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Sustainability assessment of transport operations in local Food Supply Chain networks

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Abstract

As food supply chains represent a hotspot of climate change, a rapid transition toward more sustainable processes and operations is expected. Whilst research provides decision-support models to optimize food ecosystems, the application of these techniques in practice is often discouraged by a lack of knowledge and visibility on the hidden food networks' performance and impacts. This paper overviews a case study on a regional fruit and vegetable supply chain characterized by broad fragmentation of supplies, a wide number of actors involved, multiple stages, and limited visibility on the routes traveled by a generic food order. This work analyzes the perishable flows from the growers to the retailer under the lens of environmental externalities in order to promote sustainable supply chain management strategies. Logistic flows throughout the stages are tracked and mapped to aid integrated decision-making, resulting in food miles and transport externalities assessment. A multi-scenario what-if analysis is illustrated to compare and assess transportation costs, food miles, and carbon footprint resulting from more integrated supply chain decisions and configurations. The *To-Be* scenario results in significant savings in terms of carbon emissions, traveling, and transportation costs. Moreover, the reduction of transported volumes reflects how multiple supply chain stages compel double/triple-handling of food and avoidable traveling.

Keywords: Sustainable Food Supply Chain; Food Miles, Carbon Footprint; Food Distribution; Food Logistics;Introduction

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1. Introduction

Climate change effects brought about by irresponsible human actions mandate a rapid and incisive review of all anthropogenic processes (Moore et al., 2012), starting with those that stress the environment and the natural ecosystems most (Bryan et al., 2011). Food industries and food supply chains represent a hotspot and an urgent call for scholars and practitioners to address (Koning and van Ittersum, 2009).

Food supply chains include all processes from the primary production of food to the consumption, and encompass the agricultural phase, the processing and transformation, the storage and consolidation, the packaging, transportation and the management of waste and losses (Li et al., 2014). Global trade and technological advance changed the nature of food supply chains (Villalobos et al., 2019) and require new planning and management models for food production and distribution operations able to meet the growing demand in agreement with long term environmental sustainability (Notarnicola et al., 2017; Govindan, 2018).

Decision science devotes entire research areas to modeling food supply chains and formulating mathematical tools intended for the planning and management of harvesting, processing, storage, and transport operations. Some study the location of growing areas and selection of suppliers (Cholette, 2007; Flores and Villalobos, 2018). Others design supply chain networks (Allaoui et al., 2018; Accorsi et al., 2016), the tactical and operational planning of food production and distribution processes (Ahumada and Villalobos, 2011; Ahumada et al., 2012). Others schedule food transportation given quality (Rong et al., 2011; de Keizer et al., 2017) and climate-driven constraints. Still others optimize food delivery routing (Stellingwerf et al., 2018) and the management of food waste (Buisman et al., 2019). Real-world implementation of such models requires an in-depth knowledge of all the entities involved within the decisional problem and the value of input parameters describing the system's behavior and boundaries (Ondersteijn et al., 2006; Viet et al., 2018).

For this reason, others study the understanding the dynamics of food supply chains through extensive on-field data collection (Cleveland et al., 2011; Aljohani and Thompson, 2018; Gomez-Luciano et al., 2018), on virtualizing and simulating the supply chain tasks and processes (Melkonyan et al., 2020), and on quantifying impacts, externalities, and performance (Meisterling et al., 2009) that drive decision-making toward more responsive and sustainable choices.

This paper builds upon the literature by illustrating the analyses carried out within the FUTUREMED framework (formerly introduced in Accorsi et al., 2018) intended for tracking and mapping distribution flows of fresh food throughout Mediterranean regions and identifying strategic and methodological pathways for their optimization and sustainable management. The lens of the analysis is upon the fruit and vegetable supply chain of a renowned Italian retailer characterized by broad fragmentation of supplies, a wide number of actors involved, multiple supply chain stages, and limited visibility on the routes traveled by a generic food order. The supply chain network is mapped from crop-to-table, assessing the flows of fruits and vegetables from the growers of origin to the retailers and tracking logistic flows and nodes. It quantifies the food miles and the environmental impacts from food transportation and concludes with pathways for future decision-making approaches.

The novel contribution lies in the illustrated case study of a real-world retailer supply chain of fruits and vegetables, on the on-field data collection carried out, and on the resulting metrics of environmental (i.e. carbon footprint) and logistic (food miles) assessed performance. The complexity of the observed network reflects the undertaken difficulties managed by authors, shedding light on the logistics of fruit and vegetable sector.

