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The carbon footprint of vegetable imports into Aruba: A closer look at sea and air transport

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ABSTRACT

This study aimed to give insights into low-carbon vegetable import strategies for Aruba, a Dutch Caribbean island. Our selected products were potatoes, lettuce, onions, tomatoes, and green beans. The products originated from 13 different countries, and 25 product-country combinations were identified. The system boundaries were from the farm until arrival at the supermarket. We identified actual maritime transport routes, and calculated greenhouse gas (GHG) emissions of passenger aircrafts flying from Amsterdam to Aruba. Vegetables imported by air had significantly higher GHG emissions (4.2–8.3 kg CO_2eq per kg) than products imported by sea (0.4–2.3 kg CO_2eq per kg). GHG emissions of road transport generally contributed more than those of other life cycle stages, except when products showed a high contribution of agriculture. Although sea transport was calculated with much detail, it usually did not contribute much to the GHG emissions. We recommend Life Cycle Practitioners to consider aircraft characteristics when calculating GHG emissions of air transport, and to include the weight of the 80 kg AKE container, used for cooled airfreight, when allocating impacts between passengers and freight. For this case study, GHG emissions of specific passenger aircrafts always resulted in lower GHG emissions compared to generic calculations.

1. Introduction

Increasing the consumption of vegetables is important for human and for planetary health (e.g. Kesse-Guyot et al., 2023; Willett et al., 2019). For planetary health, it is important to gain insight into the environmental impact of vegetables. Many studies have assessed the environmental impact of vegetables, covering different types of vegetables, production methods, and countries of origin (e.g. Frankowska et al., 2019; Michalský and Hooda, 2015; Milà i Canals et al., 2008; Stoessel et al., 2012).

The stages in the supply chain that usually contributed most to the carbon footprint of vegetables were land use change, production at the farm, transport, and losses (Poore and Nemecek, 2018). However, this also differed per country of origin. For example, tomatoes from Benin were found to have a relatively high contribution of greenhouse gas (GHG) emissions from land use change of 3.0–7.9 kg CO_2eq per kg, whereas the total GHG emissions of tomatoes from the United States were 0.6–0.8 kg CO_2eq per kg (Poore and Nemecek, 2018, appendix: Database). Packaging of food and beverages was usually not one of the main contributing life cycle stages. To further illustrate, Caspers et al. (2023) found that food and beverage packaging makes up 0.3 % of the overall carbon footprint of the food consumption of an average German household.

It is interesting that although it is generally stated that transport only contributes about 5–10 % to global food system's GHG emissions (IPCC, 2019), Mengyu et al. (2022) recently showed that GHG emissions of food transport might be 3.5 – 7.5 times higher than previously estimated. They indicated that transport accounted for about 19 % of total food-system emissions, and for 36 % in the case of fruits and vegetables, considering the life cycle stages of production, land use change, and transport. A higher contribution of transport to GHG emissions of vegetables compared to other foods was due to the need of temperature-controlled transportation of vegetables. For some products, similar and higher results were found by Poore & Nemecek (2018, appendix: Database), transport contributed for 49 %, 30 % and 14 % to the categories 'Other vegetables', 'Onions & leeks', and 'Tomatoes', when

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considering the same life cycle stages as Mengyu et al. (2022). However, when other life cycle stages (Processing, Retail, Packaging, and Losses) were also included, the contribution of transport lowered to 32 %, 18 %, and 9 %, respectively. Thus, it depends on the system boundaries and on the vegetable type how much transport contributed to total GHG emissions.

Among the vegetables with the highest carbon footprint are air freighted vegetables, and vegetables produced in certain types of greenhouses. Casey et al. (2022) found that the carbon footprint of lettuce could vary 51-fold, ranging from 17.8 kg CO_2eq per kg for lettuce produced in a greenhouse with coal as electricity source, to 0.15 kg CO_2eq per kg for field-grown lettuce, from cradle-to-regional distribution center (RDC). Lettuce that was produced on the field but that was air freighted from the United States to the United Kingdom (8817 km), emitted 10 kg CO_2eq per kg, mainly due to the air freight. Similarly, Milà i Canals et al. (2008) found that green beans air freighted from Kenya or Uganda to the United Kingdom had a carbon footprint of almost 11 kg CO_2eq per kg, whereas green beans produced in the United Kingdom had a carbon footprint of 1.4–1.6 kg CO_2eq per kg, from cradle-to-RDC.

In this article, we aimed to give insight into GHG emissions of vegetable imports into Aruba, from cradle-to-retail. Aruba is a small island in the Dutch Caribbean, situated North of Venezuela. The population size is ~110.000 citizens, living on 180 km^2 (The World Bank, 2021). A characteristic of Aruba is the high dependency on tourism. Aruba's hospitality and tourism sector contributed more than 87 % to the national GDP (International Monetary Fund, 2019). Aruba's food system shows a near-dependence on imports (Boyer et al. 2020). Most foods are imported to Aruba by sea, although 1.1 % of all food is imported by air. Foods imported by air are mainly fresh vegetables (37 % of flown-in foods), fresh fish (13 %), dairy (13 %), and fresh fruits (12 %). Of all vegetables, 3 % is imported by air (own calculations from data CBS Aruba, personal communication, March 11, 2021).

As mentioned above, air freighted vegetables are among those with the highest GHG emissions. However, in all studies known to the authors, GHG emissions of air transport were modelled using a generic approach, which did not consider the aircraft models used. Research using such a generic approach are Casey et al. (2022); Frankowska et al. (2019); Mengyu et al. (2022); Milà i Canals et al. (2008); Stoessel et al. (2012). It was not always clear whether the selected process was based on a passenger aircraft, a cargo aircraft, or a combination of both. Nearly all food products imported into Aruba by air were imported with passenger aircrafts, which is common for many tourist destinations, and especially for island destinations (Button, 2021). However, GHG emissions can be different when using different types of passenger aircrafts. Davydenko et al. (2020) calculated GHG emissions of transporting cargo shipped on passenger aircrafts, referred to as belly freight, were 0.41–0.77 kg CO2eq per tkm, depending on the aircraft type and distance covered. Globally, half of all air cargo is shipped by passenger aircrafts, and shipping air cargo in passenger aircrafts has increased in times of higher oil prices and fiercer competition between airlines (Bilotkach, 2021). The lack of calculating GHG emissions of transporting cargo by passenger aircraft is an important gap in the literature of LCA's associated with the food chain. Also, the difference in GHG emissions of different types of aircrafts can be important as well.

Another important aspect of Aruba's food chains is the dependency on sea transport, while not being situated on main maritime transport routes. Therefore, actual sea transport routes and types of ships used were determined in detail. This is not a mainstream approach, as most LCA practitioners use sea distance calculators and do not take into account the types of ships used (e.g. Frankowska et al., 2019; Pérez-Neira et al., 2020; Takacs et al., 2022). Other authors base sea transport distances on local documents (e.g. Bell and Horvath, 2020) or on data provided by importing companies (e.g. Goossens et al., 2019).

To study the transport routes of vegetable imports into Aruba we started from the extensive database of the carbon footprint of vegetables from Poore & Nemecek (2018) (cradle-to-retail) which contains data of 570 different agricultural studies, through a unified methodology. We then collected data on transport routes (road, air, sea) for importing vegetables into Aruba. Overall, we aimed to get insight into the carbon footprint of vegetable imports into Aruba, with emphasis on modelling GHG emissions of belly freight, and actual maritime transport routes. Our focus was on case studies of a selection of vegetables.

2. Methods

In this study, three innovations were introduced to calculate the GHG emissions of vegetable imports. First, actual maritime transport routes and ship characteristics were modelled (Section 2.4.5). Second, GHG emissions of the specific passenger aircrafts that were actually flying from Amsterdam to Aruba were modelled (Section 2.4.6). Third, the weight of the 80 kg specialized AKE container for cooled airfreighting was included in the model (Section 2.4.3).

2.1. Selection of vegetables

Vegetables were selected by their weight contribution to the total vegetable category in Trademap import statistics from 2017 – 2019 (International Trade Center, 2020), potatoes were included in this category. This timeframe was selected to represent pre-covid vegetable import levels, as Aruba was highly impacted by the pandemic, and more recent data might not reflect current vegetable consumption patterns. The most imported vegetables into Aruba were selected: potatoes (18.5 wt%), lettuce (10 wt%), onions (10 wt%), and tomatoes (8.5 wt%). Green beans were also selected as an interesting case study; these can be flown in from Kenya via the Netherlands or shipped to Aruba by sea from the United States. The import quantity of green beans was not available, as green beans were grouped together with other vegetables in the trade statistics. In total, a minimum of 47 wt% of vegetable imports were included in this analysis.

