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Developing a Methodology for Estimating Transport-Related CO_2 Emissions for Food Commodities

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Abstract

There is a significant and growing interaction between the transport sector and the food sector as globalized markets continue to increase the demand for 'food miles' i.e. the number of miles a food item travels throughout its life cycle. The concept of 'food miles' has become interesting to the public and policy makers as a way to assess the relative carbon footprint of food choices. However, there is currently a lack of information available about the transport-related greenhouse gas emissions that would allow to accurately differentiate between food items. To help address these current knowledge gaps, this paper presents a transferable methodological approach to estimating the transport related CO_2 emissions of 10 popular food commodities transported from the farm gate to the retailer. The methodology combines GIS, data from the scientific literature and detailed commodity specific data from personal communication with one of the largest food retailers in California. To travel from the farm gate to the retailer, the amounts of CO_2 emissions varied amongst the 10 foods, ranging from 47 g CO_2/kg oranges, to 78 g CO_2/kg almonds. While California was used as a case study, this method would be replicable across other locations and food life cycle assessments.

Keywords: CO_2 emission, food commodities, food miles, food transportation methodology

1. Introduction

The food sector has a great impact on the environment. It is responsible for around the 20-30% of total anthropogenic greenhouse gas (GHG) emissions. Another major contributor to climate change is the transportation sector, accounting for about 15% of GHG emissions (Hertwich & Peters, 2009; Pachauri & Reisinger, 2007). As markets continue to globalize, the interrelation of the food and transportation sectors continues to grow.

Of the total life-cycle GHG emissions related to the food chain, food production is responsible for more than 80%, while transportation accounts for less than 15% (Weber & Matthews, 2008). Nevertheless, in the U.S., transportation of food products contributes considerably to air pollution and overall GHG emissions (Egilmez, Kucukvar, Tatari, & Bhutta, 2014). Thus, in recent years, an increasing emphasis has been placed on the emissions of GHG during the transportation of products and commodities (O'Donnell, Goodchild, Cooper, & Ozawa, 2009; Weber & Matthews, 2008; Xu, Sun, Zeng, Liu, & Pu, 2015). Some authors reported that the energy used to transport some food products over long distances may be even higher than the amount required during their production (Jones, 2002). 'Food miles' has been defined as the number of miles a food item travels throughout its life cycle (Gaballa, Abraham, Barber, Taylor, & CERES, 2007). This concept of 'food miles' has become of interest to the general public and for policymakers as a way to assess the relative carbon footprints of food choices (Meisterling, Samaras, & Schweizer, 2009). This definition, however, does not account for other aspects of the transportation apart from the distance, such as the type of transport (Brodt, Kramer, Kendall, & Feenstra, 2013; Meisterling et al., 2009) or the fuel efficiency (Coley, Howard, & Winter, 2011; Egilmez & Tatari, 2012).

Non-trivial differences have been reported for the production of different types of foods according to GHG emissions (Clune, Crossin, & Verghese, 2017). There are a few studies about transport-related GHG emissions of food (Carlsson-Kanyama, 1998; Jones, 2002), but there is a lack of reliable information available assessing different food commodities that would allow to differentiate between food items (Pratt, Mackenzie, & Lockwood Sutton, 2017; Weber & Matthews, 2008).

To help address these current knowledge gaps, this paper presents a methodological approach to estimating the transport-related CO_2 emissions of 10 popular food commodities transported from farm gate to retailer in California.

2. Material and Methods

2.1 Trip Distances

For all 10 foods, data was analyzed in 3 main stages. The first stage involved the transportation of goods from the farm to the processing plant. The second stage included transportation from the processing plant to the distribution center, and the final stage involved transport from the distribution center to the retail store(s).

For stages 1 and 2, it was assumed that every loaded trip had an empty trip associated with it, as the truck has to travel to the farm or processing plant empty. Stage 3 involved more complex routing. From the distribution center, the same truck delivered to a number of retail stores according to a realistic delivery schedule, which varied according to type of commodity (e.g. perishable vs. dry groceries). This information was provided by one of the largest food retailers in California (R. Mathias, personal communication). Therefore, the number of stores delivered to and the distances between each store were accounted for. All trips (distribution center to store 1, store 1 to store 2, store 2 to store 3, and store 3 to distribution center) were calculated.