The remainder of the paper is organized as follows. Section 2 describes the observed ecosystem in terms of supply chain stages, actors, and geographic boundaries. Section 3 illustrates how quantitative metrics on food distribution operations have been calculated for the as-is scenario. We consider a hypothetical to-be scenario that evaluates bypassing a logistics stage for a select group of growers. Given the encouraging results obtained, Section 4 provides practical solutions for the reduction of food miles and carbon footprint through integrated ICT solutions and a higher supply chain's visibility and coordination. The last section concludes with the managerial implications of these findings.

2. Materials and method

This section describes the observed local food network environment regarding the fruits and vegetables distributed by a popular large-scale Italian retailer and summarizes the outcomes from data-collection while depicting the boundaries of the analysis. The retailer distributes through a downstream network made by around one thousand shops spread over Northern and Central Italy and holds a market share corresponding to between 10-12% of whole fruit and vegetable demand. The proposed analysis focuses on the supply chain of one of the four retailer's distribution centers of Emilia–Romagna. Specifically, the target distribution center serves the retailer's shops of the Province of Ravenna as drawn in Figure 1. The target of analysis was chosen with regard to the specificity of the production environment. Fruits and vegetable growers within the Province of Ravenna are responsible for 35% and 10% of regional production, respectively. Consequently, a production surplus is available in the area, given the per-capita demand for fruits and vegetables. Such surplus encouraged the retailer's purchasing managers to set up a short supply chain made of a local network of growers with the aim to fulfill the most fruits and vegetable orders. Despite the good intention, the inherent complexity of the short supply chain increases with the number of actors and stages involved as illustrated in the hierarchical scheme of Fig. 2.

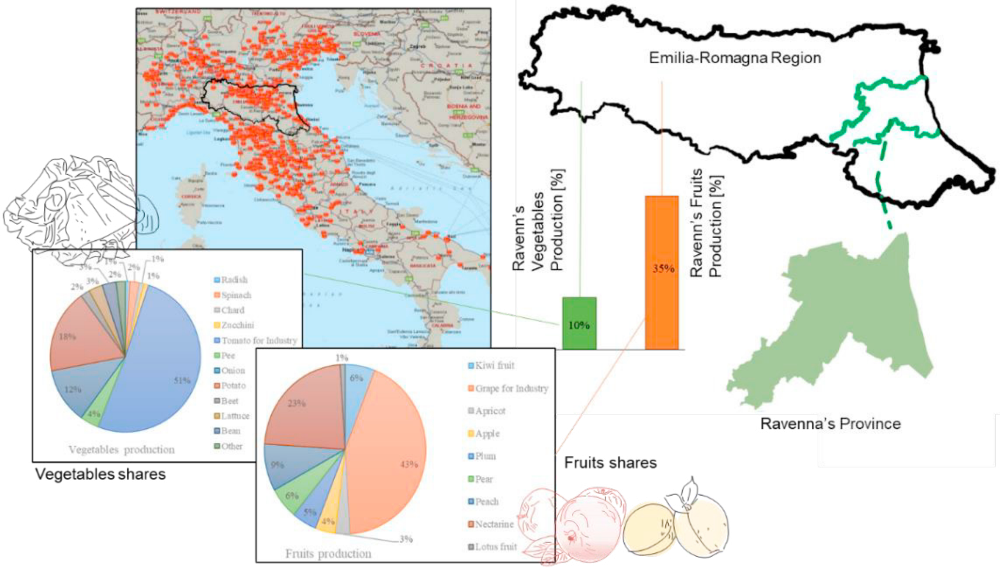

Fig.1. Observed geography: distribution of the retailer's shops; target area (Province of Ravenna); Production of fruit and vegetable varieties in percentage.

As the retailer requires certain deliveries of standardized products over time (with specified calibers and sizes, colors, Brix grades, primary and secondary packages), the supplies are concentrated onto few vendors, named processors or packagers. These are responsible to manage inventory of perishables in cooling chambers, to pack the products into proper packages, and to smooth uncertainties due to seasonality and climate/weather disruptions. At the same time, processors receive unpacked fruits and vegetables from a small number of consolidators who behave as an interface toward the agricultural stage. At the top of the hierarchy, hundreds of small and medium growers represent the origin of food and feed the entire supply chain in the light of their crop yield, the hectares of production, and the proximity of consolidation facilities. Whilst the supply chain appears simplified in Fig. 2, the different layers reflect two main criticalities as the independency of decision-making and the poor visibility of the supplies performed at the above stages.

