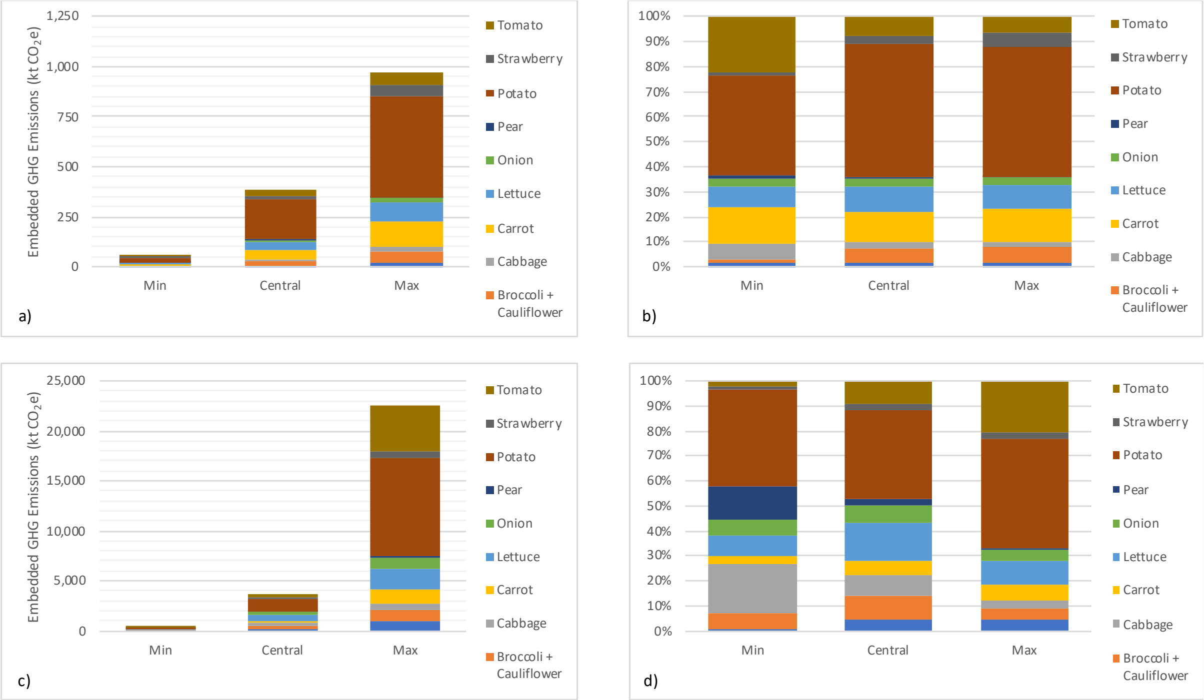

Figure 2. Production-phase embedded GHG emissions of grade-out losses by FFV (in kt CO_2e) and as a proportion of total FFV by scenario for the UK (a, b) and the EEA (c, d). The three scenarios correspond to application of the Minimum, Central, and Maximum estimates of both the *LF* and *EF* variables from Table 2 (i.e. the Min scenario represents Min *LF* and Min *EF*). Details of all nine scenarios examined are contained within Table SI 4.

2.2.3 Limitations

There is considerable uncertainty in these results, demonstrated by the range of our estimates for absolute FFV losses at farm-level and their respective embedded emissions. We have assumed that studies on these loss factors conducted on a particular crop in one country within the EEA are relevant to the same crop in another country. There is a very limited amount of data currently available on FFV loss factors at farm level. A further significant assumption in our results is that all grade-out food losses have left the agri-food chain for destinations such as composting or ploughing-in and are therefore considered waste whose embedded emissions should be accounted for. There is no discernible consensus on what proportion of cosmetic losses of FFV would have another food-related use (such as animal feed, or used in further food processing). Porter et al. (2018) reports that within the EU under the current Common Agriculture Policy, approximately two-thirds of safe, edible FFV withdrawn from market after harvest is destroyed. de Hooge et al. (2018) states ploughing in, animal feed, and anaerobic digestion were the most common destinations, and that few of their interviewees mentioned selling a lower class product was a viable option. Redlingshöfer et al. (2017) indicates reuse plays a moderate role, but estimates an destruction rate greater than 80% for even the crop most commonly redirected to animal feed (i.e. potatoes). Terry et al. (2013, 2011) indicate the destination of grade-outs depends heavily on the crop, with ploughing-in the common destination for lettuce, tomato, and strawberry, whereas potato typically goes to animal feed or compost. Jeannequin et al. (2015) and Meyer et al. (2017) argue that field-graded produce, whether picked by hand or mechanised, is simply ploughed-in, but post-harvest graded produce is more likely to be redirected to another food use.