For all five products, the countries of origin were determined via Trademap and by visiting supermarkets in Aruba. In May 2022, nine different-sized supermarkets across Aruba were visited three times during three weeks. Additional product-country combinations, that were not identified via Trademap, were discovered through the supermarket visits. Table S1 in the appendix shows the countries of origin per product and whether the origin was identified via Trademap, via the supermarket, or both. To identify the countries of origin, it was important to use both Trademap data and to visit supermarkets, as explained in section 1.1 of the appendix. Thirteen countries of origin and 25 product-country combinations were identified (visualized in Fig. 1).

2.2. Carbon footprint calculations

Life cycle assessment (LCA) is a methodology used to assess the environmental impact of products and services. In this study we focused on the environmental impact indicator climate change, also known as global warming or carbon footprint. According to the ISO 14,040 standard, we present in the following sections the goal and scope definition (Section 2.3), the inventory analysis (following sections), the impact assessment (Section 3), and the interpretation (Section 3) (Hauschild, 2018).

2.3. Goal and scope definition

This study explored the carbon footprint of vegetable imports into Aruba, with a focus on transportation by air, and sea. The system boundaries ranged from farm in country of origin until arrival at the supermarket in Aruba (Fig. 1). The system boundaries included agriculture (including land use change), processing, packaging, losses (post-harvest and distribution) and chilled road/sea/air transport. Fig. 1 also

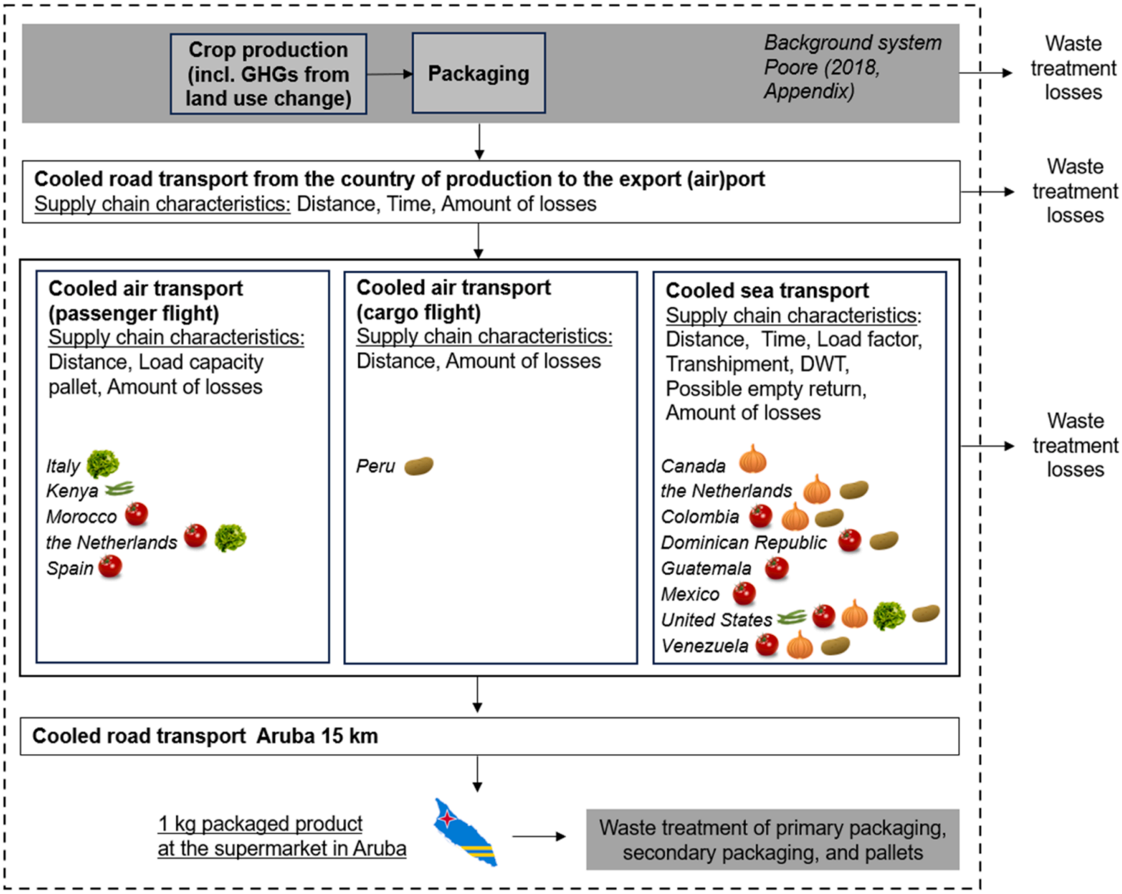

Fig. 1. System boundaries and supply chain characteristics for vegetable imports to Aruba. Dark grey boxes indicate the background systems from Poore & Nemecek (2018, appendix: Database). Processes outside of the dotted box were not included in our model.

mentions further parameters (such as distance and time) on the supply chain per vegetable and country combination. The functional unit of this study was 1 kg packaged product at the supermarket in Aruba.

2.4. *Supply chain description and inventory data*

The supply chains are depicted in Fig. 1. Three different LCA databases were used: the meta-analysis “LCA of food & drink products” from Poore & Nemecek (2018) as the basis, Agri-footprint version 4.0 for data on sea transport, and ecoinvent version 3.3 for data on road transport and air transport. Following Poore & Nemecek (2018), the characterization method IPCC 2013 GWP 100a was used. Details on these processes are displayed in the Appendix (section 1.2).

After harvest, postharvest losses occurred, and products were packaged. Then, products were transported to the harbor or airport. Products from Mexico, Guatemala, Canada, and the United States were transported by truck to port Everglades in the United States. Onions and potatoes from the Netherlands were trucked to the port of Rotterdam. Products from Colombia were trucked to the port of Barranquilla or Cartagena; it was assumed that both ports were used equally frequently. Products from the Dominican Republic were assumed to be trucked to the port of Caucedo. Tomatoes from Morocco required additional sea transport between Tanger (Morocco) and Algeciras (Spain). Sea transport distances and durations are shown in the right columns of Table 1. After sea transport or air transport of the products to Aruba, 15 km of cooled road transport occurred in Aruba (Aruba’s dimensions are 32×10 km on 180 km^2).

Some products were transported directly to Aruba, while transshipment occurred for other products. Onions and potatoes from the Netherlands were shipped to Aruba via Jamaica. Products from Colombia and the Dominican Republic were shipped directly to Aruba. All other products imported by sea were shipped via port Everglades in Florida. Potatoes from Peru were flown in directly via a small cargo plane. Other products imported by air were flown in from Amsterdam (the Netherlands), with passenger aircrafts. Green beans from Kenya required additional air transport from Kenya to the Netherlands.

2.4.1. *Agriculture and processing*

GHG emissions from agriculture and processing were selected from Poore & Nemecek (2018, appendix: Database). These authors describe how they adjusted the results of 570 different agricultural studies to make those comparable. For the present study, when data from a specific country of origin was not available, data points of all neighboring or the most nearby countries were selected as proxies. For example, as visible in the first row of Table 1, there was no data on onions from Canada and data from the United States was used as a proxy. For the majority of the data information from the country of origin actually was available (column proxy is then marked by n.a. in Table 1). Data points selected for this analysis ranged from 2006 – 2015. For some product-country combinations several data points were available. In these cases a weighted average was calculated, based on the representativeness of a data point as determined by Poore & Nemecek (2018, appendix: Database). The likelihood of specific production methods (for example, organic vs non-organic) occurring for a product-country combination was included in these weights. For the products in this study the life cycle stage ‘processing’ was only included for lettuce from Italy (Poore and Nemecek, 2018, appendix: Database).

Table 1

Characteristics of agricultural data and transport data for product-country combinations. Abbreviations for proxies are: Colombia (CO), Peru (PE), Spain (ES), United Kingdom (UK), and the United States (US). The location of the farm was determined by four different approaches or a combination of these, with the preference ranging from A to D, based on the appendix of Poore & Nemecek (2018). A: Geographic specification, B: Geographic specification of the same product, C: Geographic specification of similar products, D: Center of country. Numbers between brackets represent an average.

