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Distribution chain diagrams for fresh fruit supply chains: A baseline for emission assessment

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Background: Globalisation has undoubtedly revolutionised the way modern society functions by connecting different people, economies, cultures and technology. This integration depends on the adequate movement of goods by increasingly more complex and longer global supply chains (SCs). The structure of the distribution chain and the individual activities that jointly facilitate the transportation of commodities such as fresh fruit have not been well defined, making it difficult and ambiguous to determine greenhouse gas emissions. Mapping the various distribution scenarios of fruit and stating the emission-generating activities not only enable the analysis and management of these activities but also provide a basis for calculating emissions.

Objectives: The key objective is to describe all the physical emission-generating distribution activities that take place during the international export of fresh fruit from South Africa. These activities were used to create distribution chain diagrams that define the structure of fresh fruit distribution.

Method: To identify activities, a literature review, direct observation of distribution activities at logistical facilities and unstructured interviews with operational managers at these facilities were performed. Scenario planning was used to combine generic activities into realistic distribution chain diagrams. The activities and diagrams were validated by semistructured interviews with four industry experts.

Results: Following the identification of emission-generating activities, five generic distribution chain diagrams were created that should represent all possible distribution scenarios for fresh fruit.

Conclusion: The generic distribution scenarios not only capture the various methods by which fresh fruit is exported from South Africa but also form the basis of seven important emission-related managerial practices.

Keywords: distribution; food supply chains; GHG emissions; South African fruit exports; sustainable food systems; sustainable transport planning.

Introduction

The sustainability of product supply chains (SCs) and related organisations are no longer viewed only in terms of economic growth and profitability. The extent of sustainability has evolved to include clear societal, economic and environmental objectives (Hülemeyer & Schoeder 2018; Lalendle, Goedhals-Gerber & Van Eeden 2021). The United Nations (UN) Sustainable Development Goals (SDGs) confirm this notion, aiming to achieve the 2030 Agenda for Sustainable Development (United Nations 2016).

This sustainability drive led to the implementation of several decarbonising strategies at the organisational level as companies were compelled to take responsibility for their carbon emissions. Furthermore, the concept of corporate social responsibility (CSR) has evolved to the extent that the Johannesburg Stock Exchange (JSE) launched an index in 2004 to ensure that listed companies in South Africa align with global trends in corporate governance (Niehaus, Freiboth & Goedhals-Gerber 2018). These CSR strategies have become important for the organisation's public image because of consumer awareness of the environmental impact of carbon emissions, making it a decisive criterion for purchasing decisions by some consumers (Borin, Cerf & Krishnan 2011; Joshi & Rahman 2015).

However, as the current decarbonisation strategies are focused internally on organisations, they fail to take a systems perspective of emissions in the entire SC. This leads to burden-shifting amongst SC stakeholders by outsourcing their carbon-intensive activities, instead of actually reducing emissions in the SC. Therefore, a fundamental shift should occur to minimise the overall emissions of the SC instead of only decreasing emissions via outsourcing activities. This is confirmed by Sala et al. (2017:396), who stated that the journey to achieve a sustainable SC requires very broad systems thinking from the point of raw material extraction (cradle) up until disposal of the product (grave).

The decarbonisation of freight transport, specifically, is becoming increasingly important (Bergqvist et al. 2015; Kopp, Block & Iimi 2013). Considerable progress has recently been made to introduce efficient vehicle technologies, increase the use of alternative fuels and improve the efficiency of transport operations. Despite these achievements, research examining the end-to-end emissions across distribution activities in a product SC has been limited. Current research focuses on individual activities, such as deep-sea, road, rail and air transport in isolation. In addition, some of the current research attempts to perform a life cycle assessment (LCA) of a product's emissions, neglecting important emission-generating activities in the distribution process. Both of these approaches fail to create a holistic emissions overview of the entire distribution chain. Du Plessis, Van Eeden and Goedhals-Gerber (2022) discussed the various standards, methodologies or frameworks used to quantify distributional emissions. Note that no legislation currently compels organisations to disclose the carbon footprint of imported products, but this might change in the foreseeable future.

In the very near future, consumers of fruit exported from South Africa might want to understand the carbon emissions associated with each kilogram of produce they buy. Producers, exporters and logistics operators would individually not be able to answer this macro-systems question. This article explores how each distribution activity along the SC should be identified to measure the associated carbon emissions.

Research objective

To calculate the emissions of a shipment of fresh fruit or to analyse the distribution process, knowledge and an understanding of both the structure of the distribution chain and the individual distribution activities are prerequisites. The objective of this research is to identify all the physical emission-generating distribution activities performed during the international export of fresh fruit from South Africa. In addition, distribution chain diagrams that define the structure of fresh fruit distribution are created.

Literature review

This section captures the relevant theory relating to international fresh fruit SCs and their associated emissions. This is followed by a critical assessment of existing literature examples to prove why accounting for the emissions of distribution activities is a problem.

