A systemic approach for trade-off analysis of food loss reduction and greenhouse gas emissions

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Abstract

This paper introduces the Agro-Chain Greenhouse gas Emissions (ACGE) calculator, a calculator for estimating GHG emissions for food supply chains that addresses emissions due to agricultural production and post-harvest activities. The calculator combines direct emissions of GHG gasses by the activities in the chain and effects due to losses, differentiated for 5 stages along the chain.

One of the major challenges of analyzing a chain is data collection. In many practical situations only a limited set of (primary) data is available. In order to facilitate the use, the calculator is supplemented with a complete set of secondary data: crop GHG emission factors aggregated at product category level and FLW estimates per chain stage, aggregated at product category level; all data differentiated for 7 global regions. The tool is highly suitable for assessing net GHG emission effects of FLW reducing interventions: comparing different chain configurations, each with adequate FLW estimates.

Through two intervention analysis examples it is shown that not only agricultural production but also post-harvest chain adds significant emissions to the food supply. The FLW-reducing intervention considered adds substantial extra emissions. In one example the FLW-reduction has larger GHG emission reduction effects, but in another example the extra emissions are higher than the prevented emission from lower food losses. Consequently the intervention is not an effective GHG emission reduction intervention.

We recommend to use this approach for climate-smart FLW reduction intervention prioritization.

Keywords

Food loss & waste; GHG emissions; Emission factors.

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1. Introduction

Food losses and wastes (FLW) largely impair food security. Moreover, substantial environmental impacts are coupled to production of the lost produce. Reducing FLW is broadly considered an effective measure for both fulfilling food demand and reducing the associated environmental impacts, since the emissions associated to generation of these foods can be avoided. However, most FLW reducing interventions will not only lower environmental impacts per unit product available for consumption, but also induce extra emissions (amongst others through energy, fuel and packaging material use). Estimating net trade-offs of FLW reducing interventions on emissions is far from obvious.

Total greenhouse gas (GHG) emissions due to agriculture, forestry and other land use are estimated around 12 Gt CO2-eq. per year (IPCC, 2014). The ambition to reduce FLW (currently estimated at 30% of all food produced in the world for human consumption, Guo et al., 2019) by half in 2030 (in line with United Nations' Sustainable Development Goals target 12.3, (UN)) is supported by an increasing number of stakeholders in governments and throughout food supply and consumption chains. The realisation of this ambition corresponds to the reduction of agricultural production by one sixth. Since the loss percentages are lower for animal products (with relatively high GHG emission intensities) than staple crops and fruit and vegetables (Gustavsson et al. 2011), GHG reductions through reduced FLW will be significantly lower than one sixth of the total emissions related to food. Still, many including Springmann *et al.* (2018), estimate that “halving food loss and waste would reduce environmental pressures by 6–16% compared with the baseline projection”. However, Additional impacts due to FLW reducing interventions were not considered in those estimates. In this paper we – through a number of case analysis –show that a more nuanced perspective is needed.

In food supply chains, a large fraction of the total GHG emissions is related to agricultural production (Porter et al. 2016). Nevertheless, post-harvest operations, like long-distance transport, processing, packaging and refrigeration can significantly contribute to total GHG emissions. For instance, for typical EU configurations Guo et al. (2019) claim that for animal derived products post-harvest operations may account for 7 to 37% of the total product-attributed GHG emissions. Interventions involving further intensifying post-harvest operations could even induce higher additional GHG emissions than prevented emissions due to FLW reduction. Insight in both FLW reduction potential and net GHG emission effects is essential for decision taking on sustainable development of food supply. The question is how to estimate the net effects, thus how to compare a conventional situation to a supposed improved situation.