Embedded emissions calculations rely estimates of UK- and Europe-specific emissions factors for fruit and vegetable published between 2000 and 2018. Coverage of food commodities in this literature was variable and sometimes seemingly dated (the oldest source is from 2006). For example, UK cabbage and pear have one *EF* estimate each (from 2009) whereas there are more than a dozen from 1998-2018 for EEA tomatoes (see Table SI 2). A review of the LCA literature by Clune et al., (2017) highlighted the considerable variability in such estimates across food group and showed activity in this area dropping considerably by 2015 relative to the seven years prior. This is consistent with the results of our own literature review – little data, and with considerable variation. It also demonstrates continued, more localised research on greenhouse gas emissions of food across its full life cycle is warranted by the wider community.

3. An over-emphasis on superficial qualities (i.e. cosmetic appearance) of fresh produce

In the following we present arguments for why FFV loss and waste from aesthetic standards – as estimated in the previous section – may occur.

3.1 Waste encouraged by current marketing standards & regulations

Food safety and food quality are treated separately within EU Regulations, with safety paramount. Article 14(1) of the General Requirements of Food Law states “food shall not be placed on the market if it is unsafe” (European Parliament and Council, 2002). However, it may be that food safety laws are overly strict, thus creating unnecessary inefficiency in the food supply chain (Aschemann-Witzel, 2016). As a result, only fresh produce that is deemed safe for human consumption is subject to 'quality' standards. Fresh produce has natural variability in terms of size, colour, and shape; cosmetic appearance is not uniform. The EU's Common Market Organisation (CMO) regulations specify particular requirements for different types of fresh produce to grade them (in ascending order) as Class II, Class I, or Extra Class (European Commission, 2011, Annex I, Part B). EU Member States may permit unclassed fresh produce to be sold in retail outlets provided it is clearly labelled as 'for home processing' or similar (Defra, 2017). This regulation implies fresh produce that does not meet arbitrary cosmetic requirements is not fit for consumption in its natural form.

These EU-level marketing standards codify a common set of minimum acceptable criteria across EU Member States which, together with the EU CAP reforms of 2013, are intended to improve the competitiveness of international trade of agricultural produce of those States (DG-AGRI, 2013). For example, it is easier to pack and ship produce of standard, versus varying, proportions. The relative efficiency of the stages between the farm-gate and the consumer would appear to support this preference. Loss rates for fruit and vegetables in Europe at the handling and storage, processing, and distribution stages range from 2-7%, between a tenth and a third of the 20% estimated pre-farm-gate loss rate (Porter et al. 2016, Table SI 1).

3.2 Waste currently endorsed (and 'gold-plated') by retailers

The evidence that sub-optimal ('imperfect'/'ugly') produce won't sell is inconclusive. De Hooge et al. (2017) provides support for the claim. Their choice modelling survey reported a clear preference to 'optimal' foods whether in the home or supermarket. Much variability remains unexplained, but that 'beauty is good' seemed to apply to foodstuffs. At least in an artificial, online environment a price discount was required to equalise optimal and sub-optimal choice preference. In contrast, Aschemann-Witzel et al. (2017) states that 'quality' is linked primarily to characteristics such as taste, nutritional quality, and food safety. As we stated in Section 3.1, EU CMO marketing standards only specifically consider the latter. Whilst urban consumers in developing and developed countries (i.e. China and Denmark) may share a preference for 'perfect' produce (Loebnitz et al., 2015; Loebnitz and Grunert, 2015), only 'extremely abnormal' cosmetic appearance affects willingness to purchase in the former (Loebnitz et al., 2015). Within developed countries, a pro-environmental self-identity may also positively influence willingness to purchase 'wonky' veg (Loebnitz et al., 2015). The range of these findings suggests beliefs of what consumers will accept is too narrow, resulting in unnecessary food loss at the production phase by prohibiting 'ugly' produce from entering food supply chain.