Country	Product	Proxies	*Farm* Number of data points	*Farm* Method for location	Road transport (km)	Cooling of road transport (days)	Sea transport (km)	Cooling of sea transport (days)	Air transport (km)
Canada	Onions	US	1	C	2252 – 4829 (4685)	0.9 – 1.9 (1.6)	2330	6	n.a.
Colombia	Tomatoes	n.a.	1	B	989 – 1045 (1017)	0.6 – 0.7 (0.7)	1174	5	n.a.
	Onions	US	1	C	989 – 1045 (1017)	0.6 – 0.7 (0.7)	1174	5	n.a.
	Potatoes	PE	1	C	989 – 1045 (1017)	0.6 – 0.7 (0.7)	1174	5	n.a.
Dominican Republic	Tomatoes	CO	1	D	139	0.1	2287 – 2303 (2300)	10	n.a.
	Potatoes	PE	1	D	139	0.1	2287 – 2303 (2300)	10	n.a.
Guatemala	Tomatoes	CO	1	D	4328	2	2330	6	n.a.
Italy	Lettuce	n.a.	3	A	1121 – 1294 (1236)	0.5 – 0.6 (0.5)	n.a.	n.a.	7872
Kenya	Green beans	n.a.	1	C	33 – 41 (37)	0.0	n.a.	n.a.	14,534
Mexico	Tomatoes	US	6	C	3360 – 3513 (3404)	1.4 – 1.5 (1.4)	2330	6	n.a.
Morocco	Tomatoes	n.a.	1	A	3278	1.3	31	0	7872
Netherlands	Tomatoes	n.a.	8	2xA 6xB	57 – 64 (61)	0.0	n.a.	n.a.	7872
	Onions	n.a.	3	C	76	0.0	10,901	30	n.a.
	Lettuce	n.a.	2	C	76	0.0	n.a.	n.a.	7872
	Potatoes	n.a.	5	1xA 4xB	61	0.0	10,901	30	n.a.
Peru	Potatoes	n.a.	2	A	69 – 1307 (688)	0.1 – 0.9 (0.5)	n.a.	n.a.	2823
Spain	Tomatoes	n.a.	15	14xA 1xB	1507 – 2315 (1866)	0.6 – 0.9 (0.7)	n.a.	n.a.	7872
United States	Green beans	ES, UK	5	C	266 – 5161 (3828)	0.1 – 2.0 (1.5)	2330	6	n.a.
	Tomatoes	n.a.	6	A	266 – 4595 (2804)	(0.1 – 2.0) 1.0	2330	6	n.a.
	Onions	n.a.	1	A	4775	1.8	2330	6	n.a.
	Lettuce	n.a.	4	A	4352	1.6	2330	6	n.a.
	Potatoes	n.a.	2	1xA 1xB	5161	2.0	2330	6	n.a.
Venezuela	Tomatoes	CO	1	D	757	0.6	120 – 157 (139)	0.3 – 0.4 (0.4)	n.a.
	Onions	US	1	D	757	0.6	120 – 157 (139)	0.3 – 0.4 (0.4)	n.a.
	Potatoes	PE	2	D	757	0.6	120 – 157 (139)	0.3 – 0.4 (0.4)	n.a.

Table 2
Post-harvest losses, losses during processing, and losses during distribution per vegetable and origin, as provided by Poore & Nemecek (2018, appendix: Database). *SCAC stands for South and Central America and the Caribbean. The abbreviations for the countries are: Canada (CA), Colombia (CO), Dominican Republic (DO), Guatemala (GT), Italy (IT), Kenya (KE), Mexico (MX), Morocco (MA), the Netherlands (NL), Peru (PE), Spain (ES), United States (US), and Venezuela (VE).

Product	Post-harvest losses (Poore and Nemecek, 2018, appendix: Standardisation)	Losses during processing (Gustavsson et al., 2013)	Losses during distribution (Gustavsson et al., 2013)
Potatoes	NL: 1.9 % US: 4.1 % DO: 10.2 % CO: 11.5 % PE: 21.8 %	n.a.	SCAC* (CO, DO, PE): 3 % Europe (NL): 7 % Northern America (US): 7 %
Onions	NL: 2.7 % CA: 4.7 % US: 5.0 % VE: 12.0 % CO: 18.6 %	n.a.	Europe (NL): 10 % Northern America (CA, US): 12 % SCAC* (CO, VE): 12 %
Lettuce	NL: 3.1 % US: 5.3 % IT: 10.8 %	Europe (IT): 2 %	Europe (IT, NL): 10 % Northern America (US): 12 %
Tomatoes	VE: 2.2 % CO: 3.8 % MX: 4.0 % NL: 4.0 % ES: 4.3 % US: 5 % MA: 7.8 % DO: 9.9 % GT: 10.9 % VE: 13.0 %		Europe (ES, NL): 10 % SCAC* (CO, DO, GT, MX): 12 % Northern America (US): 12 % Africa (MA): 15 %
Green beans	KE: 4.7 % US: 5.3 %	n.a.	Northern America (US): 12 % Africa (KE): 17 %

2.4.2. *Losses*

Losses were determined based on the country of origin (not on the proxies). Losses were estimated for post-harvest handling, processing, and for distribution (Table 2). To incorporate the weight of the losses into the calculations, it was assumed that post-harvest losses occurred at the farm, and that products were packaged afterwards. Packaging of the losses was accounted for. End-of-life treatment of losses was not included (as shown in Fig. 1, being outside the system boundaries). To determine the quantity of post-harvest losses an average of 2009–2011 from FAOSTAT was used, as provided by Poore & Nemecek (2018, appendix: Standardisation). The FAOSTAT data categories on losses during distribution exactly matched for potatoes and tomatoes. The losses for onions, lettuce, and green beans were matched with the FAO STAT categories ‘onions and leeks’, ‘other vegetables’, and ‘other vegetables’, respectively.

For losses during distribution, data from Annex 1 in Gustavsson et al. (2013) was used, as provided in Poore & Nemecek (2018, appendix: Standardisation). This data was based on FAO’s Food Balance Sheets from 2007, additional resources used for products in this study ranged from the years 2001 – 2011. Losses during distribution were available in aggregated form per continent, as shown in Table 2. Losses during distribution of potatoes were matched with FAO’s category ‘roots and tubers’, whereas losses for all other products were matched with the FAO category ‘fruit and vegetables’. It was assumed that half of the losses during distribution occurred during road transport and half of the losses during sea or air transport.

2.4.3. *Consumer packaging and packaging for transportation*

It was assumed that all products were packaged at the farm and that the packaging materials remained the same throughout the supply chain. Next to primary (direct package) and secondary (boxes) packaging, also a pallet (wooden or foam), and plastic film around the pallet were included. Foam pallets were only used for products imported by air. Air freighted products were more often transported on wooden than on foam pallets, therefore the weight of foam pallets were not included in our analysis. For products flown in by large aircrafts, the 80 kg AKE container that entered the aircraft was also included. All flown-in products except for potatoes from Peru arrived in large aircrafts and in an AKE container. Transport of the weight of the packaging materials (see Table 3) was included in the GHG emissions calculations for transport. The carbon footprint of the packaging was copied directly from Poore & Nemecek (2018, appendix: Packaging).

Products could be transported either on wooden or on foam pallets. Wooden pallets were used more often and were discarded after use (Superfood, personal communication, October 2, 2023). Different types of wooden pallets were used, the average weight of a wooden pallet was 21.9 kg, based on 7 measurements (own measurements). Foam pallets weighed 3.1 kg. All vegetables were mixed on one pallet, except for

Table 3
Weight of packaging materials. For products with a (*) there was no data available about primary and secondary packaging in Davis et al. (2011), an average was calculated based on all vegetables. Products with a (**) were imported on pallets mixed with other products, therefore an average was calculated.