To calculate transportation distances from the farm to the processing plant, the biggest producing county in California for each of the 10 commodities was identified from the California Agricultural Statistics Review (California Department of Food and Agriculture [CDFA], 2014). One of the largest processing plants within the same county was also identified via an online search and its physical address was noted. ArcGIS 10.3.1 (Environmental Systems Research Institute [ESRI], 2015) software was used to process the 2012 California Cropland Data Layer (CCDL) (United States Department for Agriculture [USDA], 2012a) in order to identify the locations and land cover corresponding to the crops and animal farms within their respective county. The CCDL is released by the USDA national Agricultural Statistics Service and depicts agricultural land cover over the continental US at a resolution of 30 meters. The CCDL is an annual, geo-referenced, crop-specific data layer produced from a combination of satellite imagery and extensive agricultural measurements and observations collected during the current growing season (USDA, 2015a). Geographic Information System (GIS)-based techniques were employed to geocode each processing plant. The mean distance from each crop field or animal farm in the CCDL to the processing plant was calculated and used to define an equidistant perimeter around the processing plant. This perimeter was used to create buffers around each processing plant and the distance from each captured farm to the processing plant was averaged and used in the CO_2 calculations. For the animal commodities, the CCDL does not differentiate between cattle and chickens. Therefore the mean distance between every cattle and chicken farm and the largest processing plant in the county was used to create an equidistant perimeter around the processing plant. Within this perimeter, the distance from each farm to the processing plant was averaged and used in the emissions calculations.

For each commodity, the locations of the two distribution centers in Los Angeles and retail store(s) across Southern California provided by the retailer (R. Mathias, personal communication) were geocoded. Each of the two distribution centers handles different types of groceries and therefore the route scheduling of each food commodity was relative to the appropriate distribution center. The distances from the processing plant to the distribution center, and from the distribution center to retail store(s) were subsequently obtained through GIS mapping procedures (see figure 1).

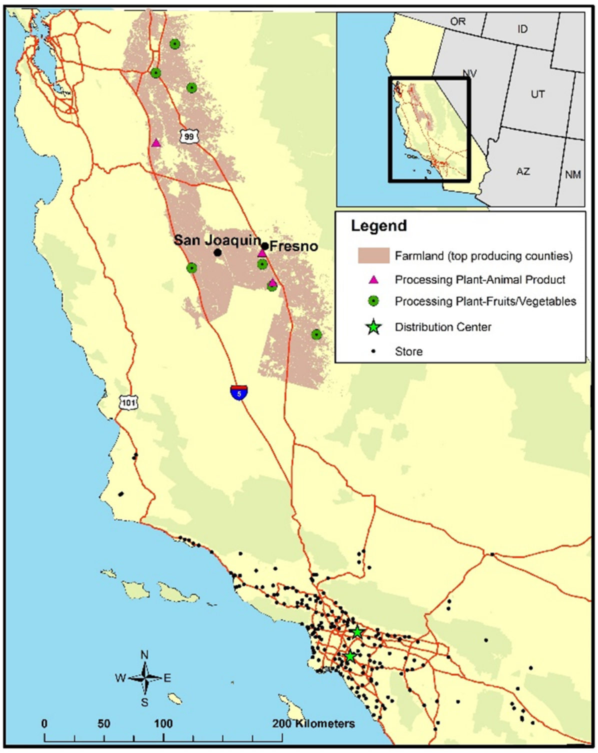

Figure 1. Map displaying the farmlands within the top producing counties used in this study and the processing plants from where food products are transported by truck along the freeway system to reach the distribution centers in Los Angeles and then distributed throughout the retail network of supermarkets in southern California. The inset map (upper right) locates the study area in the State of California

2.2 Truck Characteristics

Information provided by the retailer allowed either a direct or an estimated identification of the vehicle characteristics at each of the 3 stages for each commodity (R. Mathias, personal communication). This generally included a mixture of the vehicle type, size/dimensions, payload capacity, load weight, vehicle capacity utilization rate, trip frequency and schedule, and annual delivery weights. The precise format of information received from the retailer somewhat varied between the products (see sections 2.2.1 to 2.2.3 for an elaboration on almonds, grapes and beef).