Importance of fruit supply chains

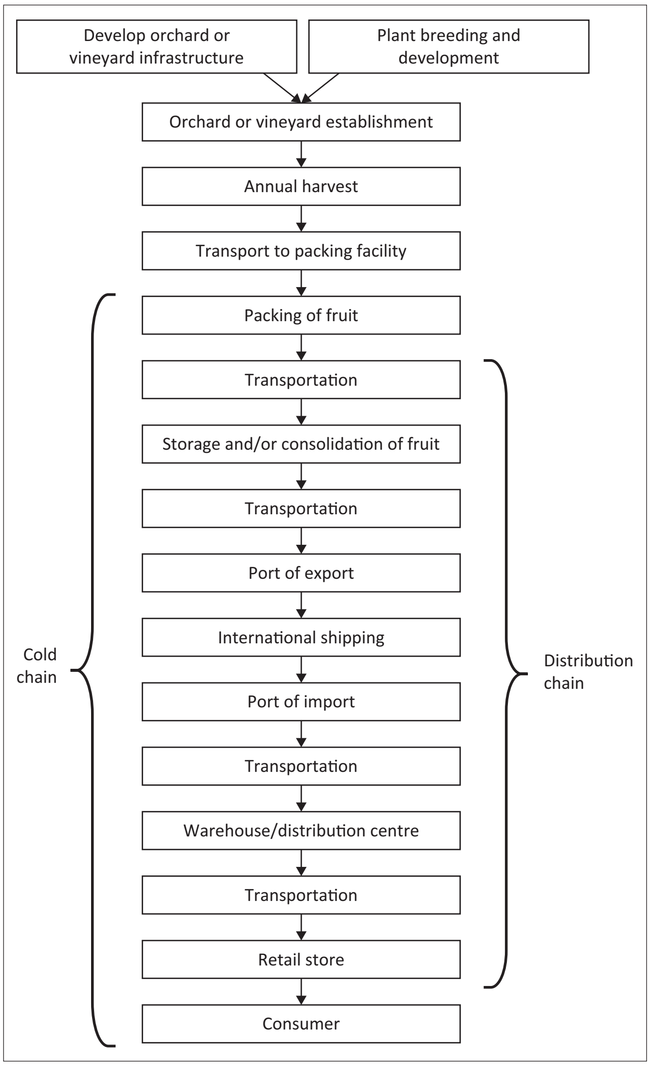
Globally, fresh fruit is in high demand all year round because of evolving consumer preferences. This necessitates a constant supply of fresh fruit to the market. However, because of production seasonality and the limited shelf life of fresh fruit, a year-round supply cannot be sourced from the same hemisphere. To resolve this supply issue, fresh produce from a different hemisphere (where the fruit is in production season) is imported. As the two hemispheres have 'opposite seasons', fresh fruit produced in the southern hemisphere is in high demand during the 'opposite season' in the northern hemisphere. The Southern Hemisphere Association of Fresh Fruit Exporters (SHAFFE), which represents Argentina, Australia, Brazil, Chile, New Zealand, Peru, Uruguay and South Africa, exported 9.8 million tonnes of fruit with a value of $14.6 billion during the 2020 season (FreshFruitPortal.com 2021). The large volumes of fruit that are distributed from the southern hemisphere show that the industry is well established.

Fruit supply chains and emissions

An SC is defined as the global network responsible for delivering products and services from the point of raw material extraction up to the end customer by means of an organised flow of money, information and physical distribution activities (APICS 2013:171). Various transformation activities or processes and stakeholders are involved in an SC to produce a final product or service and to deliver it to the consumer. Figure 1 indicates some of the important activities in a fresh fruit SC and depicts the extent of the cold chain. A cold chain is similar to an SC but refers to the temperature-controlled section of an SC (Aung & Chang 2014; Goedhals-Gerber et al. 2015); thus, it is a subsection or part of an SC during which a perishable product is refrigerated. For a fresh fruit SC, the cold chain starts at the packing facility where the fruit is refrigerated after harvest and ends at the consumer when the fruit is consumed after refrigerated storage.

A distribution chain is the collection of physical activities such as transportation, handling, storage and administrative activities involved in moving materials, normally in the form of finished goods, from a manufacturer to the customer or returning defective goods to the manufacturer (APICS 2013:50). According to Figure 1, the distribution chain of fresh fruit starts when finished packed fruit is transported for the first time and ends when the fruit arrives at a retail store.

Global fruit SCs, and in particular their distribution component, are under scrutiny because of their carbon intensity and contribution to climate change. The food-miles debate has been a subject of controversy since the 1990s. These issues prove that emissions associated with a food SC are a matter of concern in the academic community and society. Researchers such as Balster and Friedrich (2019:4) emphasised the importance of any information that will influence decision-making in the complex global food system. The latter is especially applicable to the realm of



Source: Adapted from Van Dyk, F. & Maspero, E., 2004, 'An analysis of the South African fruit logistics infrastructure', *ORiON* 20(1), 55–72. https://doi.org/10.5784/20-1-6, Freiboth, H.W., Goedhals-Gerber, L., Van Dyk, F.E. & Dodd, M.C., 2013, 'Investigating temperature breaks in the summer fruit export cold chain: A case study', *Journal of Transport and Supply Chain Management* 7(1), 1–7. https://doi.org/10.4102/jtscm.v7i1.99, Haasbroek, L.M., 2013, 'An analysis of temperature breaks in the summer fruit export cold chain from pack house to vessel', MCom thesis, Dept. Logsitics, Stellenbosch University, viewed 05 September 2021, from https://scholar.sun.ac.za/handle/10019.1/85676

FIGURE 1: A fresh fruit supply chain depicting supply chain activities and the cold and distribution chains.

emissions, as there is an increase in academic research attempting to provide industry and society with assistance in this regard (Chelly et al. 2019).

The interest in and research about the emissions generated by the global cold chain responsible for supplying fresh fruit are increasing. Various researchers (Bell & Horvath 2020; Fan et al. 2021; Iriarte et al. 2021; Loiseau et al. 2020) have investigated the global fresh fruit cold chain and its associated emissions. Other scholars such as Ala-Harja and Helo (2014) explored the environmental impact of SC decisions in the food industry. However, none of them has gone into detail to analyse or explain the process by which the fruit is distributed. This leads to the question of how these distribution chains are structured and which emission-generating activities have been included in the emission assessment process. The need for a holistic assessment is confirmed by Ala-Harja and Helo (2014:19), who stated that a 'bigger picture' of all aspects in an SC is required to analyse the sustainability performance adequately. This is especially true in perishable food chains in emerging markets (Liu et al. 2021).

Only a small number of publications calculate end-to-end emissions. In their detailed explanation of an avocado distribution chain, Du Plessis et al. (2022) examined all the emission-generating activities in the shipment from the packing facility in South Africa to a retail store in Switzerland. The analysis of all the distribution activities allowed the authors to determine the emission contribution of individual activities in the distribution chain. Subsequently, this enabled Du Plessis et al. (2022) to create an emission profile of the entire avocado shipment, which reveals that shipping 1 kg of avocados emits between 504.99 g and 782.87 g CO_2e (carbon dioxide equivalent). Although scenario dependent, Du Plessis et al. (2022) estimated that the deep-sea transportation leg is responsible for 48.33% of all distributional emissions. This shows that the remainder of distribution activities contribute significantly to the overall emissions. The authors emphasise the importance of mapping and understanding the full extent of the distribution activities to ensure that no activities are omitted from the overall calculation.