Product	Primary packaging (g kg^{-1} product)	Secondary packaging (g kg^{-1} product)	Wooden pallet (g kg^{-1} product)	Foam pallet (g kg^{-1} product)	Plastic film (g kg^{-1} product)	AKE container (g kg^{-1} product)	Total packaging (g kg^{-1} product)	
							Wooden pallet	Foam pallet
Potatoes	6*	13*	35**	n.a.	1.0**	130**	184	n.a.
Onions	6*	2	35**	n.a.	1.0**	130**	173	n.a.
Lettuce	7	8	35**	4.9**	1.0**	130**	180	145
Tomatoes	6	6	49	6.8**	1.4	180	240	192
Green beans	6*	12*	35**	4.9**	1.0**	130**	183	148
References	Table 9 from Davis et al. (2011)	Table 11 from Davis et al. (2011)	See Section 2.4.3	See Section 2.4.3	See Section 2.4.3	See Section 2.4.3	See Section 2.4.3	See Section 2.4.3

Table 4
Characteristics of Airbus A330–203 and Airbus A330–303.

	A330–203	A330–303	Source
Operating empty weight (OET)	121 ton	121 ton	(Aircraft Commerce, 2008)
Passenger capacity	248	292	(SkyTeam Virtual, 2023a, 2023b)
Cargo capacity	18.7 ton	21.2 ton	(SkyTeam Virtual, 2023a, 2023b)
Range	13,427 km	11,760 km	(SkyTeam Virtual, 2023a, 2023b)
Maximum Landing Weight (MLW)	182 ton	187 ton	(European Union Aviation Safety Agency, 2023; SkyTeam Virtual, 2023a, 2023b)
Maximum Take-off weight (MTOW)	242 ton	242 ton	(European Union Aviation Safety Agency, 2023; SkyTeam Virtual, 2023a, 2023b)
Maximum Zero Fuel Weight (ZFW)	170 ton	175 ton	(European Union Aviation Safety Agency, 2023; SkyTeam Virtual, 2023a, 2023b)

tomatoes which were imported per pallet (Superfood, personal communication, August 18, 2023). The plastic film around a pallet weighed 640 g (De Vlieghere et al., 2023). The amount of product per pallet was 435 kg for tomatoes, and on average 631 kg for other products (Center for Environmental Farming Systems, 2016).

Flown-in products were transported in AKE lower-deck containers (J. Janssen, personal communication, April 10, 2023), a type of United Load Device (ULD) that weighed 80 kg (Freja, 2023; PalNet GmbH Air Cargo Products, 2023; VRR, n.d.). Although the International Air Transport Association (2022a) recommended excluding ULDs in the calculation of GHG emissions of air freight, the authors decided to include the weight of the ULDs. Because additional infrastructure for transporting passengers is also included when allocating GHG emissions between cargo and passengers (see Section 2.4.6), and the absence or presence of ULDs influences the actual cargo capacity available for the products, which in turn influences the amount of GHG emissions allocated to cargo.

2.4.4. *Road transport*

The distance by road was based on the fastest route in Google Maps. The locations of the farms was based on Poore & Nemecek (2018, appendix: Database), using four different approaches or a combination of these, as shown in Table 1. With the preference ranging from A to D, with A: Geographic specification, B: Geographic specification of the same product, C: Geographic specification of similar products, D: Center of country. It was assumed that all countries used cooled road transport. For calculating road transport, we deviated from the methodology of Poore & Nemecek (2018) because road transport and cooling of road transport were major contributing processes during one of our iterations (Appendix section 1.3). Cooled road transport in Aruba was assumed to be 15 km.

2.4.5. *Sea transport*

Sea transport was mostly determined via the schedule of CMA CGM, one of the largest container shipping companies (AXSMarine, 2022). Their schedule showed duration, place(s) of transshipment, shipping lines, and vessel names (CMA CGM, 2022b). Data on distances between ports was obtained via the CMA CGM Eco Calculator (CMA CGM, 2022a). Data on the size of the ships was obtained via www.marinetraffic.com, expressed as summer deadweight tonnage (DWT). Often at least one transshipment was required to import products to Aruba. The size of the container ships used on different routes could differ. Smaller container ships were often used for the last transshipment to Barcadera, the port in Aruba. It was assumed that larger container ships (> 13,000 DWT) were sailing at a load factor of 100 %, and smaller container ships, used for the last transshipment to Aruba, at a load factor of 80 %. For these smaller ships an "empty return" was assumed, as Aruba has very limited exports (OEC, 2024). The transport routes from Cartagena and Barranquilla in Colombia were based on a schedule from Caribbean Feeder Services (2022). GHG emissions were determined using the Agri-footprint v4.0 database with economic allocation and were based on the characteristics DWT, load factor, distance sailed, and possible empty return. GHG emissions of cooling were included, to account for cooling of the container before and after the shipment, one additional day was added to the transit time.

Products from Venezuela were transported with smaller cargo boats with a capacity of 40 to 60 tons (ABC Online Media, 2023), either the Gaviota II or the El Maracucho (The Daily Herald, 2023). The boats departed from Venezuela either from the port las Piedras or from the port of Coro, which were between 65 and 85 nautical miles (120–157 km) away from Aruba (Harbor master Aruba, personal communication, August 7, 2023). The ships sailed back empty. It was assumed that 1000 L diesel was used in total for 50 tons of products (personal communication, marine expert Aruba, September 28, 2023).

2.4.6. *Air transport*

GHG emissions from air transport were calculated using three different approaches, of which one for a small cargo aircraft, and two for large aircrafts. First, carbon emissions of a small cargo aircraft were modelled only for potatoes from Peru. Second, for a generic approach for large aircrafts we used the GHG emissions as displayed in Poore & Nemecek (2018). Third, for a specific approach for large aircrafts we calculated GHG emissions of passenger aircrafts from the airline KLM flying from Amsterdam to Aruba, with primary data.

All flight distances were determined with www.airmilescalculator.com and 125 km was added to correct for excess distance due to stacking, traffic, and weather-driven conditions (ICAO, 2018). Small cargo aircrafts emitted 0.86 kg CO_2eq per tkm (SimaPro LCA software). Poore & Nemecek (2018) assigned 1.13 kg CO_2eq per tkm and assumed no additional cooling. Recent articles also used 1.1 kg CO_2eq per tkm for intercontinental air transport, based on a process from the ecoinvent LCA database (e.g. Casey et al., 2022; Mengyu et al., 2022; Stoessel et al., 2012). Calculations of GHG emissions of belly freight are explained in the following paragraphs.

Belly freight calculations

GHG emissions of belly freight were calculated based on an ecoinvent process for long haul intercontinental air transport. This process included airport construction, aircraft construction, cooling, kerosene, and burning of kerosene. The process was adjusted in three ways. First, by calculating the amount of kerosene used and burned. Second, by adding engine oil, as synthetic oil was used in aircraft engines (Federal

Table 5
Allocation of GHG emissions to cargo at different utilizations. Cargo included the product, packaging, and the transport infrastructure.

	A330–203		*A330–303*	
Cargo capacity utilization	Cargo quantity (tons)	Allocation of GHG emissions to cargo	Cargo quantity (tons)	Allocation of GHG emissions to cargo
0.01 %	0.01	0.04 %	0.02	0.03 %
10 %	1.4	4 %	1.5	3 %
20 %	2.7	7 %	3.0	6 %
30 %	4.1	11 %	4.5	9 %
40 %	5.4	14 %	6.1	12 %
50 %	6.8	16 %	7.6	14 %
60 %	8.2	19 %	9.1	17 %
70 %	9.5	22 %	10.6	19 %
80 %	10.9	24 %	12.1	21 %
90 %	12.2	26 %	13.6	23 %
100 %	13.6	28 %	15.2	25 %

Aviation Administration, 2013). Third, by allocating the total GHGs between passengers and cargo. This will be explained in the following paragraphs.

Kerosene

Kerosene use was dependent on the aircraft type and flight distance. The most used passenger aircrafts were the Airbus A330–203 and the Airbus A330–303. The Airbus A330–303 arrived in Aruba most frequently, the Airbus A330–203 arrived twice a week (personal communication station manager KLM in Aruba, E. Croes, April 21, 2023). Table 4 depicts the characteristics of both aircraft types. The Airbus A330–303 had a higher cargo capacity, a higher passenger capacity, and less range than the Airbus A330–203.