The application of retailer's private standards at the farm level influences production and distribution practices. Selective harvesting is an integral component of fresh fruit and vegetable production, with pickers trained to take only the produce that will meet retailer's standards for sale (Gunders, 2012, p. 8). Potential edible-quality yield may be greater than that actually harvested, but the extra costs from picking fruit that doesn't meet expected aesthetic standards and will thus be rejected at the next stage in the agri-food chain would drive down economic yield. For the proportion that would not meet standards and thus be left in the field, creative marketing/processing/distribution of such produce could reduce avoidable on-farm loss, potentially increasing farm income and food availability (Stuart, 2009, p. 102). For example, processing 'misshapen' carrots into 'baby' carrots can eliminate virtually all food waste associated with this vegetable (Peterson, 2008). Additionally, some charities and volunteer organisations, such as the St. Andrews Society in the U.S. and Feedback in Europe, engage with the farming community to collect produce that would be rejected by supermarkets for re-distribution (Feedback, 2018; SoSA, 2018). The prices obtained, and thus economic margins, of such out-graded produce may be lower than that of the highest classification (Roels and van Gijseghem, 2017), but provided they at least cover the cost of harvest, then it is worthwhile for the farmer to do so. If not, then the rational economic decision is to 'walk-by' such produce – leave it in the field and plough it under as preparation for the next cycle.

It is not in the farmer's interest to have 'quality' standards based upon appearance that results in produce not being harvested and sold if such produce is safe to eat. Such standards differentiate produce of the same variety, with higher classifications achieving a higher selling price in normal conditions, but can result in substantial levels of on-farm loss pre- and post-harvest (Garnett, 2006, p. 63). Gunders (2012, p. 8) provides several individual examples of losses for different produce (cucumbers, citrus, tomatoes, stone fruit) regularly reaching or exceeding 50% in a season.

Labelling of fresh produce is another manifestation of private standards and the demonstrates the power of supermarkets in defining a message. The use of devices that permit a 'flexible best-before date' have been successful in reducing loss between processor and distributor (Dobon et al., 2011). However, consumers commonly misinterpret 'quality' labels, such as "best before" and "sell-by", as indicative of safety, leading to avoidable waste as food is discarded whilst still safely edible (Lebersorger and Schneider, 2014). Dynamic pricing – reducing the price of produce approaching it's 'best before' – can increase purchase activity by the consumer and reduce supermarket waste (Aschemann-Witzel et al., 2016). The potential downside to such a marketing strategy is increased food waste by households if consumption patterns are not adjusted (Brook Lyndhurst and WRAP, 2012). Better 'food knowledge' on behalf of the consumer – knowledge that is built up over time through exposure to food and its uses (which is being lost in developed countries as we are ever more removed from the food chain) – could result in greater acceptability of a greater range of cosmetic appearance.

3.3 Waste perpetuated by the structural power of large supermarkets

The food supply chain in many EU countries has undergone such consolidation that it can be considered an oligopoly. For example, at the end of 2017, the five largest chain food retailers ('multiples') had over 75% of the market share in each of the UK, France, and Ireland (KANTAR WorldPanel, 2018). This concentration is a marked change from the early post-WWII years, where multiples in the UK had a market share of 30% (Harvey, 2007, p. 55). Whilst the number of institutional buyers has fallen through this consolidation, the supply-side of the relationship has not undergone a similar transformation. The relative imbalance in scarcity – there is far more competition for sellers – leads to greater power being held by the retailers as buyers (Cox and Chicksand, 2007, p. 83).

In addition to horizontal market consolidation of food retailing, some multiples have also consolidated vertically, taking a controlling interest in upstream production (Simons and Skydmore, 2017). Supermarkets exert their buyer power by imposing 'voluntary private standards' of cosmetic specifications for fresh produce (Henson & Humphrey, 2010). The power exerted by the structure of the market – many suppliers for few retailers – acts as extra-governmental regulatory reach by the supermarket multiples. Private rules may be used to enhance or maintain a retailer's reputation as well as managing suppliers (Fulponi, 2006). They are codified within business relationships of the more powerful party and often form part of contractual terms and conditions (Rindt and Mouzas, 2015). This power structure limits producers' ability to influence the imposition of 'quality standards' (Gille, 2012). Such standards lead to avoidable food loss at the farm-level (Devin and Richards, 2016).