Other case studies (e.g. Rizet et al. 2010, 2012) analysed the emissions of various food SCs for products such as apples, tomatoes and yogurt from the farm gate in New Zealand to a consumer's home in Europe. In terms of the distribution chain, only maritime transport, road transport and refrigerated storage were analysed. All loading and unloading activities at warehouses and ports were thus excluded from the scope of their estimate. Nevertheless, the results estimate the distribution emissions to be nearly 950 g CO_2e per kg of apples, but uncertainty remains as to the full emissions attributable to all activities along the end-to-end cold chain.

No other published literature could be found that attempted an all-inclusive, end-to-end cold chain carbon emissions calculation similar to that done for the above-mentioned case studies. In the study by Du Plessis et al. (2022), the Global Logistics Emissions Council (GLEC) Framework (Smart Freight Centre 2019) emissions factors adjusted for Africa were used. This choice was dictated by the lack of country-specific emission intensity factors for contributing activities.

The emission accounting problem

The process of estimating emissions for a shipment of fresh fruit is at best a complex and confusing procedure. This is evident from the 18 assumptions made and the subsequent range of carbon footprint results achieved by Du Plessis et al. (2022) in their avocado shipment study. Rizet et al. (2010) mentioned that the process of quantifying emissions can potentially be a time-consuming and complicated process. Furthermore, the results obtained from such a study are directly influenced by the boundaries of the study, the type of activities included in the assessment and the method used. Two years later, a similar study by Rizet et al. (2012) again acknowledged that both data collection and data assessment are difficult processes.

The ability to estimate the total emissions from the distribution component of a fresh fruit SC requires knowledge and understanding of both the structure of the distribution chain and the individual activities, as is evident from Du Plessis et al.'s (2022) example scenario. Without this, it will be impossible to accurately determine the carbon footprint of fruit, measured in kg CO_2e/kg.

Even if stakeholders have knowledge and an understanding of the distribution chain and the individual activities, results of independent studies are often not comparable. Using the studies by Du Plessis et al. (2022) and Rizet et al. (2010, 2012) as examples, the differences that make the studies incomparable are summarised in Table 1 in order of decreasing importance. Table 1 shows that it is critical to analyse the same set of activities in independent assessments.

Apart from the studies by Du Plessis et al. (2022) and Rizet et al. (2010, 2012), only a few related, peer-reviewed published studies could be identified that map the overall structure of, and variations within, activities in a fresh fruit distribution chain. To accurately estimate emissions, it is necessary to identify both the activities responsible for emissions and the combination of the activities that collectively create a distribution scenario. The individual distribution activities are the building blocks for which emissions are calculated. These building blocks prescribe which distribution activities are included when determining the carbon footprint (kg CO_2e/kg) of fruit because of distribution. The structure of the distribution chain, therefore, reflects the realistic combination of activities for which the total distribution emissions should be calculated.

Focus on South Africa

South Africa is world renowned for producing and exporting a large variety and volume (2.9 million tonnes[1] per annum) of fresh fruit. Table 2 presents the six largest fruit categories exported, as well as the fruit type and associated volume of export.

South Africa is the biggest exporter of fresh fruit by volume in the southern hemisphere and the second-largest citrus exporter in the world (Fresh Produce Exporters Forum 2021). It is recorded that the South African fruit industry exports approximately 60% of its fresh produce to nearly 110 countries (Kruger 2020:6). Prominent export markets for South African fresh produce include Africa, the European Union, the United Kingdom, the Russian Federation, the Far and Middle East, the United States of America, Canada and the Indian Ocean Islands.

Achieving and maintaining a sustainable fresh fruit SC with a minimal carbon footprint throughout the entire distribution process is critical for the long-term success and prosperity of the South African fruit industry. A failure to transform could be disastrous for the sector and exacerbate the current global emissions trajectory.

1.Based on the assumption that 1 pallet of citrus = 1 tonne.

TABLE 1: Comparison between the distribution chain studies by Du Plessis et al. (2022) and Rizet et al. (2010, 2012).

Variable	Du Plessis et al. (2022)	Rizet et al. (2010) and Rizet et al. (2012)
1. Scope of assessment	- Packing facility to retailer - Well to wheel	- Farm gate to retailer - Well to wheel
2. Inclusion of all emission-generating activities	Partially	Omit loading and offloading at all ports and warehouses
3. Empty repositioning of containers assessed (if applicable)	Yes	Containers used but no reference to repositioning
4. All assumptions clearly stated so that limitations and constraints are evident	Yes	No
5. Method of assessment	Activity-based method to quantify emissions	Estimate vehicle/facility fuel consumption and use fuel emission factors to quantify emissions
6. Focus of analysis	Assess each individual shipment's emissions	Assess typical or average shipment

Source: Adapted from Du Plessis, M., Van Eeden, J. & Goedhals-Gerber, L., 2022, 'Carbon mapping frameworks for the distribution of fresh fruit: A systematic review', *Global Food Security* 32(1), 100607. https://doi.org/10.1016/j.gfs.2021.100607; Rizet, C., Cornélis, E., Browne, M. & Léonardi, J., 2010, 'GHG emissions of supply chains from different retail systems in Europe', *Procedia – Social and Behavioral Sciences* 2(3), 6154–6164. https://doi.org/10.1016/j.sbspro.2010.04.027; Rizet, C., Browne, M., Cornélis, E. & Léonardi, J., 2012, 'Assessing carbon footprint and energy efficiency in competing supply chains: Review – Case studies and benchmarking', *Transportation Research Part D: Transport and Environment* 17(4), 293–300. https://doi.org/10.1016/j.trd.2012.01.002

TABLE 2: The six fruit categories, types of fruit and associated export volume.

Fruit category and year of statistics	Fruit type	Export volume in tonnes (except if otherwise stated)
Citrus fruit (2020)	Oranges	920 000 pallets
	Soft citrus	340 000 pallets
	Lemons	350 000 pallets
	Grapefruit	220 000 pallets
Pome fruit (2020)	Apples	450 000
	Pears	212 500
Table grapes (2019/2020)	Table grapes	288 000
Subtropical fruit (2020)	Avocados	60 000
Stone fruit (2019/2020)	Plums	44 625
	Nectarines	12 500
	Peaches	5125
	Apricots	1663
Exotic fruit (2019/2020)	Blueberries	12 000

Source: Adapted from Fresh Produce Exporters Forum, 2021, *Fresh produce export directory 2021*, Century City, Cape Town

Research methodology

This section contains the problem statement and discusses the research methodology used to answer the four research questions of the study. The scope and limitations as well as data collection and analysis are also discussed.