GHG emissions of burning kerosene were calculated in three steps. First, the flight distance was calculated. The great circle distance (GCD) from Amsterdam to Aruba was 7883 km (www.airmilescalculator.com). Second, fuel use was calculated based on the corrected GCD, as explained above. For the Airbus A330–203 and the Airbus A330–303 the fuel use was 55,079 kg and 56,587 kg, respectively (ICAO, 2022). Third, GHG emissions from burning fuel were calculated by multiplying the fuel use by the fuel conversion factor 3.16 kg CO_2eq per kg, which is an accepted standard in the field (Graver et al., 2019; ICAO, 2018; International Air Transport Association, 2022a).

Engine oil

Oil use ranged from 0.53–0.82 L per engine per hour. It was recommended to assume an oil use of 0.82 L (J. Jansen, personal communication, April 19, 2023). The block time for a flight from Amsterdam to Aruba was 10 hours. Therefore, the oil use of two engines during this flight was 16.4 L.

cargo:passenger allocation

Total GHG emissions were allocated to the cargo and the passengers by an allocation factor, based on the methodology of the International Civil Aviation Organization (ICAO) (ICAO, 2018), a United Nations Agency. This method was also used by Graver et al. (2019), by Davydenko et al. (2020), by Klein et al. (2021), and by the International Air Transport Association (2022). Perishable cargo was transported in Unit Load Devices (ULDs), which are one pallet-sized containers shaped to fit in a plane (see Section 2.4.3).

Allocation to cargo was calculated at different cargo capacity utilization rates. Because no data was available on cargo capacity utilization, and this may differ from flight to flight. The following formula was used to calculate the allocation factor:

$$Allocation\ to\ cargo\ =\ \frac{Cargo\ (kg)}{Cargo\ (kg) + No.\ Passenges \times 100kg + No.\ of\ seats \times 50kg}$$

In the above formula, 100 kg represented the average passenger mass with baggage, and 50 kg accounted for the on-board equipment and infrastructure associated with passenger use (ICAO, 2018). This included the seats, toilets, catering, and service staff and was included also when the seat was not occupied. The number of passengers was calculated based on the average passenger utilization of the airline KLM for flights to the Caribbean. This was 90 % from 2016 – 2019 (KLM, 2017, 2019).

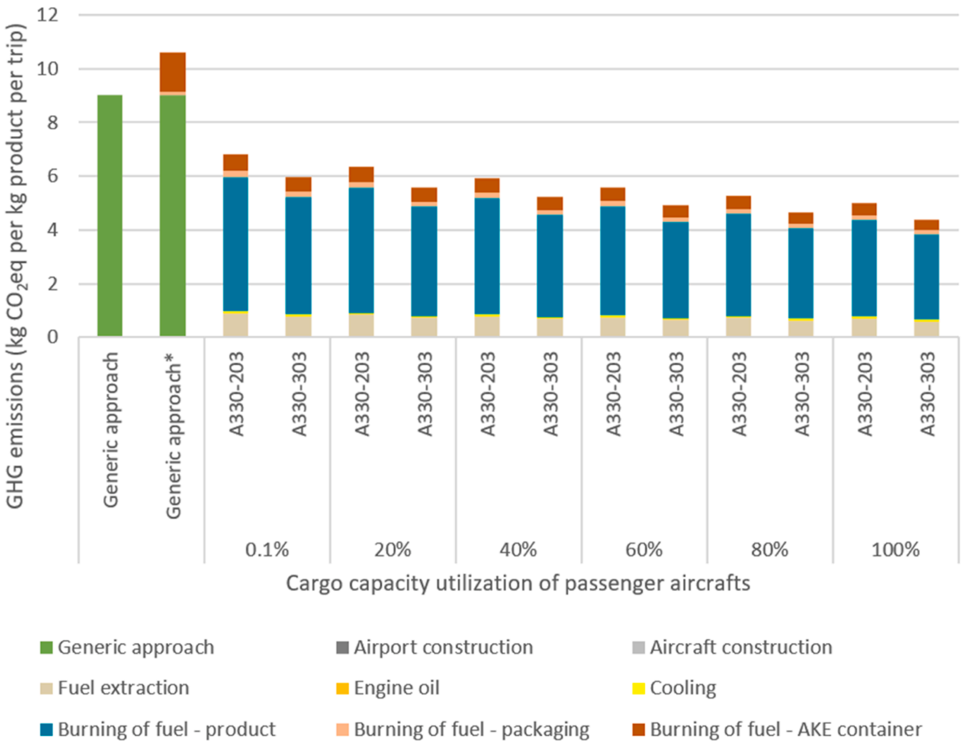

Fig. 2. GHG emissions of air transport of 1 kg packaged product, from Amsterdam to Aruba (8008 km). Calculated using a generic approach and for specific passenger aircrafts A330–203 and A330–303 at different cargo capacity utilization rates ranging from 0.1 % to 100 % (specific approach). *Results from the generic approach are shown with and without the weight of packaging and the AKE container.

The maximum cargo capacity was calculated at different utilization factors. The maximum cargo capacity was calculated by subtracting the luggage weight from the cargo capacity, based on a luggage weight of 23 kg per passenger. The maximum cargo capacity was 13,591 and 15,151 tons for the A330–203 and A330–303, respectively. At these maximum cargo capacities, freight allocation was calculated, as shown in Table 5.

3. Results and discussion

First, the results from our calculations on GHG emissions from air transport are shown. These results will assist in interpreting the subsequent results. Second, we present an overview of GHG emissions of vegetable imports into Aruba. Finally, we discuss our recommendations for future research on low-GHG emissions import strategies for vegetable imports to Aruba. All the absolute values used to create the graphs are available in the Excel appendix.

3.1. Air transport

3.1.1. Belly freight

In this section, the GHG emissions of calculating GHG emissions of air transport using a specific approach, are discussed and compared to using a generic approach (Fig. 2). GHG emissions calculated with a generic approach were about 1.6–2.5 times higher compared to specific passenger aircrafts. For example, GHG emissions of the passenger aircraft A330–303 at 100 % cargo capacity utilization are 2.5 times lower than when using a generic approach. It was assumed that the ecoinvent version 3.3 process used by Poore & Nemecek (2018) was “market for transport, freight, aircraft“. This process was based on passenger jets flying a distance of 6000 km, a cargo capacity utilization was not mentioned. It could be that our calculations show lower GHG emissions per tkm due to a longer flight distance of 8008 km, since fuel use per tkm decreases upon longer transport distances (Davydenko et al., 2020).

The weight of packaging and of the AKE container contributed for about 15 % to total GHG emissions when using a generic approach, mostly due to the weight of the AKE container. Therefore, we recommend LCA practitioners to include the weight of the 80 kg AKE container in their LCA’s.

GHG emissions from the A330–203 aircraft were higher compared to the A330–303 aircraft. This was probably because the A330–203 had a lower cargo and passenger capacity than the A330–303, while both aircrafts had the same weight. Thus, more fuel was used per kg of product, and fuel contributed most to total GHG emissions. To a lesser extent, GHG emissions were due to transport of the AKE container. Other life cycle stages (airport production, aircraft production, engine oil, cooling, and packaging) contributed very little to total GHG emissions. Although airport and aircraft production emitted GHG emissions, due to the lifespan and the allocation of GHG emissions among all products transported during their lifespan, GHG emissions per kg product were relatively low.

Our results of burning fuel to transport the product (without packaging and the AKE container) were comparable to those of Davydenko et al. (2020), who calculated GHG emissions of belly freight in passenger aircrafts with different characteristics. They calculated GHG emissions of belly freight for a trip from Shanghai to Amsterdam (11 hr and 20 min), in three different types of passenger aircrafts. They assumed a cargo capacity utilization of 80 %, which resulted in GHG emissions of 0.50, 0.59, and 0.77 kg CO_2eq per tkm, dependent on several aircraft characteristics. Whereas our calculations resulted in 0.42 and 0.48 kg CO_2eq per tkm, for transporting only the product, for a 10 hour flight. Our results were probably lower due to a lower empty operating weight (EOW) of 121 tons, whereas aircrafts in the study of Davydenko et al. (2020) had an EOW of 145 or 186 tons. Another difference between the aircrafts was the passenger capacity. Aircrafts in our study could transport a maximum of 248 or 292 passengers. Aircrafts in the study of (Davydenko et al. (2020) could transport a maximum of 275, 320, or 408 passengers.