The oligopolistic nature of many developed countries' agri-food chains effectively make supplier compliance of 'private' standards mandatory (Davey and Richards, 2013). The more asymmetric the relationship between multiples and their suppliers, the more likely the dominant party will be able to exercise power over the weaker. Within the agri-food chain, this has manifested itself in the proliferation of 'private standards' by the supermarkets (Rindt and Mouzas, 2015). These private rules 'normalise' and auto-reinforce what is otherwise an imbalanced relationship, shifting risk onto the weaker party (i.e. the supplier) via an 'intervention-enforcement-sanctioning' feedback loop (Rindt and Mouzas, 2015). The consolidation of supermarket multiples within the agri-food chain has led to a virtual vertical integration with fewer suppliers and a strengthening of power of those multiples (Hingley, 2005). By coming together as a cohesive group acting in concert (promoted as 'producer organisations' by the EU in recognition of supplier-retailer imbalance as a potential driver of food waste (European Court Auditors, 2016, p. 52); suppliers could shift the power relationship towards a balance with retailers (Maglaras et al., 2015).

3.4 Waste perpetuated by the consumer's learned experience

What produce should 'typically' look like guides purchase intentions – consumers are more likely to purchase something that is familiar and recognisable (Gigerenzer and Gaissmaier, 2011). Consumers use simple learned heuristics of visual appearance to make food selection rather than the time-consuming process of comparing large amounts of data (Schulte-Mecklenbeck et al., 2013). Consumers' lack of experience of abnormally shaped food leads them to view such produce as more risky and less natural than produce that conforms to supermarket standards (Loebnitz and Grunert, 2018). Although moderate differentiation/incongruity of produce may increase the attention paid to that product by a consumer (e.g. a new variety of familiar produce), there is a counteracting social risk of being linked with food whose appearance is atypical (Campbell and Goodstein, 2001). Visual perception and setting influences consumers' expectation of taste experience; they are less willing to purchase cosmetically 'sub-optimal' fruit than consume it in the home (Symmank et al., 2018). Consumers appear to apply a 'beauty mystique' – a sociological concept to judgement where goodness is beauty and beauty is goodness (Synnott, 1989) – to fresh produce. Being exposed to broader parameters of 'normal' during the learning phase could lead to an acceptance of 'sub-optimal' food.

Heuristics are well-entrenched, though may interact with each other. Knowledge of origins of food (e.g. organic or not) and acceptance of abnormally-shaped food may be inversely related (Loebnitz and Grunert, 2018). The 'blender effect' of Szocs and Lefebvre (2016) – greater 'processing' is required in the home to achieve acceptable palatability - may reduce likelihood of purchase. Labelling of visually sub-optimal produce that reinforces its taste may have more influence on the purchase decision of 'ugly' food than price discounts relative to optimal produce (Helmert et al., 2017). Loss aversion – e.g. avoiding throwing away 'good money' by binning uneaten produce – is a powerful modifier of behaviour (Moseley and Stoker, 2013). Unintentional or unconscious decisions may result in actions by consumer waste activity not otherwise aligned with their attitudes, referred to as the 'squander sequence' by Block et al. (2016). Wasteful behaviour or attitudes may not be universally held, even within a given culture. Over 65s in the UK exhibit behaviours that typically lead to less food waste relative to younger consumers. For the last generation to have experienced government food rationing 'wastefulness' in general is 'just wrong' (Quested et al., 2013). Consumers are key to sustainable food choices, and those choices can influence upstream efficiency, leading to more or less food loss and waste along the food supply chain.

4. Learning opportunities case study

In this section, we use a case study as a small-scale illustration of what may be possible, in a UK context, to address food loss and waste of 'ugly' produce from the endemic drivers discussed in Section 3 previously. Specifically, we are concerned with avoidable food loss at the farm-level as a function of aesthetics, a key aspect of quality within the food industry and regulatory bodies. Care was taken in choosing a case atypical to the *status quo* UK agri-food supply chain. Conclusions drawn may not be generalisable to other fresh produce or farming operations, particularly for farms and distribution that are much larger in scale and with more complex supply chains. As a single case study, it should be viewed as explorative rather than definitive; a potential precursor to inform larger scale investigations. However, whilst the case's operations may not be fully applicable to industrial food producers, removing the real or perceived need to abide by cosmetic standards unrelated to food safety could see significant cuts to food losses. This section is intended to spark discussion and review of policy, custom, and behaviour to improve efficiency across the food system.