Estimating trade-offs between FLW reduction and GHG emissions serves two purposes: (1) at macro level it is essential to know hotspots, as a basis for adequate climate policy; (2) at micro level it is relevant to estimate effectiveness of FLW reducing interventions on GHG emissions in order to assess the relevance for climate change reduction. We used datasets with GHG emission factors and FLW estimations per crop category for all global regions, and develop the *Agro-Chain Greenhouse gas Emissions calculator (ACGE calculator)* on that. This tool calculates total GHG emissions allocated to a food product along the production and supply chain based on crop-production emissions, post-harvest activities related emissions and FLW percentages per chain stage. By combining the integrated calculation of effects of loss percentages as well as emissions related to energy use, fuel use and (packaging) material use, it is very suitable for analysing GHG emission effects of loss-reducing interventions, through comparing reference situations with intervention scenarios. Based on a results from various case analyses (part of then published elsewhere) we show that net benefit of expected ‘climate smart’ measures may turn out positive or negative, dependent on the specific situation. Therefore, we recommend to analyse the potential effects before actual implementation of FLW reduction measures.
The ACGE calculator is introduced in the following chapter. Next Chapter 4 shows effects of some interventions on FLW and GHG emissions based on the ACGE calculator. Through these examples we show that net GHG emission reductions generally are significantly smaller than the emissions related to the lost produce; in some example the emissions associated with the intervention even are higher the saved emissions due to FLW reduction.

2. Method: Agro-Chain Greenhouse gas Emissions calculator

The ACGE calculator uses datasets for GHG emissions of crop production and FLW percentages for different stages along the post-harvest food supply chain (storage and handling, processing, distribution and consumption). These values are specified per food product categories according to FAOSTAT coding. They are differentiated for global regions in the world: Europe; North America and Oceania; Industrialized Asia; Sub-Saharan Africa; North Africa, West and Central Asia; South and Southeast Asia; and Latin America. The datasets are derived from the review by Porter *et al.* (2016). The differentiation to regions is relevant because of the large differences of GHG impact per crop between global regions, see e.g. (Porter et al. 2016), (Clune et al. 2017).

Estimating net emissions along the whole chain requires a chain-wise approach, that includes impacts and effects of agricultural production as well as post-harvest operations. Using common quantitative sustainability analysis methods like LCA is quite resource and time consuming, where data collection is considered the major challenge (see e.g. (Bacenetti et al. 2018), (Gutierrez et al. 2017), (Notarnicola *et al*, 2017)). Consequently, LCA are mostly focussing on specific parts of a food production chain, commonly the agricultural production phase. Costs and benefits of post-harvest loss-reducing measures are left out of consideration in most of these analysis.

Estimating emissions can be simplified through a more generic analysis tool, with predefined (sufficiently generic) chain configuration and underlying data sets. Various generic tools for analysing impacts of food production and FLW are available or under development. For instance for estimating GHG emissions due to the agricultural production the FLW Value Calculator by Quantis (Quantis) and the Cool Farm Tool (Alliance) are available. The Quantis tool, however, does not take emissions related to post-farm operations into consideration (energy, fuels, packaging materials, etc.); consequently it cannot estimate direct effects of post-harvest interventions. The Cool Farm Tool (Alliance) also does not take emissions due to post-harvest operations into consideration, neither does it model FLW and emissions related to their processing.

We introduce a tool that does include post-harvest operations-related emissions: the ACGE calculator. Through predefining a wide set of common operations along the chain, it can be applied to most practical chain configurations. Furthermore, through using secondary crop-data it is applicable for all crops. The calculator uses data sets for crops, processes and other operations along food chains (***Table 1***), specifically addressing agricultural production, post-harvest handling and storage, collection transport, primary processing and packaging, transport (max. three modalities), secondary processing/repackaging/consolidation, distribution transport and retail shop.

The crop-dataset contains crop GHG emissions and losses along the chain per product category, with different values per global region (above explained dataset). Also for energy use (electricity, fuels), refrigerated storage (distinguished for refrigerated warehouses and retail display cabinets) and various transport modalities default emission factors are used; these may be overruled by the user when more appropriate values are available in a considered configuration. The data sets can be enriched based on the growing continuously growing number of published LCA data and outcomes.

A scenario is modelled by specifying the chain configuration and crop in the calculator spreadsheet (**Fig. *1***). The first choice is the regions of production and consumption. It is assumed that all operations up to the (international) transport (see ***Table 1***) are located in the region of production, whereas the later operations are located in the region of consumption. Next, the crop (category) can be chosen. After that

In the calculator the user can define specific chain parameters. These parameter values can be filled in a ACGE calculator spreadsheet (like refrigerated storage period, transportation distances and modalities), which then calculates total GHG emissions per unit product purchased by the consumer (**Fig. *1***). Next transportation distances, modalities, packaging materials and refrigerated storage durations can be filled in. Also other energy use (processing energy use) can be specified per chain stage.