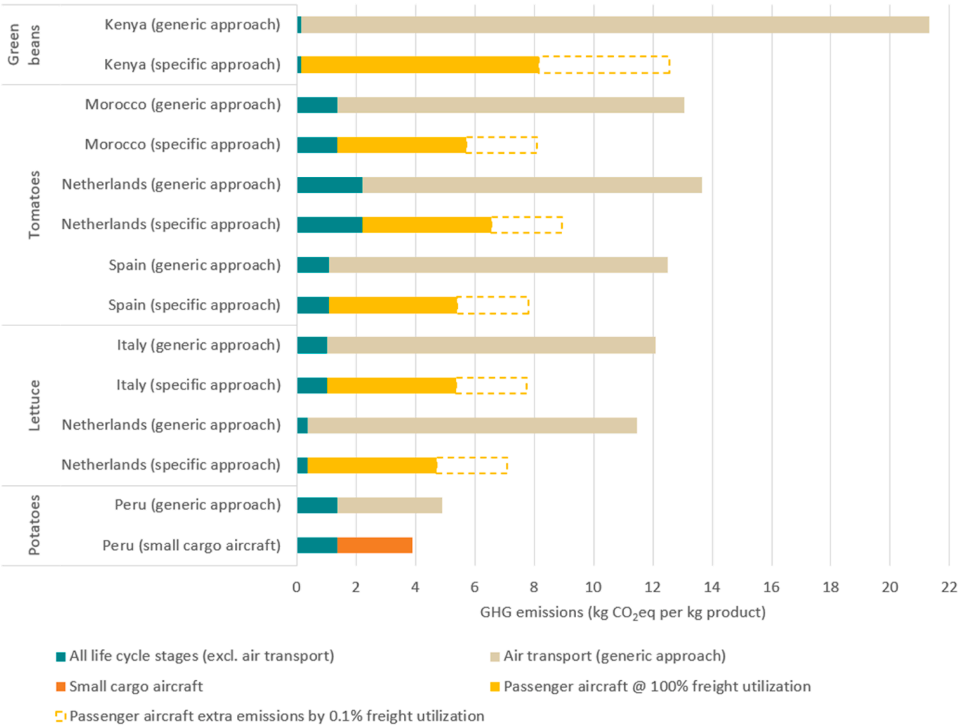

Fig. 3. GHG emissions of all flown-in products, calculated using a generic approach and calculated using specific aircraft characteristics for passenger aircrafts. The solid yellow bars show GHG emissions of passenger aircrafts at 100 % cargo capacity utilization of an A330–303 aircraft. The sum of the solid and transparent yellow bars show GHG emissions of passenger aircrafts at 0.1 % cargo capacity utilization of an A330–203 aircraft.

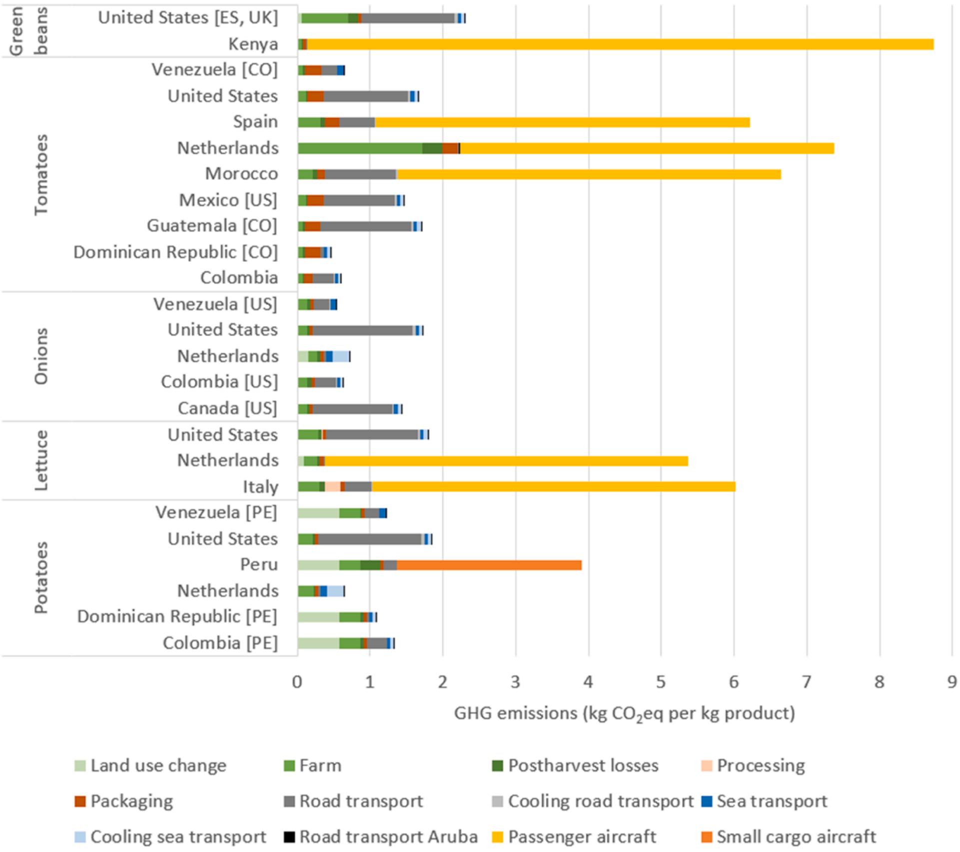

Fig. 4. GHG emissions of products from different countries of origin imported into Aruba. GHG emissions of losses are included in the respective life cycle phases. The 2 letter codes represent the proxies used for the farm stage only: Colombia (CO), Spain (ES), Peru (PE), United Kingdom (UK), and the United States (US).

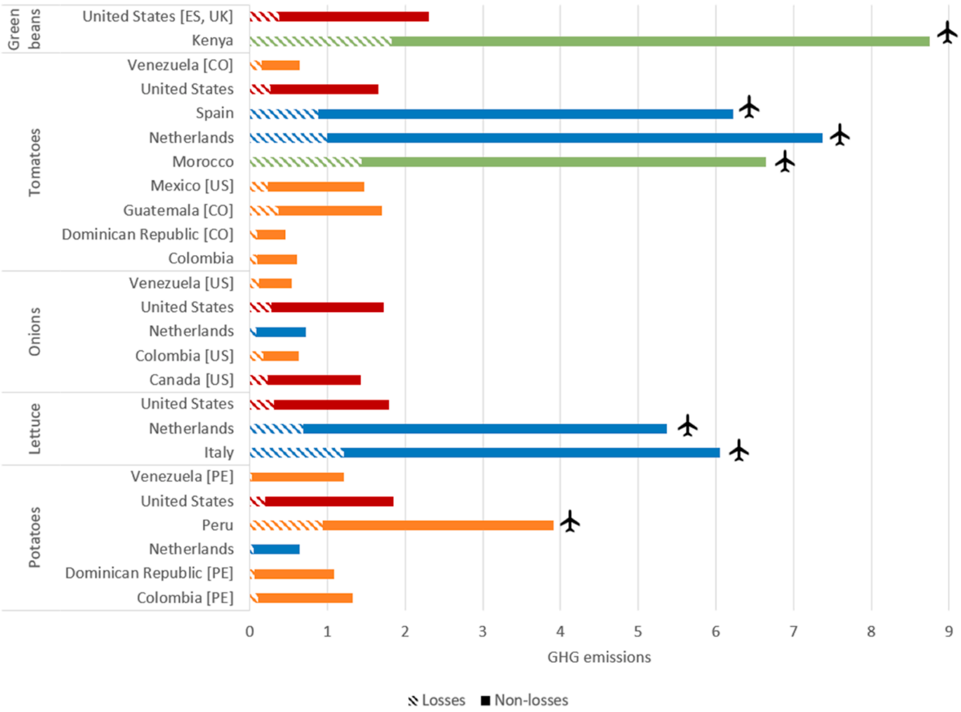

Fig. 5. Contribution of losses to total GHG emissions of products. The symbols of a plane depict products imported by air. Each continent is represented by a color: North America (red), Africa (green), Europe (blue), Latin America (orange). The 2 letter codes represent the proxies used: Colombia (CO), Spain (ES), Peru (PE), United Kingdom (UK), and the United States (US).

The above example showed the variability of GHG emissions of cargo transported by passenger aircrafts, due to different characteristics such as the trip length, EOW, and amount of passengers. Additionally, it is important to consider the volume restriction of an aircraft, the values calculated for this research can not be copied directly. For example, a plane filled to the maximum capacity with only flowers, a product with a low weight to volume ratio, will not reach the maximum weight capacity of the aircraft. This would result in higher GHG emissions per kg flowers.