4.1 Illustrative atypical case study: Description of case and data collection methods

A medium-sized farm (c. 500 acres) in the Central Belt of Scotland was selected as the case study, with strawberry production as the unit of interest. The farm has been run under a perpetual lease by the same family for three generations, with the current generation in place for over 15 years. The farm uses standard production techniques for Scotland, such as raised coir-beds within covered poly-tunnels. This protects the crop, increases the length of the growing season, and eases the effort to harvest.

The case-study farm's changes to its business model allows an examination of each of the four drivers cosmetics-related loss identified in the previous section. Losses from other food supply stages inherent in more complex supply chains – specifically storage, handling, process, and transport to distribution centres – are excluded here for comparability. The farm had previously operated within a typical environment of supplying to supermarket multiples. Dissatisfaction on multiple levels led the owner to completely change to an atypical model. For the past 10 years, the food supply chain of this case study is the shortest possible – direct from farmer to final consumer. There are no other agents in the chain (i.e. no packers, distributors, retail supermarket multiples, or other 'middlemen'). The farm thus has complete control over what it sells to consumers, and when, including the level of grade-outs due solely to aesthetic reasons.

A mix of qualitative and quantitative data collection methods were employed. These included extensive interviews conducted over several months with the farm's owner and general manager, and direct measurements of produce. As part of the case-study, we sought to generate a rough estimate of avoidable aesthetics-related losses in UK-wide strawberry production and their embedded production-phase GHG emissions (Eq 4). We use the term 'avoidable loss' as there are no health-based reasons for the fruit to not enter the supply chain; it remains safely edible. Supermarket multiples in the UK are now selling some proportion of non-Class I (i.e. 'sub-optimal') fruit and vegetables as 'ugly', 'imperfect', or 'wonky' – a relatively recent occurrence within the UK. This is taken into account in our estimates of avoidable loss in Table 2 as the variable $Suboptimal_{Supermarket}$. Based upon our interviews, the typical supply chain has no other economic use for out-graded fruit (i.e. that proportion of fruit not meeting Class I criteria); it is composted on-site by the producer, thereby being lost to the FSC.

The percentage of $Suboptimal_{Farm}$ fruit was estimated from strawberry produce offered for sale at the case-study farm. On six days over the course of a 15-day period in the latter half of June 2017 (peak season), we collected a random sample of 10% of punnets for sale in the farm shop. Under the guidance of the farm owner, we applied EU quality standards to categorise each berry in the sampled punnets into Class I and non-Class I, which we then weighed separately. As a proxy for variable $Suboptimal_{Supermarket}$, we took direct measurements of shelf linear feet allocated to Class I and Class II strawberries by a national supermarket chain on the same days as we collected the farm samples. $Harvest_{total}$ is the five-year average of the UK strawberry harvest for 2012-16 (Defra, 2016). Finally, we applied the UK-specific EF for strawberries from Table 1 to estimate embedded production-phase GHG emissions of the avoidable loss ($Em_{Avoidable}$).

Eq 4

$$Em_{Avoidable} = \left(\left(Suboptimal_{Farm} - Suboptimal_{Supermarket}\right) * Harvest_{total}\right) * EF$$

4.2 Overcoming waste encouraged by market standards/regulations

The case-study farming business uses a more holistic definition of quality than EU marketing standards or retail multiples whilst retaining a quality-control/quality-assurance effort. By selling direct to consumers, the specific EU-level marketing standards on the appearance of the fruit for grading into official Classes needn't be applied. Therefore, the farm shop has greater flexibility to decide what is suitable for sale to its customers. However, interviews with the farm owner and manager indicate that those fruit selected for the farm shop are the best quality available on the plants each day.