For each chain stage the calculator derives default loss percentages per chain stage; these values may be overwritten. Waste management/application can be specified per loss stream.

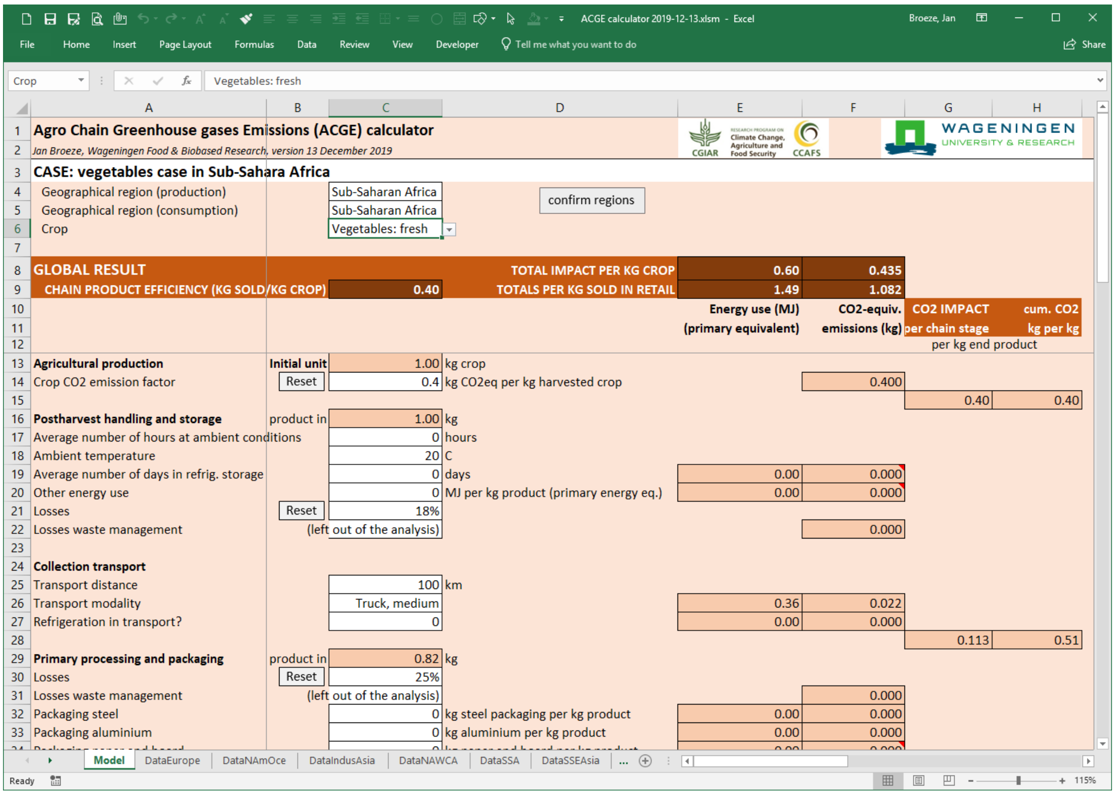
The relatively large set of secondary data facilitates analysis of existing chains. It is even more useful for analysing intended modified chain configurations, for which adequate consistent primary data are mostly lacking. What's more, average values from literature (based on different practical situations) can be more generally relevant than one primary (incidental) value.

Table 1 *Factors for GHG emissions used in the ACGE calculator and sources for default data*

Chain stage	**Factors included**	**Sources for default data**	**Chain configuration parameters**
Agricultural production	GHG emissions	(Porter et al. 2016): aggregated impacts for crop categories for 7 global regions, extended with outcomes of published LCA results.	(Default) GHG emission factor may be adjusted