Problem statement

The various distribution methods and individual activities by which fresh fruit is exported from South Africa are not clearly defined. This complicates the process of calculating the carbon footprint (kg CO_2e/kg fruit) of an individual shipment of fruit. In addition, the lack of a standard distribution diagram inhibits benchmarking of independent studies, as not all studies assess the same set of emission-generating activities. This article will identify the various distribution methods and activities involved in the export of fresh fruit from South Africa.

Research questions

Research for the study was guided by the following four research questions:

1. What are the individual distribution activities and the variations of these activities?
2. How is the overall distribution structure of a fresh fruit SC configured?
3. How can the analysis of distribution chain activities facilitate the calculation of the carbon footprint of export fruit?
4. What other potential contribution can the diagrams make?

To answer these four questions, generic diagrams that capture the structure of the distribution chain and the individual distribution activities were created. The term 'generic' is used to group different distribution scenarios together based on shared characteristics, such as the type of transport vehicle used, whether storage is applicable, etc. Each 'generic' diagram effectively describes a range of distribution scenarios that have small differences or permutations in a specific activity, such as the specific type of truck or vessel used.

Research scope and limitations

The analysis focused on the distribution of the six fruit categories listed in Table 2. These fruit types are the major contributors (> 95% of volume) to the South African fruit export industry (Fresh Produce Exporters Forum 2022). The scope for identifying emission-generating activities is from the door of the fruit-packing facility, where packed fruit is loaded, up to the international port of destination. The study does not include the offloading of fruit at the port of discharge or any further distribution activities to the point of retail. However, the return of empty refrigerated containers (reefers) and unit load devices (ULDs) in the air-freight industry was included in the scope.

Data collection and analysis

In this study, a qualitative research methodology (Van Note Chism, Douglas & Hilson 2008) was used. The aim was to understand and explain how specific phenomena, such as fruit exports, occur by examining specific distribution instances in detail. The examination of distribution instances uses a collective case study research methodology in which several different cases (distribution scenarios and facilities) are studied individually and then combined to provide insight into general phenomena, such as fruit export structures. This research approach allows for considerable flexibility in terms of the data collection methods employed.

The qualitative case study approach shown in Figure 2 was divided into two distinct phases: phase 1 – 'determine activities' and phase 2 – 'create and validate process diagrams'. Phase 1 consists of three actions: (1) a literature review to establish the activities and general structure of fresh fruit distribution chains, (2) direct observation of distribution activities at several facilities and (3) unstructured interviews with operational managers at the facilities observed. Observations and informal interviews are essential as they provide first-hand experience of the activities performed in a fresh fruit distribution chain. Phase 1 was used to answer research question 1. In phase 2, the authors created several generic distribution chain diagrams. These diagrams were validated through several iterations of semistructured interviews with subject matter experts. This phase was used to answer research question 2 and validate the results of research question 1, as the generic diagrams ensure that all distribution activities are covered.

For the phase 1 literature review, master's theses with a focus on South African fruit exports or the cold chain by Haasbroek (2013), Khumalo (2018), Conradie (2019) and Fedeli (2019) were analysed. This analysis provided a basic understanding of the distribution activities performed in a fresh fruit SC and prevented the duplication of existing literature. It is noteworthy that none of the authors mentioned above nor numerous other authors (Liu et al. 2021; Polderdijk et al. 2006; Roibás, Elbehri & Hospido 2015; Rong, Akkerman & Grunow 2011; Shoji et al. 2022; Soto-Silva et al. 2016; Verdouw et al. 2010) have investigated the distribution activities or process in detail, which leaves considerable room for interpretation and future work.

Because existing literature does not describe activities in detail, the obligation to answer research question 1 depended on primary research through observation and informal interviews. Regarding observations, Van Note Chism et al. (2008) advised that direct observation by an outsider is the best method to understand the working of a system or process as the system

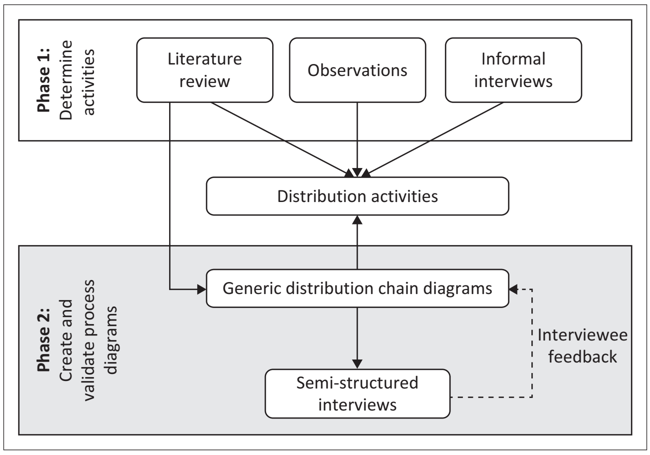


FIGURE 2: A visual explanation of the research methodology applied in this article.

TABLE 3: List of logistical facilities visited for the purpose of observations and informal interviews.

Facilities visited	Description
MorgenCargo Air and Sea Freight Logistics	An air-freight service provider at Cape Town International Airport's cargo terminal
FPT Group (Pty) Ltd leasehold in the Port of Cape Town	The break-bulk terminal at the Port of Cape Town
Transnet Port Terminals (TPT) - Cape Town container terminal	The Cape Town container terminal
Cape Fruit Coolers (CFO) - Richmond Park	Storage and transhipment of fruit
South Atlantic Fruit Terminals (SAFT) - Atlantic Hills	Storage and transhipment of fruit

is not disturbed during observations. The primary researcher visited the logistical facilities described in Table 3. These facilities were specifically chosen because they are large-scale and important transition points in the cold chain process for fresh fruit exports from South Africa.

To ensure a proper understanding of the process at each facility by the primary researcher, a comprehensive, in-person explanation of the various activities performed at each logistical facility was obtained from facility representatives. These explanations were then summarised and validated through verbal feedback to the respective representatives.