The class of truck used to transport the food commodities from farm gate to the processing plant was assessed according to the minimum payload capacity. The class of trucks and their characteristics, including payload capacity and fuel efficiency, were provided by the National Academy of Sciences (National Academy of Sciences [NAS], 2010). Apples, dried beans, oranges, peaches and watermelons were transported from the farm to the processing plant in a class 3 (2.4 ton payload capacity) truck. Grapes and almonds were transported in a class 8a (22.7 ton payload capacity) truck, eggs and chicken were transported in a class 6 (5.2 ton payload capacity) truck and beef was transported in a class 7 (8.4 ton payload capacity) truck. From the processing plant to the distribution center and from the distribution center to the store, all commodities were transported in a class 8b (24.5 ton payload capacity) refrigerated truck.

While a standard procedure was generally followed for each commodity (as described above), specific methods were also applied when appropriate. To provide further insight into the commodity-specific methods used, a detailed description is provided for 3 examples: almonds, grapes and beef.

2.2.1 Almonds

The leading county for almond production in California is Fresno (CDFA, 2014). The largest almond processing plant in the county of Fresno was located in the city of Modesto. The processing plant receives almonds in loads of 50,000 lbs per truck (Superior Almond Hulling [SAH], 2013). Using this load weight, an appropriate truck (class 8a) was assigned based on payload capacity required from farm to processing plant (NAS, 2010).

2.2.2 Grapes

The leading county for grape production in California is Fresno (CDFA, 2014). Data on the load weight and the specific truck used to transport grapes from the farm to the processing plant were provided (R. Mathias, personal communication). A 32 ft. flatbed truck was used to transfer 16 4 ft. wide pallets, each containing 85 packages of grapes weighing 19 lbs. each. Using this information, an appropriate truck was assigned from farm to processing plant (class 8a) based on payload capacity (NAS, 2010).

2.2.3 Beef

The largest beef producer in the State was located in Fresno County, California. The loading space per animal from the farm to the slaughterhouse was obtained from published data (Grandin, 2010). A truck length of 24 ft. and width of 8 ft. and a weight of 1310 lbs. per animal (USDA, 2015b) would provide space for 11 animals to be transported per truck with a minimum payload capacity of 14,410 lbs. Using this information, an appropriate truck (class 7) was assigned from farm to processing plant (NAS, 2010).

2.3 Carbon Emissions

The current study included the related CO_2 emissions to vehicle operation from the farm gate to the retailer, also taking into account refrigeration during transport. Transportation of cultivation inputs, such as fertilizer, diesel fuel, animal feed, packaging and spoilage/waste produce to disposal sites were not included. CO_2 emissions related to operations at the processing plant, distribution center, and retail outlet were not included.

Total CO_2 emissions (from farm to retail) (E_T) were a sum of CO_2 emissions for each trip. We took into account the emissions of every fully loaded trip (E_L), the emissions of the empty trip associated with it (E_E), and the complexity of transportation during stage 3 (see section 2.1 for more detail).

$$E_T = (E_L + E_E)_{Farm\text{-}Processing\ plant} + (E_L + E_E)_{Processing\ plant\text{-}Distribution\ Center} + (E_L + E_E)_{Distribution\ Centre\text{-}Retail}$$

The relative loads of trucks and their fuel efficiency were taken into account. For each trip, 10% of the vehicle payload capacity was added to account for the additional weight of tare and packaging, including crates, as advised by the retailer (R. Mathias, personal communication). For stage 3, the starting weight and the weight unloaded at each store were also factored into the calculations. Equal weight delivery was assumed at each store. The truck then returned to the distribution center containing pallet returns, cardboard bundles, and crates.