With the purpose to overview the logistics of fruits and vegetables throughout this supply chain from the side of the retailer, we spent preliminary efforts to discover and track the hidden connections between growers, consolidators, and packagers. Such a discovering process commences considering the set of purchasing orders released by the retailer to four processors over a horizon of one year. The amount of food supplied to the retailer's distribution center is almost nine thousand tons, distinguished into fifteen varieties as reported in Table 1. After the packaging operations performed at this stage, the fifteen generic product categories explode into 163 new items differentiated by different caliber, package size and material, and labeling.

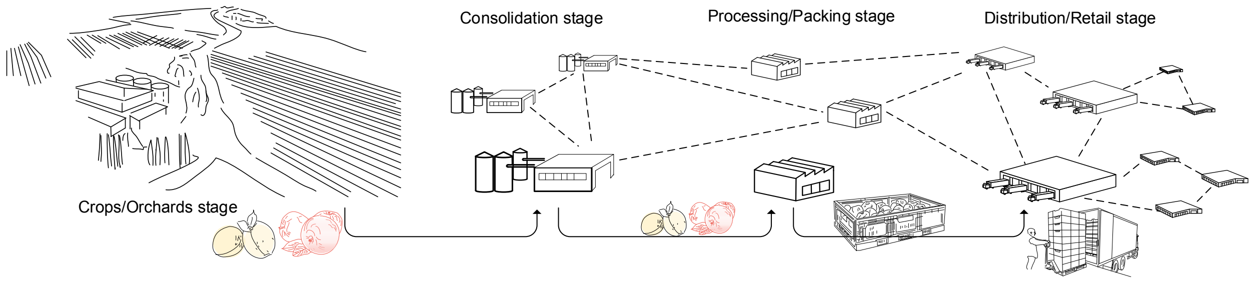

Fig. 2. Hierarchy of stages in local food supply chain (from-grower-to-consumer).

The four processors, in turn, receive fresh unpacked products from seventeen consolidation facilities that collect fruit and vegetable flows from 950 growers. Given the high concentration of growers within the Province of Ravenna, 70% of the retailer orders are fulfilled through local supplies, while just 1% is imported (from Spain, Chile, and New Zealand). Despite the surplus of production for most of the food varieties, the need for a flat and seasonally distributed offer over the retailer's shelves necessitates a limited number of supplies from producers abroad. The analysis conducted upon the network underlines the strong concentration of rural areas within the Province of Ravenna and justifies establishing a short food supply chain. Nevertheless, the number of primary growers involved hides potential weaknesses and ignites further considerations on the logistics of food products.

Table 1. Cumulative annual food volumes purchased by the retailer.

Fruit/Vegetable variety	Purchased volume [tons/year]	%		Purchased volume [tons/year]	%
Potato	1913.332	22.0	Tomato for Ind.	409.929	4.7
Nectarine	1272.547	14.6	Apricot	287.658	3.3
Apple	1043.007	12.0	Plum	258.744	3.0
Kiwi fruit	759.134	8.7	Tomato	231.651	2.7
Watermelon	644.353	7.4	Strawberry	170.204	2.0
Peach	541.694	6.2	Pumpkin	109.957	1.3
Pear	536.453	6.2	Lotus fruit	67.065	0.8
Asparagus	33.650	0.4%			
∑				8716.263	

Table 2 reports and draws statistics on the size and the production capacity of the 950 growers. It is worth noting that few growers cultivate more than two types of produce. Moreover, most growers have a small growing area.

Table 2. Growers' population: distribution of hectares and production capacity.