Phase 2 of the methodology entailed the creation and validation of the generic distribution chain diagrams to confirm that they were correct. In addition, the diagrams were used to validate that all emission-generating activities had been identified in research question 1. To create diagrams, scenario planning was done whereby all realistic processes in a shipment are stated. The diagrams were then refined and integrated into a single generic distribution chain diagram. Following the creation of the diagrams, four experts in the field of fruit export and logistics were interviewed. Each interviewee was purposefully chosen by the researchers for their unique fruit export cold chain perspective because of different backgrounds covering the extent of the fruit export process. Their combined experience of 101 years included being head of logistics at the Soft Fruit Board, manager of operations and risks at a leading exporter, exporter of fresh fruit and food products at the largest global fruit and vegetable corporation and working as a private consultant.

The generic distribution chain diagrams were sent to the interviewees in advance, allowing for preparation before the interview. During the interviews, each distributional possibility captured in a diagram was discussed. The interviewees were then asked for their views and invited to propose alternatives. After incorporating the suggested improvements in the diagrams, an iterative approach was followed through repeat sessions and incorporating the experts' feedback. The result was a more comprehensive set of final diagrams.

All four interviewees confirmed that the developed generic distribution chain diagrams were comprehensive and representative of the status quo of fruit exports from South Africa. Furthermore, all interviewees stated that these diagrams represented the real-world process whilst accommodating significant variations in the distribution chain choices.

Ethical considerations

Ethical clearance to conduct the study was obtained from the University of Stellenbosch, Social, Behavioural and Education Research Ethics Committee (ref. no. 19464).

Results: Generic distribution chains

In this section, the various distribution activities that were identified via the literature review and observed during the site visits to the logistical facilities are discussed. This is followed by an overview of the generic distribution chains developed after the literature review and observations (see Figure 2). Finally, the generic distribution chain diagrams and their structure – validated by means of four semistructured interviews – are explained.

Distribution activities

All the activities performed during international fresh fruit distribution can be classified into four categories, namely *transport*, *loading*, *offloading* and *storage*. Using this classification scheme enables the systematic analysis of all possible distribution activities and their variations. Both the forward or the downstream movement of packed fresh fruit and the reverse movement of empty reefer containers and empty airline ULDs ('empty containers' from hence forward) are analysed using this classification. All activities follow the same order: loading, transport, offloading and storage. This recurring order of activities is the basis of all the diagrams.

Transportation may be defined as the activity where pallets of fruit or empty or loaded containers are physically moved between two different locations. Transport modes are as follows: road, rail, deep-sea and air transport. The first two modes, road and rail, are only used for domestic transportation or *precarriage*. These modes are used to move fruit to the port of export or to and from a logistical facility where the fruit is stored or consolidated. Road and rail are also used to reposition domestic empty containers. Deep-sea and air transport are used for the international leg of transportation – the *main carriage*. The fruit lifespan and demand dictates the mode of international shipping, with deep-sea transport responsible for most of South Africa's fruit exports. Combinations of two or more modes may be used for a shipment or for repositioning empty containers. Airline ULDs are always repositioned via air transport (Combrink 2021; Viljoen 2021), as fast turnaround times are crucial.

There are physical differences between road transport vehicles; for example, trucks may be classified as either refrigerated (reefer container or refrigerated body) or nonrefrigerated (tautliner or flat-deck body). Transport via rail is to a large extent standardised, as the number of rail wagons and the type of drive system (diesel or electric) are the only variables. Deep-sea transportation can occur by either a container vessel, a dedicated reefer vessel (which transports pallets of fruit) or a combination vessel (which can transport both pallets and reefer containers). For air transport, both cargo aircraft and combination aircraft (passengers and cargo) can be used. Note that empty transportation vehicles are never refrigerated.

Loading is the activity where fruit, empty reefer containers or airline ULDs are loaded into or on-board the transportation vehicle. The type of loading vehicle and the exact method of loading depend on the transport mode, specific vehicle characteristics, the unit of transport (a pallet, container or ULD) and the operational circumstances of the scenario or facility. For pallets, the common types of loading vehicles used are height-adjustable loading vehicles (electric or internal combustion forklifts), horizontal loading vehicles (pallet jacks), on-board vessel cranes (ship's gear) and gantry cranes. For reefer containers, the common types of equipment used are reach stackers, straddle carriers, rubber-wheeled or fixed-track gantry cranes, Mafi tractors and on-board truck cranes. The two vehicle types used to load ULDs into aircraft are airport tow tractors and aircraft loaders.

The *offloading* of fruit, empty reefer containers and ULDs is conceptually identical to loading but in the opposite direction. The offloading of fruit is therefore subject to the same physical and logistical considerations as the loading and the same types of equipment or vehicles are used.

The *storage* or holding of fruit in pallets or reefer containers is required at certain stages or positions in the distribution chain. These holding points conceptually perform two functions: (1) they act as consolidation points for different geographical locations and (2) they act as buffers or storage points. Storage can either be for a short time or for extended periods. Fruit is stored for a short time when there is a change in transport mode or transport unit, if responsibility is transferred to another stakeholder, or when it is necessary to re-cool the fruit. Long-term storage is often used to ensure a constant supply of fresh fruit to the market. The duration of storage is dependent on market factors such as the global supply and the price for the fruit, the maximum storage period or contractual obligations, where continual supply of certain fruit types to supermarkets has been contracted. Storage of fruit on pallets and in containers and airline ULDs can occur at four types of logistical facilities: an inland fruit facility, a container facility, a rail facility and the port of export.

Identifying and analysing all the emission-generating activities in the highest level of detail is important as this will determine the accuracy of the calculated emissions value for a particular activity. The higher the level of detail within the activity, the closer the estimated emissions value will be to the actual emissions value.

Overview of generic distribution chains

Using the classification scheme for activities explained in the previous section – transport, loading, offloading and storage – the distribution of fresh fruit can conceptually happen in two scenarios, A and B, as shown in Figure 3. The difference between these scenarios is the number of logistical facilities through which the fruit moves in the distribution chain. This is influenced by (1) the volume of produce packed at a packaging facility, (2) the market demand for the fresh fruit or (3) the logistical aspects involved.