To adjust the CO_2 calculations for losses due to spoilage and/or processing, the weight change from the farm to the retail store was calculated for each commodity. For beef and chicken, the losses were calculated at the slaughterhouse/processing plant using live weight-to-carcass weight ratios, combined with carcass weight-to-retail meat weight ratios (Nijdam, Rood, & Westhoek, 2012). For all other commodities, losses were calculated from the farm to the retailer using loss-adjusted data published by the USDA (USDA, 2012b), except for almonds (Environmental Protection Agency [EPA], 1995) and beans (Frate, Klonsky, & De Moura, 2013). The weight loss applied at each stage is shown in table 1, equalized to receiving 1 unspoiled kg at the store for each commodity. Due to differences in loss factors, the starting weight of each commodity is unique.

A standard emissions factor (10.15 kg CO_2/gallon (EPA, 2011)) for diesel fuel was applied.

Therefore,

$$E_T = (E_L + E_E)_{Farm\text{-}Processing\ plant} + (E_L + E_E)_{Processing\ plant\text{-}Distribution\ Center} + (E_L + E_E)_{Distribution\ Centre\text{-}Retail}$$

Where:

$$E_L = g \ x \ ef/wc$$

$$E_E = ee \ x \ d \ x \ l \ x \ ef/wc$$

$$E_L = g\ CO_2 \text{ emissions per kg of commodity per loaded trip}$$

$$E_E = g\ CO_2 \text{ emissions per kg of commodity per empty trip}$$

$$g = \text{gallons of fuel used: } e \ x \ d \ x \ w_f \ x \ l$$

$$e = \text{gallons/ton-km (1/tons payload capacity x km per gallon)}$$

$$d = \text{trip distance (km)}$$

$$w_f = \text{load weight of commodity, tare and packaging (tons) (payload capacity x capacity utilization rate)}$$

$$e_f = \text{emissions factor (10.15 kg } CO_2\text{/gallon) for diesel fuel}$$

l = *weight loss factor due to spoilage/processing (%)*

w_c = *load weight of commodity (tons) (payload capacity x capacity utilization rate)*

e_e = *gallons per km (1/km per gallon of empty truck)*

The main results were reported as CO_2 emissions related to the transportation of one kg of product at the store. We performed other secondary analyses to assess carbon emissions of food commodities. We used energy data from the U.S. Standard Nutrient Database (USDA, 2014) to assess the CO_2 emissions according to energy provided by the foods (g CO_2 emissions per 1000 kcal). To compare from an efficiency perspective, we also report emissions controlling for distance in order to highlight other important aspects of CO_2 emissions from transportation irrespective of it. To derive equal distances, the distances at each stage were averaged across all 10 commodities. The average distance for each stage was then applied to each commodity. CO_2 emissions per kg per 1000 km is also presented, in order to check the efficiency and the distance at the same time.

3. Results

According to table 1, the food commodities that lost more weight from farm gate to the retail were almonds, beef and chicken (to obtain 1kg of product at retail, the weight at farm gate were 5.15, 2.73 and 1.83 kg, respectively). For these three products, the majority of the weight lost occurred at the processing plant. For the rest of the products, the weight loss was minor.

Table 1. Weight and weight loss at each stage of the distribution chain relative to delivering 1 kg at the store

Commodity	Weight at farm gate kg*	Processing plant		Distribution Center		Retail Store	
		Weight loss %	Exit weight kg	Weight loss %	Exit weight kg	Weight loss %	Exit weight kg
Almonds	5.15	80.0	1.02	1.0	1.01	1.0	1
Apples	1.04	1.3	1.03	1.3	1.01	1.3	1
Dried beans	1.11	8.0	1.02	1.0	1.01	1.0	1
Grapes	1.09	3.0	1.06	3.0	1.03	3.0	1
Oranges	1.03	1.0	1.02	1.0	1.01	1.0	1
Peaches	1.05	1.7	1.03	1.7	1.02	1.7	1
Watermelon	1.10	3.3	1.06	3.3	1.03	3.3	1
Eggs	1.02	0.5	1.01	0.5	1.01	0.5	1
Chicken	1.83	43.2	1.04	2.0	1.02	2.0	1
Beef	2.73	61.8	1.04	2.0	1.02	2.0	1

*Due to differences in loss factors, the starting weight of each commodity is unique.