Growing Area [Hectares]	Growers	Growers %	Growers Cum %	Products per grower (Avg)	Annual Food Production (Avg) [tons/year Grower]	Annual Food Production [tons/year]	Production %	Production Cum %
>100	1	0.1%	0.11%	7	2818.19	2818.19	6.1%	6.1%
50-100	4	0.4%	0.53%	4	143.62	574.49	1.2%	7.3%
30-50	7	0.7%	1.26%	3	247.30	1731.15	3.7%	11.1%
20-30	11	1.2%	2.42%	2	148.17	1629.93	3.5%	14.6%
10-20	33	3.5%	5.89%	2	150.90	4979.73	10.8%	25.4%
5-10	107	11.3%	17.16%	2	106.69	11,416.04	24.7%	50.0%
3-5	144	15.2%	32.32%	2	57.67	8304.62	18.0%	68.0%

2-3	152	16.0%	48.32%	2	38.14	5798.64	12.5%	80.5%
1-2	210	22.1%	70.42%	1	29.20	6132.63	13.3%	93.8%
<1	281	29.6%	100.00%	1	10.24	2879.12	6.2%	100.0%
∑	950					≅49,241		

Thus, to ensure stable supplies with year-round availability these fruits and vegetables, the retailer relies on a multitude of small producers and enhances the number of food sources within the upstream supply chain network.

The complexity of the upstream network brings about the need for entrusting few actors for the supply operations. Consequently, the number of stages increases with the vertical connections among growers, consolidators, and packagers. In passing through these stages, food products travel throughout the network experiencing double/triple-handling, increasing food miles and carbon emissions from transportation. Understanding and tracking the flows of food across this network is crucial to meet the goals of reducing the carbon footprint of food items, and decreasing GHG emissions. The following section describes the methodology undertaken along with the data collection phase and provides an overview of the logistics of the observed food supply chain.

2.1. Data collection

A bottom-up approach, based upon the progressive involvement of the actors from the retailer up to the growers, led the phase of data collection. Firstly, the retailer provided the database of the arrivals at the distribution center over a horizon of one year. The collected records tracked the incoming shipments and the consignor, the truckload and the quantities (i.e. kilograms and packages) received per variety. Hence, on the basis of the list of consignors, the retailer's suppliers (i.e. the processors) were identified and contacted by email to share the project targets and the set of input data required. A sequence of interviews clarified understanding of the available data, the observation horizon, and the required records. Data collection focused on arrivals. These underline the set of consolidators serving each processor and the flows of generic and unpacked fruits and vegetable products in terms of the number and schedule of shipments, vehicles used, and shipped food volumes.

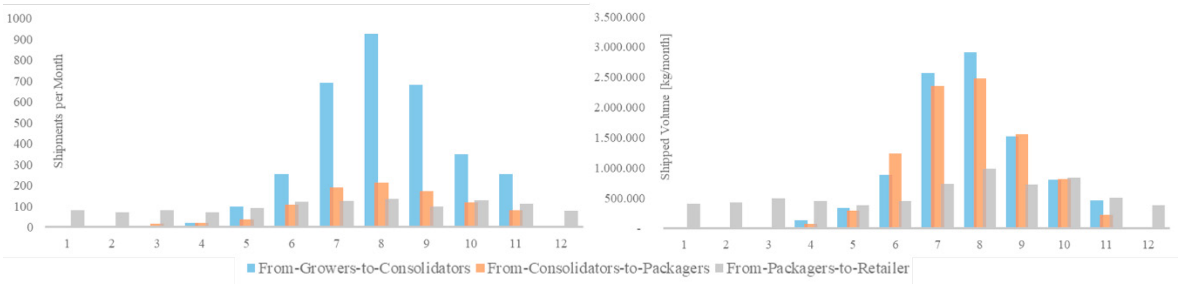

Fig. 3. Distribution of food flows across the supply chain network's stages over the months (1 to 12).

Lastly, the list of suppliers per each consolidator provided references to the multitude of growers involved in the retailer's supply chain. Questionnaires sent to and filled in by the growers provided details on the cultivated hectares and varieties, the monthly supply capacity, the type of vehicles used, and the list of consolidators served. The collection of primary data from questionnaires and the companies' ERP systems was completed by analyzing the address and geographical location of all the logistic nodes within the network. Lastly, a tailored GIS plug-in built via MS MapPoint enabled us to calculate routes and traveled kilometers between each couple of nodes.

Fig. 3 provides a preliminary overview of the collected data and illustrates the monthly distribution of food flows across the stages of the supply chain. The flow records refer to the logistics of a network made of four regional processors, three suppliers from Spain, Chile, and New Zealand, 17 consolidators, and 950 growers. The above chart reports the shipments over the year, highlighting the strong seasonality of the supplies from the local growers, concentrated between June and October. Comparing shipments with supplied volumes, shows that the consolidators behave as logistic nodes for growers and enable loads groupage into fewer, more saturated deliveries. In order to maintain a stable offer of seasonal products over the year (as shown by the grey bars in Figure 3), the retailer imports from Spain, Chile, and New Zealand during the European continental winter (from December to March).