It is important to realize that these GHG emissions were estimated based on a direct flight from Amsterdam to Aruba. Currently, there was always a direct flight, but the flight schedule may change every six months (Air cargo specialist, personal communication, January 27, 2022). Direct flights are not the case for all (Dutch Caribbean) islands. For example, flights from Amsterdam to Bonaire may navigate via Aruba. A stopover would increase GHG emissions due to another take-off and landing.

Although it is known that GHGs emitted in high altitude have specific effects, expressed by the radiative forcing index (RFI), this was not included in this research due to a lack of scientific consensus (Graver et al., 2019; International Air Transport Association, 2022b; Jungbluth and Meili, 2019).

3.1.2. Contribution of air transport to GHG emissions of vegetable imports

GHG emissions of all flown-in products are shown in Fig. 3. In the next section the GHG emissions of products that were not flown in will also be shown. To show the differences between methodologies, results are shown calculated by the methodology of Poore & Nemecek (2018), and by the methodology for passenger aircrafts described in this article. Also, for potatoes from Peru the results from selecting the process for a small cargo aircraft are shown. The solid yellow bar depicts the minimum GHG emissions of using a passenger aircraft, whereas the sum of the solid and transparent yellow bar indicates the maximum GHG emissions of using a passenger aircraft. Minimum GHG emissions were calculated at 100 % cargo capacity utilization of an A330–303 aircraft. Maximum GHG emissions were calculated at 0.1 % cargo capacity utilization of an A330–203 aircraft. Two different aircraft types were used because the A330–203 aircraft always had higher GHG emissions (see Fig. 2).

It stands out that for all flown-in products the most contributing process was air transport. Using a specific approach to calculate GHG emissions of air transport always resulted in lower GHG emissions, especially upon a higher cargo capacity utilization. This illustrates the importance of including aircraft characteristics when calculating GHG emissions of cargo transport by air. It is even better when the average cargo capacity utilization is known, as an aircraft flying at a 100 % cargo capacity utilization emits about one-third less GHG emissions per kg product, compared to an aircraft flying at a 0.1 % cargo capacity utilization. For potatoes from Peru, differences in GHG emissions due to selecting a specific process for a small cargo aircraft instead of using a generic number, were low.

The calculations above were based on mass allocation. Future research could include different approaches to allocation of GHG emissions between passengers and freight. Given that passenger aircrafts fly primarily to transport tourists, with freight as a side business (personal communication air cargo specialist in the Netherlands, January 27, 2022). This is especially relevant for tourist destinations, such as Aruba and other islands. An alternative approach to allocation could be based on allocating the GHG emissions of fuel used to fly the aircraft and passengers to the passengers, and to allocate the extra fuel use for an additional pallet to the freight.

3.2. GHG emissions of vegetable imports into Aruba

We made an overview of GHG emissions of vegetable imports into Aruba (Fig. 4), depicting the GHG emissions of passenger aircraft A330–303 at an 80 % cargo capacity utilization. We selected this plane because the A330–303 was used most frequently in Aruba, and Davydenko et al. (2020) also assumed an 80 % cargo capacity utilization. Fig. 4 includes GHG emissions from losses in two ways. First, ‘post-harvest losses’ describe the GHG emissions of food losses emitted at the farm. Second, transportation and packaging of the losses are included in their respective life cycle stages. More details about the contribution of losses to overall GHG emissions are displayed in Fig. 5.

Products imported by air had significantly higher GHG emissions (4.2–8.5 kg CO_2eq per kg) than products imported by sea (0.4–2.3 kg CO_2eq per kg). A high contribution from air transport for vegetable imports was also found by Frankowska et al. (2019) who conducted an LCA on imported vegetables to the United Kingdom. Sim et al. (2007) found that air transport contributed for 89 % to the carbon footprint of importing French beans from Kenya to England. In our study, the air transport of green beans from Kenya contributed for 99 % to the total GHGs. The higher contribution of this study is related to the relatively long flight because green beans were first transported to the Netherlands, and then to Aruba. Michalský & Hooda (2015) found that when importing different fruits and vegetables to the United Kingdom, transport outside of the United Kingdom contributed for 80 %–96 % to total GHG emissions. This was mainly due to air transport.

For most products that were not flown in, the road transport contributed mostly to the GHG emissions. Except when there was only little road transport or when GHG emissions from agriculture were relatively high. For example, the amount of road transport was relatively low for the Netherlands (61–76 km) and the Dominican Republic (139 km), and relatively high for products from the United States, Canada, Guatemala, Mexico, and Morocco (2800–4700 km). GHG emissions of agriculture were particularly high for potatoes from Venezuela, Peru, the Dominican Republic, and Colombia. It should be kept in mind that for these potatoes, on-farm GHG emissions were based on a proxy of potatoes from Peru. For vegetables from these countries the fastest shipping route to Aruba was via Port Everglades in Miami, which resulted in a long road transport.

GHG emissions from packaging were highest for tomatoes. The reason is that tomato was the only vegetable in our selection that Poore & Nemecek (2018) categorized as delicate, while other vegetables were categorized as durable and therefore had less packaging with lower GHG emissions. However, not all products were always packaged, and for some products that were not observed in the supermarket but only via Trademap, it is unknown whether they were packaged or not. Therefore, we advise that when comparing the GHG emissions of low-carbon products, such as sea-freighted vegetables, it is recommended to consider the packaging of the products. When making procurement decisions, one should also consider if the packaging protects the product and extends the product’s shelf-life. For example, Shrivastava et al. (2022) have shown that the plastic wrapping of cucumbers reduced the carbon footprint of cucumber imports from Spain to Switzerland because it reduced food waste at retail by 4.8 %.

The product with the highest differences in GHG emissions at the farm stage was tomatoes. GHG emissions at the farm for tomatoes from the Netherlands and Spain were about 22x and 4x higher compared to Colombia, respectively. The high GHG emissions of Dutch tomatoes were due to energy consumption of heated greenhouses. GHG emissions of Dutch tomatoes can fluctuate due to different production methods, but also due to fluctuating electricity sources (Vermeulen and Van Der Lans, 2011). Verteramo Chiu et al. (2024) recently conducted a meta-analysis on LCA and LCI data of tomato and lettuce production and analyzed studies published from 2000–2023. They found that GHG emissions were highest for tomatoes produced in greenhouses which were ventilated and/or heated, ranging from 0.13 to 10.10 kg CO_2eq per kg, with a mean of 2.00 kg CO_2eq per kg, from farm-to-regional retail. Whereas tomatoes produced on an open field or using plasticulture had mean GHG emissions of 0.68 and 0.40 kg CO_2eq per kg, respectively. For lettuce, the meta-analysis depicted a mean of 0.21, 0.22, 1.40, and 4.58 kg CO_2eq per kg, for open field production, plasticulture, greenhouses,

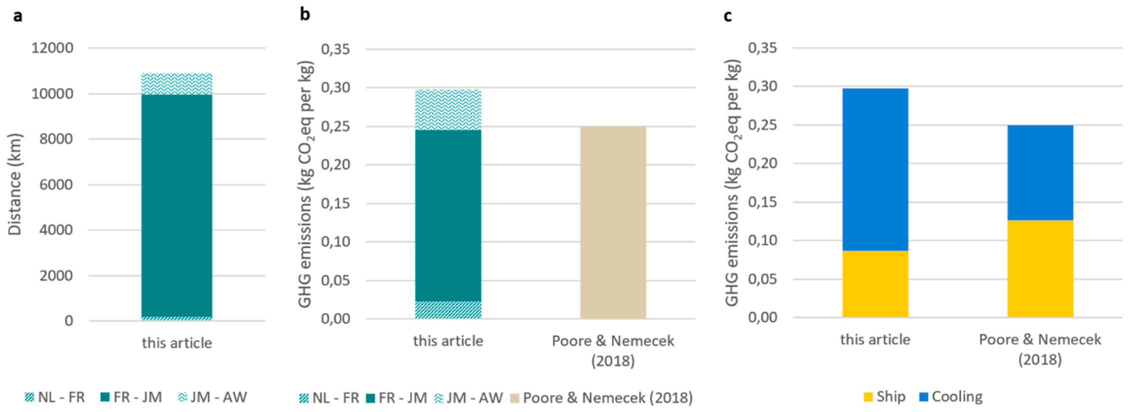

Fig. 6. a) Distance covered during each transshipment: Netherlands to France (NL – FR), France to Jamaica (FR – JM), and Jamaica to Aruba (JM – AW). b) GHG emissions of transporting 1 kg from the Netherlands to Aruba, calculated using the methods of this article and using the methodology of Poore & Nemecek (2018) c) GHG emissions from sailing the ship and from cooling.

and vertical farming, respectively (Verteramo Chiu et al., 2024). Other sources reported a range of 0.15–17.8 kg CO2eq per kg for lettuce, from cradle-to-RDC (Casey et al., 2022). Therefore, when making procurement choices, it is important to consider the production method of products produced in heated greenhouses.