According to data reported in figures 2 and 3 (which present the distance travelled and CO_2 emissions at each of the 3 distribution stages, respectively, not including empty back haul, weight loss adjustment at any stage or animal feed (for the animal products)), we observed that, at the store, eggs showed the furthest travelled distance (739.7 km), while dried beans had the highest total CO_2 emissions related to transportation (47.8 g CO_2) followed closely by watermelon (47.2 g CO_2). Oranges were the food commodity that showed the shortest distance and the lowest emissions from farm gate to retail (437.1 km and 29.7 g CO_2). By stages, from the farm to the processing plant, almonds travelled the farthest (38.3 km) but were not the food commodity with the highest amount of emissions from transportation (4.8 from almonds vs 8.6 g CO_2 from dried beans, the food with the highest emissions). From the processing plant to the distribution center, apples were the product that showed the highest values in both assessments (518 km and 38.1 g CO_2), while oranges presented the lowest figures for both distance and emissions (252.2 km and 18.5 g CO_2). From the distribution center to the store, eggs, chicken and beef travelled the farthest (276.6 km) and showed the highest emission during this stage (8.1 g CO_2). Almonds and dried beans were the items that travelled the shortest distance and emitted the least (108.4 km and 4.5 g CO_2). For all commodities, the longest stage was from the processing plant to the distribution center, which was also the stage associated with greater CO_2 emissions.

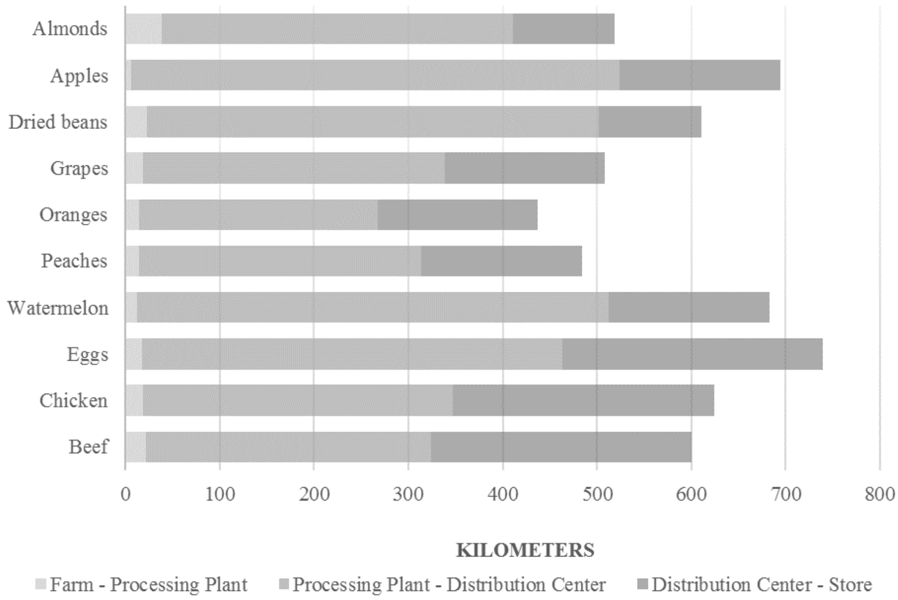

Figure 2. Kilometers at each stage based on the actual load weights transported, distance and truck type for each commodity*

*Does not include empty back haul, weight loss adjustment at any stage.