Chain stage	Factors included	Sources for default data	Chain configuration parameters
Post-harvest handling and storage	Refrigerated storage energy use Other energy use	Refrigerated storage energy use: derived from (Evans et al. 2014) with estimated filling degree. “Other energy use”: default 0.	Duration of refrigerated storage. Other energy use per kg product (fuel-based and electric)
Collection transport	Fuel use, well-to-wheels (impacts related to vehicles and infrastructure construction and maintenance are neglected, EcotransIT 2018)	Values in line with EcoInvent 3 and ecotransit.org (visited December 2018). The following vehicles are included: • delivery van (average filling degree) • delivery van (full load capacity used) • lorries (small, medium, large, very large) • cargo train (electric, diesel) • cargo ships (inland, sea ship, sea ship containers) • air cargo (continental, intercontinental)	Distance Modality
Primary processing and packaging	Packaging materials Refrigerated storage ene Other energy use	Packaging materials: • plastics: (Hekkert et al. 2001) • paper and board: (Laurijssen et al. 2010) • steel: average from APEAL (APEAL 2012), Worldsteel Association (Association 2018) and (Garofalo et al. 2017) • aluminium: (Simon et al. 2016) (assuming 50% recycling), (Stotz et al. 2017) • glass: (Schmitz et al. 2011)	Packaging material use per kg product. Processing energy use per kg product
(International) Transport (optionally multi-modal)	Fuel use	see above	see above
(Secondary) processing, repackaging, cross-docking	See *Primary processing*	See above	see above
Distribution transport	Fuel use	Values in line with EcoInvent 3 and IMO (IMO 2015).	see above
Retail outlet	Energy use, specifically refrigeration	Refrigerated storage in retail shelfs: energy use data derived from literature study.	Duration of refrigerated storage (display cabinet)

Chain stage	**Factors included**	**Sources for default data**	**Chain configuration parameters**
All stages along the post-harvest chain	Percentage of FLW per chain stage	Values from (Porter et al. 2016).	(Default) FLW percentages may be adjusted
All stages along the post-harvest chain	GHG emissions due to waste management process (varying from landfilling to bio-fermentation)	Values from EPA (EPA 2016).	



	A	B	C	D	E	F	G	H
1	**Agro Chain Greenhouse gases Emissions (ACGE) calculator**							
2	*Jan Broeze, Wageningen Food & Biobased Research, version 13 December 2019*							
3	**CASE: vegetables case in Sub-Sahara Africa**							
4	Geographical region (production)		Sub-Saharan Africa	confirm regions				
5	Geographical region (consumption)		Sub-Saharan Africa					
6	Crop		Vegetables: fresh					
7								
8	**GLOBAL RESULT**			**TOTAL IMPACT PER KG CROP**	**0.60**	**0.435**		
9	**CHAIN PRODUCT EFFICIENCY (KG SOLD/KG CROP)**		**0.40**	**TOTALS PER KG SOLD IN RETAIL**	**1.49**	**1.082**		
10					**Energy use (MJ)**	**CO2-equiv.**	**CO2 IMPACT**	**cum. CO2**
11					**(primary equivalent)**	**emissions (kg)**	**per chain stage**	**kg per kg**
12							per kg end product	
13	**Agricultural production**	**Initial unit**	1.00	kg crop				
14	Crop CO2 emission factor	Reset	0.4	kg CO2eq per kg harvested crop		0.400		
15							0.40	0.40
16	**Postharvest handling and storage**	product in	1.00	kg				
17	Average number of hours at ambient conditions		0	hours				
18	Ambient temperature		20	C				
19	Average number of days in refrig. storage		0	days	0.00	0.000		
20	Other energy use		0	MJ per kg product (primary energy eq.)	0.00	0.000		
21	Losses	Reset	18%					
22	Losses waste management	(left out of the analysis)				0.000		
23								
24	**Collection transport**							
25	Transport distance		100	km				
26	Transport modality		Truck, medium		0.36	0.022		
27	Refrigeration in transport?		0		0.00	0.000		
28							0.113	0.51
29	**Primary processing and packaging**	product in	0.82	kg				
30	Losses	Reset	25%					
31	Losses waste management	(left out of the analysis)				0.000		
32	Packaging steel		0	kg steel packaging per kg product	0.00	0.000		
33	Packaging aluminium		0	kg aluminium per kg product	0.00	0.000		