The most GHG efficient country of origin differed per product. Considering the actual product-country of origin combinations, the following can be stated. For green beans, importing from the United States emitted least GHG emissions, as GHG emissions due to air transport were avoided. For tomatoes, importing from the Dominican Republic, Colombia, or Venezuela emitted least GHG emissions, due to the limited road transport, because mostly sea transport was used. However, if products would be sourced from farms relatively far away from the export ports, this would increase the GHG emissions. For onions, importing from the Netherlands, Venezuela, or Colombia emitted least GHG emissions, as a relatively long road transport step was avoided. For lettuce, importing from the United States emitted least GHG emissions, as GHG emissions due to air transport were avoided. For potatoes, importing from the Netherlands emitted least GHG emissions. However, when country-specific data on potatoes from the Dominican Republic and Colombia would be available, this may change the conclusion. In the previous figure, the contribution of losses was incorporated in the different life cycle stages. Fig. 5 shows the contribution of losses to total GHG emissions. The contribution of losses to total GHG emissions was lowest (3 %) for potatoes from Venezuela, and highest for onions from Colombia (28 %). There was not a single product or country of origin with most GHG emissions due to losses. Flown-in products had the highest contribution of GHG emissions due to losses, due to the transport of products that were lost during distribution. It should be kept in mind that we assumed that half of the losses during distribution occurred during air transport.

Most GHG emissions due to losses occurred for green beans from Kenya and for tomatoes from Morocco. However, losses occurred during different life cycle stages. GHG emissions of losses for green beans from Kenya were nearly all due to air transport, whereas GHG emissions of losses for tomatoes from Morocco were mostly due to air transport, and partly due to road transport. Because, tomatoes from Morocco travelled a much greater distance by road (3278 km) than green beans from Kenya (37 km).

Additional details about the contribution of different life cycle stages to GHG emissions of losses are shown in Figure S1 in the appendix. These show that GHG emissions due to losses were mostly due to air transport or road transport, and due to postharvest losses in some cases.

3.2.1. *Sea transport*

Although sea transport was calculated with detailed information on maritime transport routes and ship characteristics, it usually was not one of the life cycle stages that contributed most to the overall GHG emissions. This was not the case for onions and potatoes from the Netherlands, which were shipped in chilled reefer containers for about one month. For these products, GHG emissions of maritime transport contributed to about half of the total GHG emissions, mostly due to cooling. GHG emissions of cooling were based on transit time. The average transit time from the Netherlands to Aruba was 30 days (www.cma-cgm.com), based on actual transport routes. Other sea distance calculators used by LCA practitioners (see introduction) estimated the average transit time at 18 days (www.sea-distances.org), 25 days (www.ports.com), or 46 days (www.searates.com). It should be kept in mind that maritime transport routes can change. To illustrate, for this research the average transit time was estimated at 30 days (January 2022), with one transit in France and one in Jamaica. Later (March 2024), the average transit time was 34 days as the route has changed and only one transit occurred in Colombia. Whereas container ships from the Netherlands used to take just 9–10 days in the past, this changed in 2020 (Superfood, personal communication, February 9, 2021).

Fig. 6 gives more insight into the build-up of the carbon footprint of maritime transport when using actual data on routes and container ships, for the route from the Netherlands to Aruba. The container ship sizes used for the first phase (the Netherlands to France), second phase (France to Jamaica), and third phase (Jamaica to Aruba) of the trip were 35,000 DWT, 50,000 DWT, and 15,000 DWT, respectively. GHG emissions (excl. cooling) of these ship sizes were 0.008 kg CO_2eq per tkm, 0.006 kg CO_2eq per tkm, and 0.025 kg CO_2eq per tkm. The smallest ship size did not only emit more GHG emissions per ton of cargo due to its smaller size, but also because an 80 % load factor and an empty return of the ship were assumed, due to Aruba's remoteness and limited exports. GHG emissions from Poore & Nemecek (2018) were 0.012 kg CO_2eq per tkm (excl. cooling). GHG emissions estimated with our more detailed method were 19 % higher than using Poore & Nemecek (2018)'s method. This was mainly due to differences in GHG emissions from cooling, which were based on actual transit times (kg CO_2eq*day) in this article, whereas Poore & Nemecek (2018) based GHG emissions on distance sailed. Therefore, we recommend to LCA practitioners who need to calculate GHG emissions of relatively long sea transport, to consider using actual transit times, based on the schedule of an actual freight company.

3.3. Low-GHG emissions vegetable imports into Aruba

For the vegetable imports in this study, there were two rules of thumb to lower the GHG emissions. First, source from origins that did not require air transport. Second, avoid products with relatively long road transport. In the case of Aruba these were products from North America that were grown relatively far from Miami, and products from South America that were first trucked to port Everglades in Miami. At this moment, the only countries in South America that exported directly to Aruba were Colombia and Venezuela. A suggestion for future research is to test these two rules of thumb for other case studies. When making procurement decisions, it would also be relevant to consider the degree of land use change, and the agricultural method for products produced in greenhouses, if this information is available.

4. Conclusion and recommendations

When identifying the product-country combinations of Aruba's vegetable imports, it was important to use trade data as well as to visit supermarkets. Vegetables that were imported to Aruba by sea rather than air had the lowest carbon footprint, due to the relatively high GHG emissions of air freight. The carbon footprint was even lower when significantly less road transport was required. Although GHG emissions of maritime transport were calculated in detail, these mostly still contributed little to overall GHG emissions. Although air freight was the most polluting transportation mode, our calculations showed that GHG emissions may have previously been overestimated by using generic data instead of data based on specific passenger aircrafts in use.

We suggest five recommendations to LCA practitioners: (1) For flown-in products, consider whether passenger or cargo aircrafts are being used in the case-study at hand. (2) GHG emissions of airfreight of perishable products may be underestimated when not including the weight of the 80 kg AKE container. Therefore, we recommend to include the 80 kg AKE container or other container types in use. (3) We argue that when calculating the GHG emissions of air freighted imports it is important to consider which aircraft model was used. Additionally, it would be best to know the (average) freight and passenger utilization of the aircraft(s) (4). For more accurate GHG emissions of relsea transport, we recommend to use real transit times, as cooling contributed most to GHG emissions of sea transport. (5) If the goal of an LCA is to compare the GHG emissions of low-impact products, such as sea-freighted vegetables, it is advised to consider the amount of road transport and packaging types, as these formed hotspots in the GHG emissions for some products.

For consumers, we recommend to follow our two rules of thumb, since additional information on the production process is only rarely available in the supermarket or on the packaging. We recommend to avoid products that were known or suspected to be flown-in, and if possible to avoid products that were suspected to have had a relatively long road transport. For Aruba, those are products from North America that were grown relatively far from Miami, and products from South America that were first trucked to port Everglades in Miami.For importers who want to procure vegetables with a relatively low carbon footprint, we have three more recommendations next to our two rules of thumb described above: (1) For products produced in greenhouses, acquire information on the type of greenhouse used and the subsequent GHG emissions. (2) Acquire information about the likelihood of occurred land use change during production. (3) Acquire information about the packaging and if and how the packaging prevents losses.

Declaration of competing interest

The authors declare that there are no competing interests.

AI statement

The authors have not used AI during the research or writing process.

Ethical statement

The authors confirm that this study was not conducted in humans or animals.

CRediT authorship contribution statement

Amber S. van Veghel: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Salys Sultan:** Writing – review & editing, Supervision. **Annemie Geeraerd Ameryckx:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2024.100469.

Data availability

The authors made the data available in the Supplementary Information

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