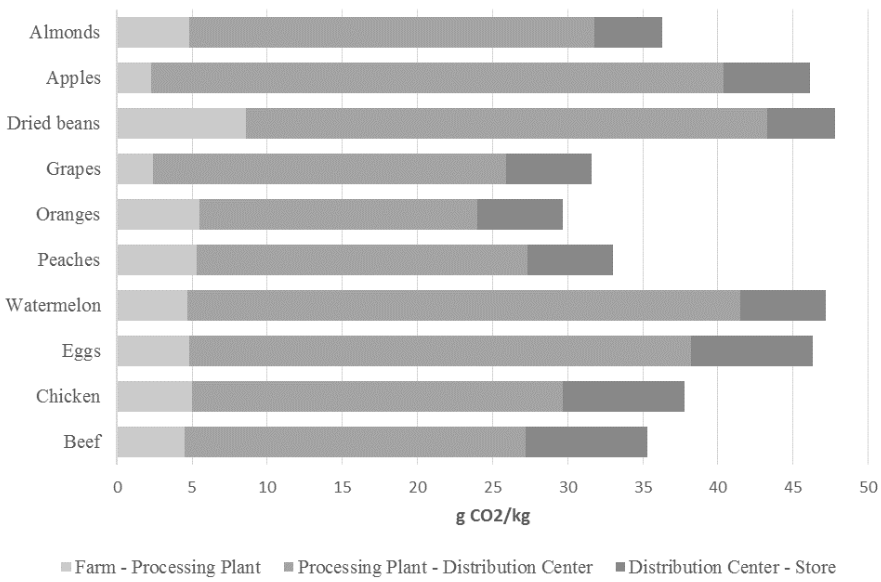

Figure 3. CO_2 emissions at each stage based on the actual load weights transported, distance and truck type for each commodity*

*Does not include empty back haul, weight loss adjustment at any stage

Table 2 shows the total CO_2 emissions related to each commodity at all stages and the percentage of the total emissions, including adjustments for weight loss and accounting for empty back haul trips (table 1). By weight at the store, almonds had the highest total CO_2 emissions related to transportation (78 g CO_2/kg), while oranges had the lowest amount of CO_2 (47 g CO_2/kg). For all commodities, stage 2 (processing plant to distribution center) produced more than the half of the total CO_2 emissions. When comparing among different food commodities, this stage made up 84% of the total emissions for the transportation of apples, and, at the same time, their transportation emitted the most during this stage (61 g CO_2/kg). It was relatively less intense for almonds (54 % of its total emissions (42 g CO_2/kg)). However, oranges were the product that emitted the least (30 g CO_2/kg).

Table 2. g CO_2 from transport* at each stage to deliver 1kg of commodity at the store, with % of total

Commodity	Farm to processing plant (%)	Processing plant to distribution center (%)	Distribution center to store (%)	Total g CO_2/kg
Almonds	29 (37)	42 (54)	7 (9)	78
Apples	4 (5)	61 (84)	8 (11)	73
Dried beans	16 (21)	53 (71)	6 (8)	75
Grapes	4 (7)	38 (77)	8 (16)	50
Oranges	9 (20)	30 (63)	8 (17)	47
Peaches	9 (17)	35 (68)	8 (15)	52
Watermelons	8 (11)	60 (79)	8 (10)	76
Eggs	7 (10)	56 (76)	11 (15)	73
Chicken	13 (20)	42 (63)	11 (17)	66
Beef	18 (27)	38 (57)	11 (16)	68

*the figures presented factor in weight loss adjustment and empty back haul

On a calorie provision basis, watermelons had the highest associated CO_2 emissions (253 g CO_2/1000 kcal), while almonds had the lowest (13 g CO_2/1000 kcal) (table 3). Controlling for distance gave beef the highest CO_2 emissions per kg of commodity (171 g CO_2) and grapes the lowest CO_2 emissions (116 g CO_2/kg) (table 3). All 10 commodities showed almost identical results when distance was factored in (table 3).

Table 3. Total g CO_2 from transport for each commodity from farm to the store* in relation to calorie return, controlling for distance** and taking distance into account

Commodity	g CO_2/1000 kcal of commodity	g CO_2/ kg**	g CO_2/ kg/1000Km
Almonds	13	155	59.8
Apples	140	148	56.9
Dried beans	22	147	64.3
Grapes	72	116	54.5
Oranges	96	146	61.8
Peaches	133	147	61.1
Watermelons	253	149	59.5
Eggs	51	136	58.2
Chicken	31	160	61.2
Beef	23	171	63.6

*the figures present factor in weight loss adjustment and empty back haul

** the distances at each stage were averaged across all 10 commodities. The average distance for each stage was then applied to each commodity.

4. Discussion

This analysis combined primary and secondary data sources to develop a methodology for assessing transport related CO_2 emissions for 10 popular food commodities grown, distributed and sold in California by one of the largest retailers. This method is replicable for future assessments of transport-related food emissions across other locations and commodities. While the primary objective was to develop a transferable methodology, the results revealed some interesting findings. We demonstrate that a variety of factors aside from food miles were all important factors in overall emissions, including the fuel efficiency of the trucks and weight changes between stages. Additionally, we show variability regarding transport-related CO_2 emissions among different commodities.