Fig. 1 Screenshot of part of the ACGE calculator

The ACGE calculator can be applied for understanding impacts of different operations along a chain and for analysing chain configuration scenarios: 1. Weighing impacts of the operations/impacts along the chain. Such analysis gives understanding of total impact of the food product supply as well as to what extent each operation along the chain contributes to the impact. 2. Comparing various options for supplying a specific food component, for instance comparing options for market supply of a non-seasonal product: frozen vegetables from local seasonal production, canned vegetables from local seasonal production, and fresh imported vegetables. 3. Comparing a reference scenario with an ‘improved scenario’ like:

- shift processing to a location near the crop production (regional small-scale facility generally has lower energetic efficiency than large-scale centralized processing facility; however this may reduce losses).
- Apply refrigeration or apply lower refrigeration temperature in the chain (which may result in extended retail shelf life and lower percentage of losses, but will cost more energy).
- Apply protective packaging (may lead to reduction of losses, but at the cost of the packaging).

3. Analysing trade-offs between FLW and GHG of loss-reducing interventions in a post-harvest chain

Trade-offs between FLW and GHG can be analysed through modelling the reference situation and the supposedly improved situation. For both chains the parameters like transportation distances, packaging materials, storage durations and FLW percentages per chain stage (***Table 1***) must be estimated (Figure 2).

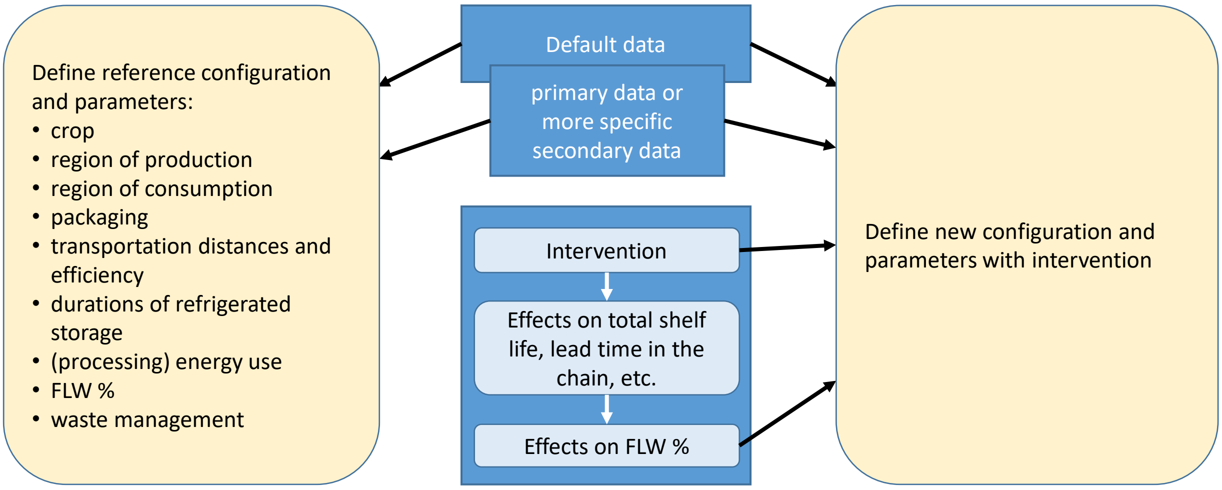


Figure 2. Procedure for defining reference and intervened chains.

FLW reducing measures include technical, logistical or marketing interventions. Technical interventions are often shelf life extending measures (refrigeration, packaging or other preservation methods). Logistical or marketing interventions may lead to supply chain lead time reduction, reduction of demand variance, etc. (see (Tromp et al. 2016)). Each intervention will have multiple direct and indirect effects affecting FLW and GHG emissions. There are direct effects, like emissions related to energy and packaging material use. Indirect effects are for instance related to increased tare weight (packaging) in transport, altered average storage durations (influencing energy use in refrigerated storage) and loss percentages which will be affected and/or shifted to other stages along the supply chain, etc. Quantitatively estimating such effects requires understanding of product quality decay, logistic processes and demand. Quantification based on collecting primary data is one option. This requires data for the reference and new configuration where all conditions except for the intervention are comparable. This will only be possible in exceptional situations. Estimating effects from secondary data is another option. For instance, by deriving effects from comparable interventions in analogous systems (measured or described in literature). Or by making use of model-wise estimation of the effects. This will require quantitative models (for product quality decay/shelf life, quantifying effects of the intervention on shelf life), logistic models (quantifying effects on transportation quantities, distances and efficiency) and/or market models (quantifying for instance effects of supply characteristics and shelf life on loss percentage). An adequate methodology is described by (Tromp et al. 2016).