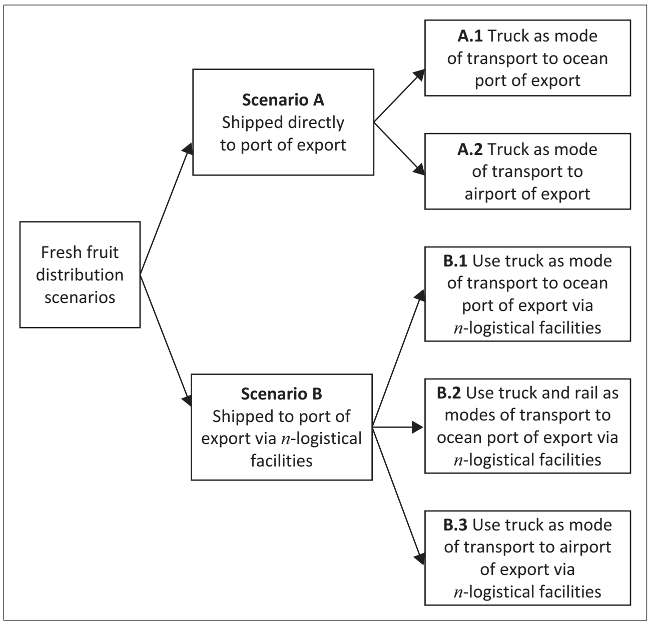


FIGURE 3: Outline of generic distribution chain scenarios.

Scenario A in Figure 3 represents the movement of packed fruit directly to the port of export. This scenario is common when large volumes (full truckload or filled container) of produce are shipped or when the lead time should be minimal. The chain starts at the packing facility, where fruit is loaded onto a road transport vehicle and shipped to a port of export, where it is offloaded and possibly stored for a short period. What is distinctive about Scenario A is that trucks are the only transport mode used to move the fruit between the packing facility and the port of export. Packing facilities are often located in remote regions and do not have access to rail infrastructure as the primary transport mode. Transport by truck is thus responsible for the entire precarriage. For the main carriage, the fruit is transported by either deep-sea transport or air.

In Scenario B (see Figure 3), fruit is shipped via *n*-logistical facilities.[2] This generic distribution chain is applicable if (1) the output of the packing facility is small (less than a truckload or container), (2) the long- or short-term storage of fruit or reefer containers is required or (3) rail is used as a transport mode. The chain starts at the packhouse or packing facility where packed fruit is loaded onto or into a road transport vehicle. Once the fruit arrives at a logistical facility, the fruit is offloaded and stored for the desired time. Several iterations of the latter interlogistical facility distribution legs are possible, but the number of repetitions (*n*) should be minimised, as each repetition adds cost. From the final logistical facility, fruit can be loaded and transported by either road or rail to a port of export. The fruit is offloaded at the port of export and once again stored for a short period of time before being loaded onto or into the main carriage vehicle. The modal option for main carriage is deep-sea or air

2. The letter *n* denotes the maximum number of logistical facilities (inland fruit facility or container facility) moved through during the upstream or downstream distribution process. *n* = 0, 1, 2, 3, etc.

transport. Note that South African airports of export are not connected to rail infrastructure, meaning that this scenario was excluded, but it might be possible elsewhere.

Generic distribution chain diagrams

Each generic distribution chain diagram has two dimensions, shown by columns and rows. The columns represent the four distribution activity categories in recurring order: loading, transport, offloading and storage, as mentioned in the distribution activities section. The rows in the diagrams represent the functional unit of movement, which can either be pallets or reefer containers. Each column in a diagram indicates the possible vehicle types used for a specific activity. Transport via road, for example, can use several truck types as described. Transport via deep-sea transport similarly can use different vessel types. The same principle is used to indicate the type of logistical facility and the type of loading or offloading vehicles used.

In terms of the direction of movement in diagrams, activities that move from left to right involve forward or downstream movement of fruit from the point of initial loading at the first packing facility up until the main carriage. The right-to-left movement indicates the upstream movement of empty containers. Note that the reverse direction is only applicable to empty containers and not to pallets. Figure 4 shows the convention for connecting arrows used in diagrams.

In addition, sections of diagrams are greyed out, indicating a highly unlikely distribution possibility. However, these exceptions are included because the alternative they indicate could possibly occur. Each scenario will now be introduced and discussed in more detail.

Scenario A: Shipped directly to port of export

In these scenarios, fruits are transported directly from the packing facility to the port of export and do not move via a logistical facility.

Generic distribution chain A.1: Directly to ocean port by road

Scenario A.1, shown in Figure 5, indicates the direct movement of packed fruit to an ocean port of export, meaning n = 0, as indicated on the left side of the diagram. To conceptually explain the distribution process, each activity is allocated a number from (1) to (19).

- - - -▶	The forward or downstream movement of reefer containers filled with fruit
◁- - - -	The reverse or upstream movement of empty containers (empty repositioning)
——▶	The forward or downstream movement of pallets of fruit
◁——	The reverse or upstream movement of ULDs (repositioning)

ULD, unit load device.

FIGURE 4: The conventions used in the distribution chain diagrams.

A lack of imported refrigerated cargo and the seasonal nature of fruit exports require empty reefer containers to be transported either via a container vessel (1) or a combination vessel (2). The empty containers are offloaded (3) from the vessel using a combination of the mentioned loading equipment and stored in the port's container stack (4). As the container is empty, it does not have to be plugged in and is stored with other empty containers. The container is loaded onto a truck using the loading vehicles stated in (5). The container truck (6) travels to the packing facility where loading of the fruit will commence. Once loading of fruit starts, the direction of movement in the diagrams is reversed to the downstream direction.

At the packing facility, two loading scenarios are possible. The empty reefer container can be offloaded from the truck using a reach stacker or an on-board truck crane (7), loaded with pallets of fruit and reloaded onto the truck. The alternative is to load pallets into the container whilst the container remains on the truck. In both scenarios, however, a combination of horizontal and vertical loading vehicles (8) is used.

The full reefer container truck (6) travels directly to the port of export. Two options for offloading are possible. In the first option, the reefer can be offloaded by the equipment stated in (5) and then be stored in the container terminal's reefer stack (4). The equipment stated in (3) is then used to load the container onto either a container vessel (1) or a combination vessel (2). In the second option, the truck drives directly onto the quayside (9) next to the vessel. This is only applicable if the reefer is loaded onto a vessel at a multipurpose terminal (MPT). A fixed-track gantry crane (10) is then used to load the reefer onto a container vessel (1) or a combination vessel (2). After loading, the vessel departs on the main carriage.