> *"Would you be happy paying for and eating that strawberry yourself? We don't mind if there's some misshapen fruit that goes in there or anything like that. Basically, if you're happy to eat it yourself then it's a Class I fruit for us." (Owner)*

Fruit for the farm shop is sold at a price premium relative to supermarkets as 'picked fresh' yet avoidable waste on the case study farm is practically zero. This is due to flexibility in decisions of what fruit is sold and how, by not being beholden to EU classifications. The case study farm has invested in infrastructure such as an industrial kitchen and farm café to be able to use what fresh produce is left unsold at the end of the day in the farm shop. It is processed on-site into other products, such as jams, or otherwise used in the café. Fruit that is unsafe for consumption – the unavoidable losses – is composted on-site. This proportion was estimated by the farm owner at less than 1% of annual harvest yield, though is not systematically recorded.

4.3 Avoiding waste encouraged by retailers' cosmetic standards

The case-study farm is both producer and retailer – produce grown on site is sold only on site. The have full control over what and how produce is presented to customers of the farm shop, which differs from EU or the more strict supermarket classification standards. For example, whilst colouration is an aspect of visual appearance taken into consideration during the selection decision of fruit for the farm shop, size and shape are not. This approach is in direct contrast to industry 'quality' standards.

> *"Our spec, it's very loose. It's very rare that I go in and reject any fruit. The basic requirement is that it's picked that day, and that it looks appealing to eat". (Owner)*

The mean proportion of 'ugly', or non-Class I, fruit from farm shop punnet samples was 19%, with a median of 23%, and ranged from 0 to 27%, dependent upon sample. There was one outlier with a measure of zero non-Class I fruit. If this single data-point were excluded – it is more than two standard deviations from the nearest – the minimum proportion of 'uglies' rises to 14%, the mean matches the median at 23%, and standard error contracts to 1.9% from 3.8%. The average proportion of retail space allocated to non-Class I strawberries in the supermarket sample was 12%, just over half the proportion measured from the case study farm (Table 2). This suggests actual FLW at farms supplying the large retail multiples may be about 10%, similar to the value in Table 2 of 12%.

Annual UK strawberry production in the five years to 2016 averaged 102,000 t (Defra, 2016), of which roughly a quarter (25,300 t) was produced in Scotland (Scottish Government, 2017). Scaling up the difference in non-Class I fruit sold via supermarkets and that produced by our case study farm to the whole of the UK, we estimate approximately 10,000 t of strawberries may be lost from the FSC due to aesthetic standards. This estimated loss has the equivalent of 8000 t CO_2e of embedded emissions. It must be noted that these estimates are very preliminary, and are presented as only potentially indicative of the avoidable loss due to cosmetics. Broader and deeper investigation of the full supply chain for strawberries and other produce in the UK is needed.

	Sub-optimal Fruit (%)	
	Case-study Farm	Supermarket
Mean	23	12
Median	23	10
Standard Error	1.9	3.4
Maximum	27	24
Minimum	14	6

Table 2. Proportion of 'ugly' fruit sold through different distribution channels. The case-study farm values in this table exclude a single outlier of 0%. Including that data point into the set reduces the mean to 19% and increases the standard error to 3.8%. There were no outliers in the supermarket data.

4.4 Reducing waste encouraged by the structural power of supermarkets

Our case study interviewees clearly communicated the lack of power they had with respect to selling their produce to retail multiples under the previous business model. From their perspective, the supermarkets 'held all the cards'. At times the participants discarded entire harvests by ploughing under, or even not harvested at all, where the cost of harvesting was more than the price being offered by supermarkets for the produce. Costs to grow the produce would still be incurred, but further losses to harvest and 'sell' it would be avoided – a practice they felt was anathema to farming.

Farmers are expected to honour production contracts or risk being dropped. If short of produce, a farmer must source it wherever possible and absorb the cost of doing so. Selling direct to customer puts at least some of that power back into the hands of the farmer – they have full decision-making power over what they offer for sale to the customer. It is not necessary to strictly comply with the EU marketing standards. At the same time, selling direct also exposes the farmer to different risks; they take full responsibility for marketing their produce. Selling produce that lacks value for money could quickly have a negative feedback effect, particularly if it is already selling at a premium to a similar supermarket offering.