California is a useful example as it produces a large range of commodities grown on large-scale farms and processed by major handlers. Using California as a case study also has the advantage that the scale of the area makes the methodology relevant to some countries. In this case, the methodology could represent domestic food flows, for example in the UK.

Food policy-makers assess the sustainability of food transportation focusing exclusively on the distance that a food item travels throughout its life cycle (food miles). Our results confirmed previous analyses reporting that the average distance travelled per commodity was around 1065 km, similar to the average distance of 1092 km in our analysis (Pratt, 2013). However, others showed an average of 1650 km from producer to retail (Weber & Matthews, 2008), which is much higher than our data. Their assessment of the food miles did not use as reliable data as we used in the current study. For example, we used real data from the location of farms, processing plants, distribution center and stores. Additionally, geospatial techniques were utilized when assessing distance. This trustworthy information was not considered in previous studies (Weber & Matthews, 2008).

In spite of the increasing attention focused on food miles, our results concur with previous assessments which showed that food miles are of little value per se (Brodt et al., 2013; Coley, Howard, & Winter, 2009; Coley et al., 2011). We observed that a longer distance is not equivalent to higher emissions (figures 2 and 3, and table 3). In fact, some authors reported that assessing the environmental impact of food transportation just by food miles is too simplistic as it overlooks other relevant sustainability matters (Passel, 2013). Instead, it appears that a range of factors together influence overall CO_2 emissions without any one dominant factor. The unadjusted data (figures 2 and 3) shows that distance and CO_2 emissions are not as closely correlated as might be expected. This is a result of non-identical trucks being used across the commodities, which resulted in differences in fuel efficiency. For example, grapes travelled further than peaches yet had lower associated CO_2 emissions as they were transported in a much more fuel-efficient truck from the farm to the processing plant. This also applied between stages for the same commodity. For example, for almonds, stage 2 was around 10 times the distance of stage 1, however the carbon emissions increased only by a factor of 5. Also, stage 3 was more than 2 times the distance of stage 1, yet had fewer CO_2 emissions (figure 3). These results are due to differences in the fuel efficiency of trucks (for almonds the fuel efficiency was 57 ton miles per gallon in stage 1 compared to 98 ton miles per gallon in stages 2 and 3). The importance of taking into account the fuel efficiency of the means of transportation has been already reported (Egilmez & Tatari, 2012). In fact, the implementation of plans to increase the utilization of more efficient vehicles has been proposed as a potential measure to reduce the CO_2 emissions (Egilmez & Tatari, 2012). When weight loss and empty back haul trips were also factored in, the relationship between distance and CO_2 emissions became even less dramatic. For example, almonds and grapes were from the same source area and therefore had very similar unadjusted distances and CO_2 emissions (figures 2 and 3), yet had very different emissions after adjusting for weight changes (table 2). While weight loss was very important for the total emissions of almonds, this was less important for beef, which had lower emissions than eggs (table 2) despite a much greater weight loss associated with beef (table 1). These findings confirm Coley et al. (2011) when reporting that GHG emissions related to transportation would depend on the food miles, the mode of transportation used and the amount of product transported (Coley et al., 2011).

We observed clear differences in CO_2 emissions from the transportation of the same amount of different food commodities, ranging from 47 to 78 g CO_2 per kg of product. As we reported here, most of the analysis assessing food sustainability consider CO_2 emissions in terms of weight of food. Nevertheless, it is also important to consider this assessment in relation to other relevant food aspects, as energy provision, as the results could be altered significantly (Weber & Matthews, 2008). We observed that while almonds had the highest associated CO_2 emissions on a weight basis, they had the lowest CO_2 emissions in terms of calories provided (table 3). There was a much higher variation in CO_2 emissions based on energy return amongst the fruits (which tend to have a low energy density), ranging from 72-253g CO_2/1000 kcal), compared to the high protein and energy dense commodities (almonds, beans, chicken and beef), with a range of 13-31g CO_2/1000 kcals (table 3).