Regarding pallets of fruit, the distribution process starts with using a combination of horizontal and vertical loading vehicles (8) to load the pallets onto or into a truck with a refrigerated body (11), a tautliner (12) or a flat-deck truck (13). Once loaded, the truck travels to the port of export where two offloading options are possible. In the first option, the truck drives onto the quayside next to the ship (15) where the fruit is offloaded using the offloading equipment stated in (14). This option is, again, only applicable if the pallets of fruit are handled at an MPT. Once offloaded, on-board cranes on the vessel (16) are used to load the pallets onto either a combination vessel (2) or a reefer vessel (17). The second option is where the fruit is offloaded (14) and then stored in the fresh fruit terminal's refrigeration facility (18). Once the ship is ready to be loaded, the equipment in (19) is used to load the pallets of fruit on either vessel type (2) or vessel type (17).

Generic distribution chain A.2: Directly to airport by road

Scenario A.2, shown in Figure 6, indicates the direct movement of packed fruit to an Airport of export. Once again, note that n = 0 on the leftmost side of the diagram.

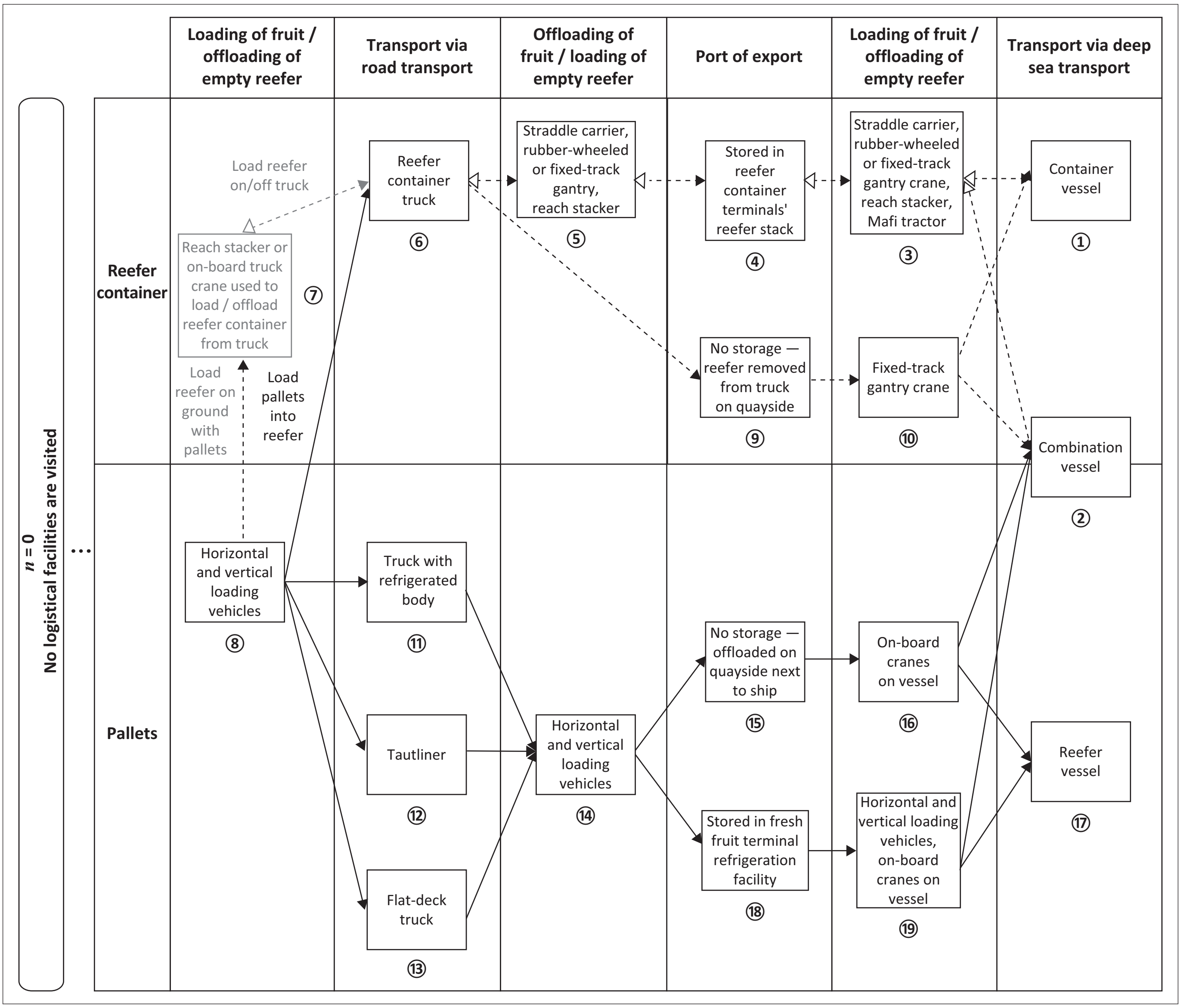


FIGURE 5: Scenario A.1, where fresh fruit is distributed from a packing facility to an ocean port of export via road transport.

The distribution chain starts with the loading of pallets using a combination of horizontal and vertical loading vehicles (1). Pallets are loaded into either a truck with a refrigerated body (2), a tautliner (3) or a flat-deck truck (4). Once the truck has arrived at the Airport of export, the offloading equipment stated in (5) is used to offload the pallets. Pallets are stored in the terminal's refrigeration facility (6), where airline ULDs are packed. Once the aircraft is ready for loading, airport tow tractors and aircraft loaders (7) are used to load the ULDs into the cargo hold. The majority of aircraft used to transport cargo from South Africa are combi-planes, meaning both cargo and passengers are transported.

Unit load devices are always repositioned via air transport and are normally loaded with cargo to ensure minimal empty repositioning. However, if ULDs are to be repositioned empty, specifically because of a distribution chain requirement, the logistical activity has to be included for accurate emissions attribution. The empty ULDs are flown by an aircraft (8) to a South African airport of export where they are offloaded using an airport tow tractor and aircraft loader (7). From there, the ULDs are stored (6) until they are used again.

Scenario B: Shipped to port of export via n-logistical facilities

In these scenarios, fruit are transported via a logistical facility from the packing facility to the port of export.