> *"I've got 100% control over what we do. If I make a good job of marketing and get customers in to buy the products, then I get a high return. If I make a bad job, then I get a low return. To me that's what gets me up in the morning; it's having control over your own destiny, which you don't have if you're doing it the other ways." (Owner)*

5. Conclusion

We have argued there are likely to be several drivers of avoidable loss of 'ugly' food, involving multiple actors within the food supply chain. These include: regulations that incorporate purely cosmetic elements at national and supranational levels; private 'voluntary' grading criteria by retail multiples; power differential between farmer and retailer; and, learned expectations of consumers. Via our atypical case study, we suggest it may be possible for some actors to overcome these drivers, generating multiple benefits. Less discard of safe, edible food for aesthetic reasons could help reduce food insecurity. Less avoidable food loss would also lower the climate cost and increase agriculture's GHG-efficiency, in terms of embedded GHG emissions, by needing to produce less food. An efficient food supply chain, where food loss and waste are minimised within and between the various stages, could increase food availability without the need for producing more.

The use of fresh fruit and vegetable produce that would otherwise be lost or wasted requires alternative routes that are available to farmers, and provide a sufficient price to make it economical to do anything other than plough-in or walk-by an out-of-specification harvest. Entrepreneurs have launched new businesses aimed at both consumers and producers, with the aim of using more of food that is produced (e.g. Olio, Imperfect Produce, FoodCloud, etc.). A law passed unanimously by both French legislative Houses in late 2015 aims to empower all actors within the food supply chain to eliminate avoidable food waste, emphasising efforts to maintain its use as food for human consumption (French Senate, 2015). In contrast to France, a food waste reduction private member's bill, also targeting supermarkets, first tabled in the UK Parliament in late 2015 remains mired at the first stage of the process (McCarthy, 2016). Positively however, all major supermarkets in the UK publicly support the voluntary Courtauld 2025 Commitment of 20% reduction of food waste by 2025 (WRAP n.d.). Further, some supermarkets have seen this as a marketing opportunity, with new branding for fruit and vegetables that would have previously fallen short of their aesthetic/quality criteria (e.g. Asda's 'Wonky Veg' and Tesco's 'Perfectly Imperfect'). This could reduce avoidable food loss at source, generating benefits for the climate through reduced emissions from waste. Other co-benefits, such as less food poverty, and greater stability of farm income, may also be obtained.

A changing political climate within the UK also looms large on the horizon for the agriculture industry. The details and domestic policy implications of the UK's expected exit in 2019 from the European Union (or 'Brexit') remain unknown. Brexit may offer the UK the opportunity to develop and apply policy options for domestically-consumed FFV that current EU regulations may not permit, such as banning the use of cosmetic characteristics as factors in determining 'quality'. However it is far from certain the UK government would adopt such a policy, especially if they choose to keep open the prospects of trade with EU countries. Moreover the UK government has not taken other measures available to it as an EU member (or where membership should not inhibit action), such as: educational initiatives to increase knowledge and familiarity of food produce; and, revisit labelling of foods to provide consumers with clear information they can use in their decision-making process. The potential impact of policy on food loss warrants further research, building upon that begun by the EU FUSIONS project (EU FUSIONS, 2015).

Much research continues to be focused at the consumer end of the food supply chain in Europe (e.g.: De Laurentiis et al. (2018) on quantification; Gaiani et al. (2018) on attitudes; von Kameke and Fischer (2018) on behaviour change; Aschemann-Witzel et al. (2017a) on success factors). However, there remain considerable levels of uncertainty in many aspects of estimating food loss and waste in early FSC stages and its embedded climate impact. Here, we have attempted to provide some measure of additional clarity on such wastage. Our specific perspective has been one of viewing avoidable loss as a function of arbitrary quality standards. The case study we used focused only upon one crop – strawberries – grown and sold in the UK. The estimates presented with respect to the UK strawberry industry are very rough, based on this small-scale pilot, and are meant to be illustrative of possible climate cost due to application of cosmetic standards to fresh produce. Without generalising from a single specific case, our conclusion is there are very likely to be substantial avoidable losses, yet also a great deal of uncertainty of the quantity. Larger-scale investigations to generate a more robust quantification of food loss at the farm stage, from all drivers, is necessary. A clearer picture of the scale and nature of the issue is also needed, recognising that different food crops in different geographic and social contexts may have different issues.

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