4. Contributions of post-harvest operations to food-related GHG emissions – Case studies

According to above hotspot analysis outcomes, international food transport adds only a few percent GHG emissions compared to total agricultural production. GHG emissions due to other post-harvest operations – which are not included in above results - can be generated through explicit analysis of example chains. Below, we analyse contributions from other post-harvest operations in three case studies.

Case study: bovine meat in The Netherlands

With an eye on the high GHG emission factor for beef, any loss has high associated GHG emissions. One intervention (partially implemented in practice) is lowering the maximum refrigerated storage temperature from 7 to 4°C. This results in extended shelf life, and consequently leads to reduced FLW. Consequently FLW-associated GHG emission are reduced, but this goes at the price of increase of refrigeration energy use and energy-induced GHG emissions.

Table 2. Impact factors and FLW factors for the bovine meat product (reference configuration)

Impact factors	*Value*	*Source/comment*
Bovine meat GHG emission factor	22.9 kg CO_2-eq./kg product	(Porter et al. 2016)
Processing/packaging loss factor	5%	(Porter et al. 2016)
Retail shelf loss factor	3%	Estimated with the method presented by (Tromp et al. 2016) for a representative supply chain in The Netherlands, assuming total shelf life 7 days days

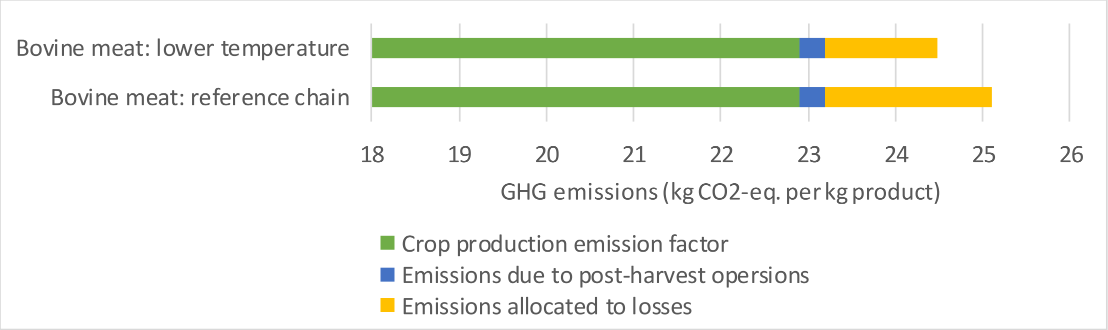
Table 3. Chain configuration for the bovine meat product

Chain configuration parameters	*Value*	*Source/comment*
Processing energy use	-	GHG emissions up to meat processing are included in the product’s GHG emission factor, thus should not be added in the calculations.
Refrigerated storage duration in processing/packaging stage	1.3 days	practical expert estimate
Packaging plastics	0.05 kg plastics/kg meat	practical samples measurement
Transport from packaging station to distribution centre	80 km, large truck	practical expert estimate
Refrigerated storage duration in distribution centre	0.5 days	practical expert estimate
Transport from distribution centre to retail shop	50 km, large truck	practical expert estimate
Refrigerated retail display duration	40 hours	Estimated with the method presented by (Tromp et al. 2016) for representative supply chain in The Netherlands

Result: For the reference situation the total calculated total GHG emission are 25.1 kg CO2-eq. per kg sold in retail, which is 2.2 higher than the impact factor of the produced meat. This is due to losses (1.9), packaging material use (0.2), transport (0.03) and energy use for refrigerated storage (0.05). Obviously 8% of the emissions are attributed to losses, and post-harvest operations add 1% to the total emissions. Through the intervention the total maximum shelf life is extended by about 3 days (Tromp et al., 2016). Model simulations of a typical retail and buying pattern show average keeping period (and thus refrigeration energy use) increase of 5 hours. Furthermore, the energy use per day is increased because of the lower temperature (estimated at

+50%). The model simulations show average loss reduction in shelf by about 2%. In this new configuration the net GHG emissions per kg sold is reduced to 24.8 kg CO2-eq. per kg sold in retail.