Due to the aforementioned production surplus, the food volumes supplied by the growers exceed retailer demand during the growing season and are distributed through other channels (i.e., other retailers, gross markets, catering sector, local markets).

The phase of data collection fed a set of structured tables belonging to a relational database illustrated and described in depth in Accorsi et al. (2018). The database is then accessed through a tailored decision-support platform (named Network Analyzer 2.0) intended for aiding decision-making on food supply chain ecosystems. The platform's functionalities include a GIS plug-in to map networks and supply chain node, a set of reporting charts to summarize performance metrics and statistics, a digital supply chain twin for simulation purposes, and a set of optimization tools. The complete description of the platform is detailed elsewhere (Accorsi et al., 2018; Baruffaldi et al., 2019).

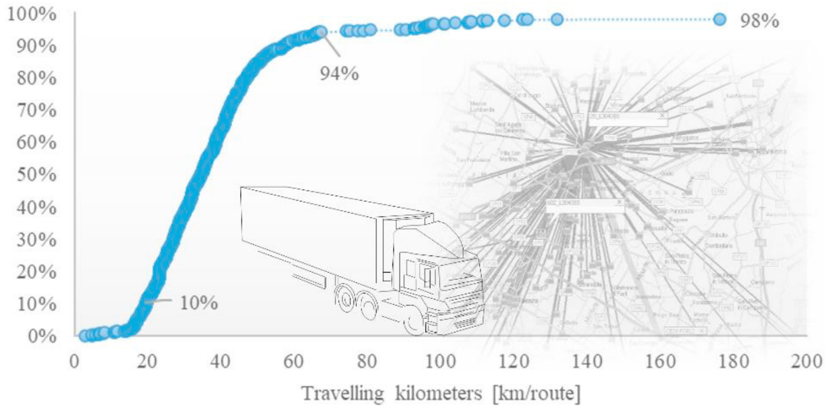

Fig. 4. Distribution of network's nodes and of the logistic routes.

Fig.4 results from the application of the platform to the observed case study and plots the distribution of the connecting routes between the nodes of the network and the retailer's distribution center. According to Figure 4, 10% of the nodes are located within 20 kilometers from the warehouse and nearly all (94%) are located than 70 kilometers. This analysis confirms the high concentration of the network and the prevailing local configuration of the observed retailer supply chain. The following section summarizes the results of the food miles analysis carried out upon the observed supply chain ecosystem and provides findings toward the logistic integration of the supply stages and actors and more environmentally friendly management of the supply operations.

3. Analyses and results

The analyzed supply chain presents a high degree of complexity both upstream and downstream because of the number of actors involved and of stages crossed by food products. The logistic chain enables linking a multitude of very small actors involved in the cultivation phase with the consumer's side through a fixed pattern of distribution operations. The growers consolidate their harvests into consolidation facilities, which cluster shipments of unpacked products toward the processors. Here, food is checked and separated by quality, ripeness, caliber, then packed into different containers per size and material, and stored in climate-controlled chambers until an order from a retailer's distribution center occurs. At the retailer's distribution center, loads of packed products are cross-docked and clustered into delivery tours to the retailer's shops. Whilst Figure 1 depicts the reference architecture, the boundaries of the analysis involve a single distribution center (DC) placed in Forlì, a few kilometers out the province of Ravenna, and the related whole supply network. The delivery tours from the retailer's distribution center to their shops are out of the scope of the analysis.

We next performed a food miles analysis. Instead of evaluating the single stage of the supply chain independently (node-oriented analysis), we focused on the connections between nodes (arc-oriented analysis), detecting the physical food flows as virtual shipments and cumulating the traveling kilometers experienced from grower-to-DC by each lot of product.

Fig. 5. Maps of virtual flows of food among the network nodes.