As with every analysis, assumptions were made regarding the transportation pathways, distances, and backhaul. In reality, such assumptions will vary due to numerous factors including modal use, commodity, and distribution practices (O'Donnell et al., 2009). In turn, the results could vary dramatically. For example, just varying assumptions related to empty backhaul and vehicle utilization can lead to substantial reductions in emissions

(Facanha & Horvath, 2007). Also, the results showed that weight loss was an important determinant of CO_2 emissions. The reliability of such factors is therefore very important. It is possible that future analyses could improve on the data used in this analysis. For example, the data sourced losses for watermelons and grapes from first distribution to the retail store, were 10% and 9% respectively, whereas for eggs this figure was much lower at 1.5% (USDA, 2012b), despite the high likelihood of losses due to shell breakage.

This study is exclusively focused on road transportation. Rail and shipping modes tend to be much more efficient and hence emit less CO_2 per km travelled per unit of commodity in comparison to road vehicles (O'Donnell et al., 2009). Therefore, the results presented here, which exclusively used road freight transport, could be lower if more efficient modes were used. However, it should be emphasized that road transport moves around two thirds of freight tonnage in the U.S., and accounts for 78% of CO_2 emissions from freight (US Department of Transportation [DOT], 2005). Road transport is also the main mode for food freight tonnage in the U.S. (DOT, 2015), and the main mode for most non-domestic imports and exports to and from the U.S. (DOT, 2013). Hence, our results are relevant to current issues and trends related to freight transportation.

The results presented here account for less than half of all transport-related food emissions (Weber & Matthews, 2008). Transportation of cultivation inputs, such as fertilizer, diesel fuel, and packaging were not included, which can account for around 45% of the total transport emissions (Manfredi & Vignali, 2014). While the majority (77%) of CO_2 emissions from road transport arise from tailpipe emissions, the results presented here would be higher if all transport related emissions were included, such as those resulting from vehicle manufacturing, maintenance, and end of life, infrastructure construction, operation, maintenance, and petroleum exploration, refining, and fuel distribution (Facanha & Horvath, 2007).

The focus on CO_2 emissions in this analysis excludes other emissions of gasses with greenhouse effect, such as NOx, SOx and O_3. The US Department of transportation has recently reported that CO_2 from fossil fuel combustion is responsible for almost all (95%) GHG emissions from transportation sources (DOT, 2017). Thus, it does not seem probable that the main result would significantly change taking the other gasses emissions into account. We did not assess other transportation externalities, such as traffic congestion, road accidents, noise pollution (Coley et al., 2009), and other adverse health effects on local communities (Soret, Montgomery, & Spencer-Hwang, 2015). Future methodological developments of transport-related food emissions could thus be improved by taking into account the limitations discussed here.

Besides the observed variation in CO_2 emissions derived from the transportation of different food commodities, it is essential for the assessment of food sustainability to consider the overall lifecycle impacts of the food. Some authors have previously pointed out that the life cycle approach is more suitable than transportation (Coley et al., 2011). In fact, the food emissions derived from their transportation on average represents a relatively small proportion (11%) of total emissions from production to post-consumer waste disposal (Weber & Matthews, 2008). The fact that a food had been produced near the destination does not necessarily imply that is more sustainable (Pratt et al., 2017). For example, tomatoes grown in Sweden to be consumed in Sweden resulted in higher CO_2 emissions compared to tomatoes imported from the Netherlands and Spain, which had the lowest associated CO_2 emissions (Carlsson-Kanyama, 1997). A previous study assessing food production and its transportation came to the conclusion that emissions related to transportation could vary among different food products, but the distance travelled is not such a relevant factor when assessing the whole sustainability of a product (Weber & Matthews, 2008). It has been reported that the emissions related to the production of different foods, and the differences among these values, are much higher than the emissions derived from food transportation (Clune et al., 2017).

5. Conclusion

This analysis combined primary and secondary data sources together with geospatial technologies to develop a methodology for assessing transport- related CO_2 emissions for 10 popular food commodities, conventionally grown, distributed and sold in California. While California was used as a case study, this method is replicable across other locations and commodities. Future assessments of transport-related food emissions could further progress the method developed here by taking into account the associated limitations. Nevertheless, policy-makers should consider the overall lifecycle of the food when making decisions according to the global sustainability of food.

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