To conclude, the intervention reduces the waste by 2% and reduces the total GHG emissions per kg sold in retail by 1%. Obviously this intervention has positive trade-off between GHG emission and FLW.



Case study: packaged fresh cut vegetables in Western Europe

Here the same intervention as for beef is tested for cut vegetables. The lowering of refrigerated keeping temperature on total shelf life and loss percentage is quite comparable to beef.

Table 4. Impact factor and FLW factors for the cut vegetable product (for reference chain)

Impact factors	*Value*	*Source/comment*
Vegetables GHG emission factor	0.30 kg CO2-eq./kg product	(Porter et al. 2016)
Handling and storage loss factor	7.3%	(Porter et al. 2016)
Processing/packaging loss factor	2.0%	(Porter et al. 2016)
Retail shelf loss factor	3%	Estimated with the method presented by (Tromp et al. 2016) for a representative supply chain in The Netherlands, assuming total shelf life 7 days days

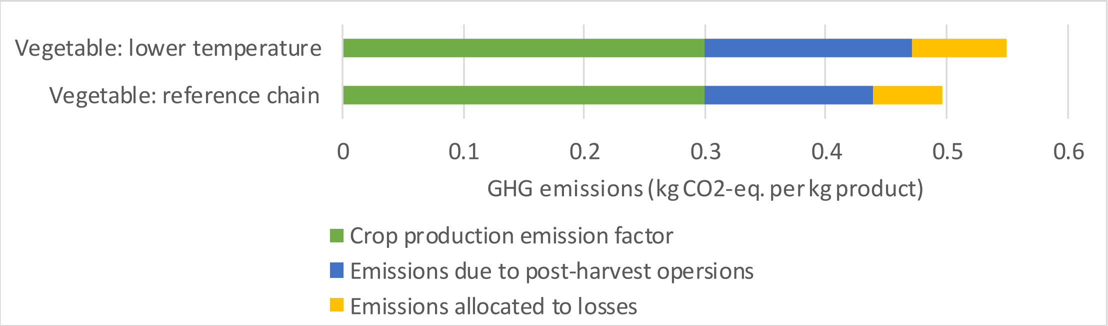
Table 5. Chain configuration for the cut vegetable product

Chain configuration parameters	*Value*	*Source/comment*
Processing energy use	-	neglected
Collection transport	50km, medium size truck	practical expert estimate
Refrigerated storage duration in processing/packaging stage	1.3 days	practical expert estimate

Packaging plastics	0.015 kg plastics/kg product	practical samples measurement
Transport from packaging station to distribution centre	80 km, large truck	practical expert estimate
Refrigerated storage duration in distribution centre	0.5 days	practical expert estimate
Transport from distribution centre to retail shop	50 km, large truck	practical expert estimate
Refrigerated retail display duration	40 hours	Estimated with the method presented by (Tromp et al. 2016) for representative supply chain in The Netherlands

Result: Calculated total GHG emission 0.50 kg CO2-eq. per kg sold in retail, which is 0.20 higher than the impact factor of the produced vegetable. This is due to post-harvest losses (0.057), packaging material use (0.055), transport (0.038) and energy use for refrigerated storage (0.046). Obviously post-harvest losses induce 19% extra emissions in the post-harvest chain, and other post-harvest operations add 46% to the total emissions.

Results from this analysis are shown in below figure. Obviously for this product the FLW reducing intervention results in an increase of GHG emission per unit sold to the consumer.



Discussion

This paper introduces a calculator for estimating GHG emissions for food supply chains that includes emissions due to agricultural production and post-harvest activities. The calculator combines direct emissions of GHG gasses by the activities in the chain and effects due to losses, differentiated for 5 stages along the chain.

One of the major challenges of analyzing a chain is data collection. In many practical situations only a limited set of (primary) data is available. In order to facilitate the use, we have provided a complete set of secondary data (including crops GHG emission factors aggregated at product category level and FLW estimates per chain stage, aggregated at product category level; all data differentiated for 7 global regions).

The tool is highly suitable for assessing net GHG emission effects of FLW reducing interventions: comparing different chain configurations, each with adequate FLW estimates.