Fig. 5 displays the connections traveled by food products over the observed horizon of one year, illustrating the complexity of the supply chain network. The three maps draw the inbound and outbound flows handled by two of the four processors (top of Fig. 5), and the import flows received from Spain by truck, and Chile and New Zealand by vessels through the ports of Leghorn (Livorno) and La Spezia respectively. The routes (i.e. arcs) traveled by different transport modes vary by the stage and the actor considered. Growers use agricultural vehicles, like tractors (*T1*), and small vans (*T2*) to move products from crops to the closer consolidation facility. Two types of modes connect the consolidators and the packagers: the tilt trucks (*C3*) and the semi-trailers (*C1*). Reefer semi-trailers (*C2*) commonly serve the retailer's distribution center. The table reports the main characteristics and metrics of the adopted transport types, whilst the full GHG emissions data refer to the Lipasto database (VTT, 2015).

Table 3. Characteristics of the adopted transportation modes. The column *Fix* and *Var* refer to impact of the empty vehicle and of the load respectively.

Code	**Vehicle**	**Way**	**Load [tons]**	**CO_2eq. Fix [g/km]**	**CO_2eq. Var [g/tkm]**	**Fuel Fix [g/km]**	**Fuel Var [g/tkm]**	**Avg Speed [km/h]**
Grower Vehicle 1 (T1)	Farm Tractor	Unpaved Road	6	595.7	330.63	190.18	105.34	10
Grower Vehicle 2 (T2)	Van, Diesel	Paved Road	1.595	240	25.705	81	8.15	25

Truck 1 (C1)	Semi-trailer	Paved Road	25	778	11.2	261	3.76	48
Truck 2 (C2)	Reefer Semi-trailer	Paved Road	25	830.90	11.96	278.75	4.015	48
Truck 3 (C3)	Tilt truck	Paved Road	9	465	11.33	154	3.88	45
Vessel (S1)	Container ship	Maritime	-	0	28	0	8.8	30

This dashboard includes economic metrics (i.e., transportation costs), logistic performance (i.e., number of shipments, traveled kilometers) and environmental impacts (i.e., GHG emissions from transport operations and fuel consumption) a set of KPIs dealing with the food miles and the environmental impacts of the logistics from the grower to the retailer warehouse. We used this platform to virtualize the logistic flows per each food lot and supply order and to calculate a dashboard of metrics and measures of performance.

The platform enables quick adjustments of the imported virtual supply chain, through modifying the distribution pathway (i.e., nodes visited at each stage) per every supply order, and measuring the impacts of such decision through a what-if multi-scenario analysis. We illustrate and compare two scenarios. The first scenario, called *As-Is*, reflects the current "business-as-usual" configuration of the supply chain organized upon the four stages drawn in Figure 1. A single food lot travels from the grower where it was harvested to the retailer's distribution center according to a deterministic sequence of visits, justified by the different supply chain's roles and operations (i.e groupage, packaging, storage). This practice may lead to produce travelling great distances even though may actually be grown quite close to the end destination because it needs to travel to both the consolidation and packaging nodes.

With the aim to explore improvements, the second scenario, called *To-Be*, flattens a few growers' supply chains, by enabling direct shipments to the retailer's distribution center. Instead of selecting the closer growers, we considered the top sources in terms of hectares, varieties, and supplied volumes according to the details proposed in Table 2. The supply capacities of these growers are clustered per zip code and drawn for several products in Figure 6 in accordance with the legend of Table 1. Despite the distance, the pool of growers selected (the largest 12 out of 950) provides a broad offer of fruits and vegetables, with enough volumes to exploit economies of scale and to encourage investments in storage chambers or packaging lines. This motivates the *To-Be* scenario which is optimistic but entirely feasible.

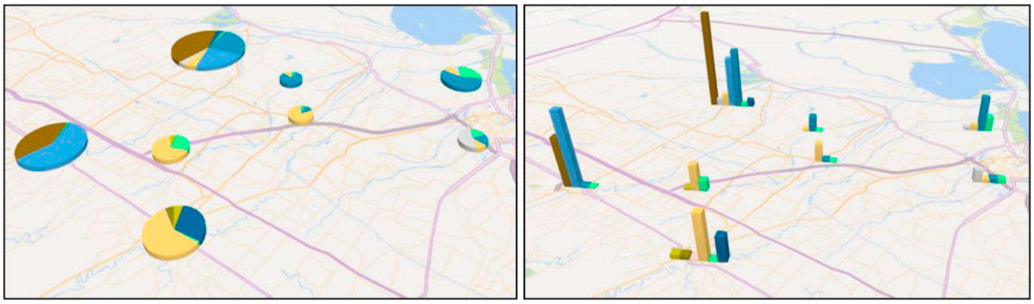

Fig. 6. Supply capacity from the growers selected for the flattened supply chain of the *To-Be* scenario.