Through two intervention analysis examples we have shown that not only agricultural production but also post-harvest chain adds significant emissions to the food supply. The intervention considered adds substantial extra emissions; in one of the examples these are even higher than the prevented emission from lower food losses.

We recommend to use this approach for climate-smart FLW reduction intervention prioritization.

The ACGE calculator is made available through CCAFS website.

References

Alliance CF Cool Farm Tool. https://coolfarmtool.org/coolfarmtool/greenhouse-gases/. Accessed 27 November 2018

APEAL (2012) Life cycle assessment on tinplate (leaflet).

Association (2018) World Steel Association, Life cycle inventory study.

Bacenetti J, A. Cavaliere, G. Falcone, V. Giovenzana, Banterle A, Guidetti R (2018) Shelf life extension as solution for environmental impact mitigation: A case study for bakery products Sci Total Environ 627:997–1007

Clune S, E. Crossin, Verghese K (2017) Systematic review of greenhouse gas emissions for different fresh food categories J Clean Prod 140:766-783

EPA (2016) Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM). Background Chapters, Report. Prepared by ICF International for the U.S. Environmental Protection Agency,

Evans J et al. (2014) Specific energy consumption values for various refrigerated food cold stores Energ Buildings 74:141–151

FAOSTAT FAOSTAT Data. http://www.fao.org/faostat/en/#data. Accessed May 1, 2019

Garofalo P, L. D'Andrea, M. Tomaiuolo, Venezia A, Castrignanò A (2017) Environmental sustainability of agri-food supply chains in Italy: The case of the whole-peeled tomato production under life cycle assessment methodology J Food Eng 200:1-12

Guo, X., J. Broeze, J. Groot, H. Axmann & M. Vollebregt (2019): A global hotspot analysis on food loss & waste and associated greenhouse gas emissions, CCAFS working paper xx.

Gustavsson J, C. Cederberg, U. Sonesson, Otterdijk Rv, Meybeck A (2011) Global food losses and food waste: extent, causes and prevention. Food and Agriculture Organisation of the United Nations (FAO), Rome

Gutierrez MM, Meleddu M, Piga A (2017) Food losses, shelf life extension and environmental impact of a packaged cheesecake: A life cycle assessment Food Res Int 91:124–132

Hekkert MP, D.J. Gielen, Worrell E, Turkenburg WC (2001) Wrapping up greenhouse gas emissions: An assessment of GHG emission reduction related to efficient packaging use J Ind Ecol 5:55-75

IMO (2015) Third IMO Greenhouse Gas Study 2014: Safe, secure and efficient shipping on clean oceans

Laurijssen J, M. Marsidi, A. Westenbroek, Worrell E, Faaij A (2010) Paper and biomass for energy? The impact of paper recycling on energy and CO2 emissions Resour Conserv Recy 54:1208–1218

Notarnicola, B., S. Sala, A. Anton, S.J. McLaren, E. Saouter & U. Sonesson (2017): The role of life cycle assessment in supporting sustainable agri-foodsystems: A review of the challenges, Journal of Cleaner Production 140 (2017) 399-409.

Porter SD, D.S. Reay, P. Higgins, Bomberg E (2016) A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain Sci Total Environ 571:721-729

Quantis FLW Value Calculator. http://flwprotocol.org/why-measure/food-loss-and-waste-value-calculator/. Accessed 18 December 2018

Schmitz A, J. Kaminski, Scalet BM, Soria A (2011) Energy consumption and CO2 emissions of the European glass industry Energ Policy 39:142–155

Simon B, Amor MB, Földényi R (2016) Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles J Clean Prod 112:238-248

Springmann M et al. (2018) Options for keeping the food system within environmental limits Nature 526:519-526

Stotz PM, M. Niero, Bey N, Paraskevas D (2017) Environmental screening of novel technologies to increase material circularity: A case study on aluminium cans Resour Conserv Recy 127:96–106

Tromp SO, Haijema R, Rijgersberg H, van der Vorst JG (2016) A systematic approach to preventing chilled-food waste at the retail outlet Int J Prod Econ 182:508-518

UN (2015) United Nations General Assembly. Resolution Adopted by the General Assembly on 25 September 2015. 70/1 Transforming Our World: the 2030 Agenda for Sustainable Development.

Willett W et al. (2019) Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems Lancet 393:447–492