Table 4 summarizes the results of the multi-scenario supply chain comparison. The metrics of performance calculated for both configurations and transportation mode include the annual shipments, the overall carbon emissions, and food miles, the transportation costs, the distributed volumes, and the fuels consumption. The results obtained with the *As-Is* scenario demonstrates the impact of logistics on an albeit locally distributed supply network. Food supply operations from growers to the retailer's warehouse release more than 700 tons of CO_2 eq. in the atmosphere, and 18,157 shipments over the year. It is worth noting how within a multiple-stages supply chain, each node visited from the origin to the destination multiplies the volumes of food transported. Furthermore, even the frequency of the demand orders released by the retailer contributes to increasing the number of shipments.

Table 4. Comparison of the economic, logistic and environmental performance between the two supply chain scenarios.

As-Is	Shipments [ship/year]	CO_2eq. [tons/year]	Traveling [km/year]	Transport Cost [k€/year]	Shipped Volume [tons/year]	Fuels [kg/year]

T1	2229	33.671	28,462	50.558	4332.948	5331.558
T2	3274	15.324	59,724	9.633	2635.554	318.905
C1	1498	37.119	40,849	76.267	18,494.445	1802.942
C2	3841	409.297	193,686	266.927	35,973.477	6763.679
C3	7311	53.884	106,398	64.034	24,857.358	1481.265
S1	4	183.037	60,906	45.759	385.752	57.526
∑	18157	732.333	490,024	513.179	86,679.534	15,755.876
To-Be						
T1	2229	33.671	28,462	50.558	4332.948	5331.558
T2	3274	15.324	59,724	9.633	2635.554	318.905
C1	817	28.360	31,522	54.803	8837.053	1296.091
C2	4010	333.478	196,271	251.343	34,756.875	6351.394
C3	7162	53.265	105,072	63.379	24,250.918	1466.090
S1	4	183.037	60,906	45.759	385.752	57.526
∑	17496	647.136	481,957	475.476	75,199.099	14,821.564

The improvements from the *To-Be* scenario deserve mention. Adjusting the distribution pathways for just the top 12 growers (1.26% of the total population) results in significant savings in terms of carbon emissions (-11.63%), traveling (-1.65%), and transportation costs (-7.35%). Moreover, the reduction of transported volumes (-13.24%) reflects how multiple supply chain stages lead to double/triple-handling of food and avoidable traveling.

Figure 7 depicts the food miles and carbon footprint (due to transportation) for all the food varieties in both *As-Is* and *To-Be* scenarios and provides relevant insights on their associated logistics.

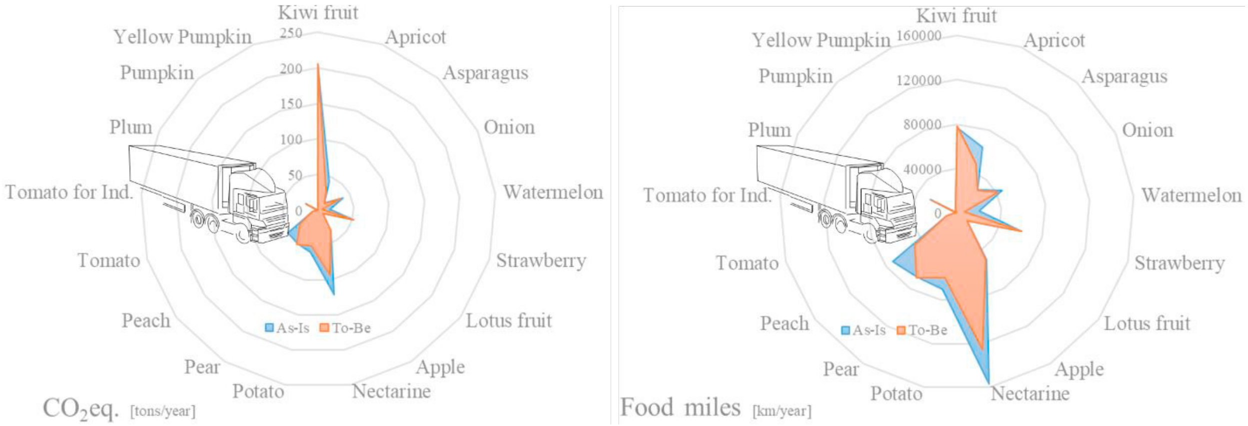

Fig. 7. Comparison of carbon footprint and food miles for the *As-Is* and *To-Be* scenarios.

As long as most of the supplies to the retailer are local, the impacts of products imported from foreign producers stand out. Kiwi fruit, imported during the winter from New Zealand, have the largest carbon footprint with more than 200 tons of CO_2 eq. released by ships in a few trips. For this item, no differences occur between the *As-Is* and the *To-Be* as imports are necessary to cover the seasonal drop of the local production in both scenarios. This result further confirms the huge environmental impact of long/global supply chains compared to those of local or regional suppliers. Fig. 7 illustrates a second point: illustrating the strong association between the transportation carbon footprint and food miles, highlighting the key role logistic managers have in making decisions in improving both environmental and economic performance.

Comparing food miles among the different varieties shows significant improvements for products with high local production capacities: nectarines, apricots, watermelons, tomatoes, and potatoes. These quantitative and objective findings may seem evident and obvious but have previously been hard to demonstrate with real-world instances.

These results shed light on the previously hidden economic and environmental impacts of informed and integrated supply chain decisions.

4. Discussion and practical implications

This analysis on the retailer supply chain of fruit and vegetable products demonstrates the importance of more accurate and informed decision-making by logistic managers and other supply chain actors. This platform enables the precise calculation of economic, logistic and environmental quantitative metrics per each lot of food, shipments, and supply chain connection. Thus, evidence-based decisions could lead to significant improvements: supply chain flattening (i.e. reducing stages), the optimization of the distribution routes, and the implementation of integrated ICT solutions for data tracing aiding operations planning and traceability. The current lack of integrated ICT systems operating from the growers to the retailer limits awareness of the flows of food throughout the supply chain, decreasing visibility and coordination among the stages.

Whilst researchers recommend the adoption of ICT solutions in the agriculture and food industry, very few supply chains and companies have put this suggestion in practice, as they are discouraged by the high infrastructural investments and the cost of coordination required. This paper provides evidence of the technical, environmental, and even economic benefits resulting from more coordinated logistic decisions involving all the supply chain actors from the growers to consumers.

Moreover, the carbon footprint and food miles analyses would lead managers toward the quantification of the impacts of the supply chain operations. By providing information to consumers about the impacts of their purchasing and consumption habits (e.g., fruits and vegetables consumed out of season, food waste), such education may result in more sustainable choices (Christopher et al., 2008; Virtanen et al., 2011; Wakeland et al., 2012).

From a holistic perspective (in contrast with Figure 1), the comparison between the two supply chain configurations enables the quantification of the transportation costs saved during a year, by enforcing direct shipments to the retailer's warehouse from 12 growers. The resulting positive annual cash flow of around 40 k€ might be invested in the following ways: implementing integrated ICT solutions for decision-making, funding infrastructural improvements (e.g., new storage chambers or packaging lines at the grower and the consolidator stages), promoting strategies for environmental impact mitigations (e.g., carbon plantings, renewables to power the supply chain facilities) or transitioning growers toward organic production.

5. Conclusions

This paper illustrates a case study of the distribution operations of fresh fruits and vegetables from growers to a retailer's distribution center. An on-field data collection conducted on the whole actors involved along supply operations was carried out to determine the contribution provided by each node and arc to fulfilling the demand, and to track the distribution paths followed by food products. What emerged is a locally distributed supply chain made of four stages (growers, consolidators, packagers, and one retailer) and almost 1,000 nodes. This data fuels a tailored decision-support platform that analyses and simulates the logistics of a food supply chain. The obtained results quantify the logistic, economic, and environmental impacts of fruits and vegetable distribution and highlight the huge carbon footprint and food miles generated within a mostly local supply chain. The alternative scenario of forcing direct shipments to the retailer's warehouse for a small group of growers, shows significant savings in terms of transportation costs and carbon emissions, encouraging supply chain managers to enhance visibility on the supply network and to adopt more integrated and informed decisions.

Further research developments, fully described into future papers, will entail formulating a multi-stage optimization model to aid sustainable distribution operations planning and environmentally-friendly integrated network design.

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