Let n denote the maximum number of logistical facility movements in either the upstream ($n_{upstream}$) or the downstream ($n_{downstream}$) distribution process. Therefore, using a mathematical notation, the number of times the events as depicted in Figure 7 are repeated may be calculated as:

$$n = \text{Max}\{n_{upstream}, n_{downstream}\} \quad \text{[Eqn 1]}$$

where $n_{upstream}$ denotes the maximum number of logistical facility movements in the upstream distribution process and

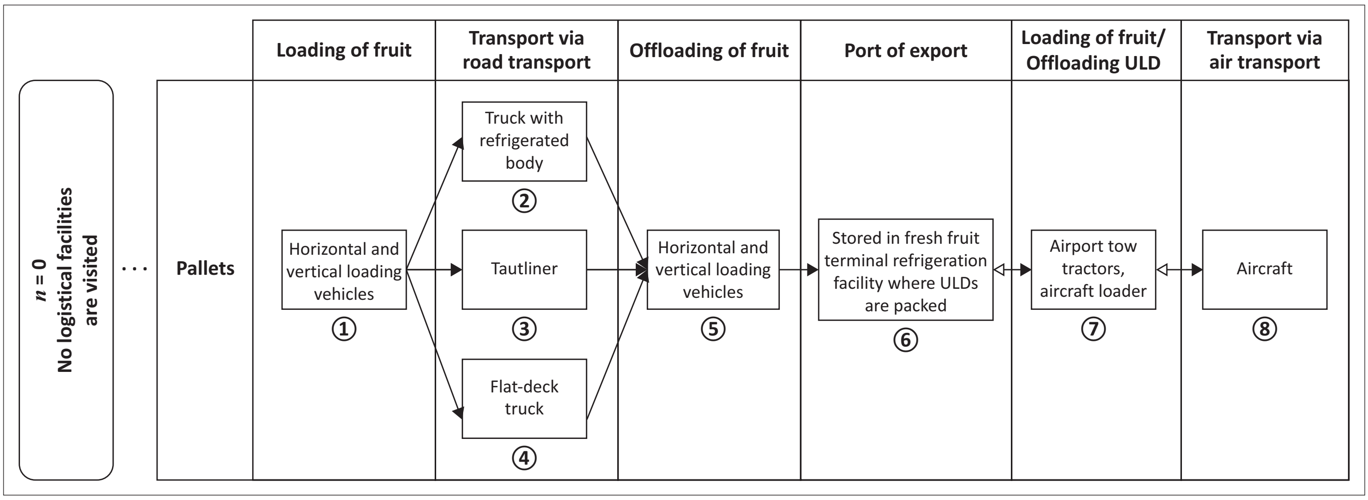


FIGURE 6: Scenario A.2, where fresh fruit is distributed from a packing facility to an airport of export using road transport.

$n_{downstream}$ denotes the maximum number of logistical facility movements in the downstream distribution process.

A single logistical facility movement (n = 1) is illustrated in Figure 7. As indicated previously, the only conceptual difference between Scenario A and Scenario B in Figure 3 is the introduction of a movement via n-logistical facilities. The diagram in Figure 7 can thus be potentially repeated n-times before Figures 5 and 6 to create a large number of unique distribution and SCs.

The number of logistical facilities visited by empty containers in the upstream movement ($n_{upstream}$) does not necessarily equal the number of logistical facilities through which fruit passes in the downstream movement ($n_{downstream}$). However, both $n_{upstream}$ and $n_{downstream}$ must be greater than or equal to zero. Thus, using a mathematical notation, the constraint may be written as:

$$0 \leq n_{upstream} \leq n \text{ and } 0 \leq n_{downstream} \leq n \quad \text{[Eqn 2]}$$

This repetition leg allows the diagrams to capture and incorporate all possible distribution variations. Note that road transport is the only domestic transportation mode used between different inland fruit facilities or container facilities. Rail transport is not used between facilities, as rail infrastructure is not available between all the different facilities. This might be possible for different countries. The functional unit of movement can either be pallets or reefer containers, and the upstream movement is only applicable to empty reefer containers and not to pallets.

The n-logistical facility repetition diagram will be explained in terms of reefer containers and then pallets. Note that the same logic applies to other scenarios where n is more than one. In Figure 7, n = 1, meaning that either $n_{upstream}$ or $n_{downstream}$ is equal to one.

If $n_{upstream}$ = 1 and $n_{downstream}$ = 1, then an empty reefer container arrives via road transport and is offloaded and stored at the container facility (1). When the container is needed, the equipment stated in (2) is used to load the empty reefer onto a container truck (3), whereupon the truck travels to a packing facility. Once the empty reefer arrives and the loading of the fruit commences, the direction of the events or activities in the diagram reverses. The container is then stuffed with pallets whilst on the truck, using the equipment in (5). Alternatively, the equipment in (4) and (5) is used to offload the reefer from the truck. The reefer is filled and then reloaded onto the truck. The container truck (3) then travels to a container facility for storage. The equipment stated in (2) is used to offload the reefer for storage at (1).

If $n_{upstream}$ = 1 and $n_{downstream}$ = 0, then the upstream movement of the empty container is the same as the example above, but after filling the container with fruit, the filled reefer container truck (3) moves via (6) directly to the port of export (joining the flow in Figure 5). The connecting arrow (6) in Figure 7 thus allows the container truck to bypass (2) and (1).

If $n_{upstream}$ = 0 and $n_{downstream}$ = 1, then the empty container does not move through a container facility during the upstream movement. The empty containers arrive by road transport directly from the ocean port of export. This move is indicated with the vertical arrow below (6). The container is then filled and travels along (3), (2) and (1), where it is stored.

Regarding the distribution of pallets, horizontal and vertical loading vehicles (5) are used to load either truck type (7), (8) or (9). The truck then travels to an inland fruit facility (11), where the pallets are offloaded using the equipment stated in (10). The pallets of fruit are then stored in the inland fruit facility (11).

The various generic distribution chain diagrams generated by these repetitions are given in the figures in Appendix 1 (Figures B.1–B.3). Figure B.1 indicates the distribution process of fresh fruit to an ocean port of export via n-logistical facilities using only road as transport mode. Figure B.2-A1 shows the possible distribution variations of exporting fresh fruit via n-logistical facilities using rail and road as transport modes to an ocean port of export. Figure B.3-A1 indicates the

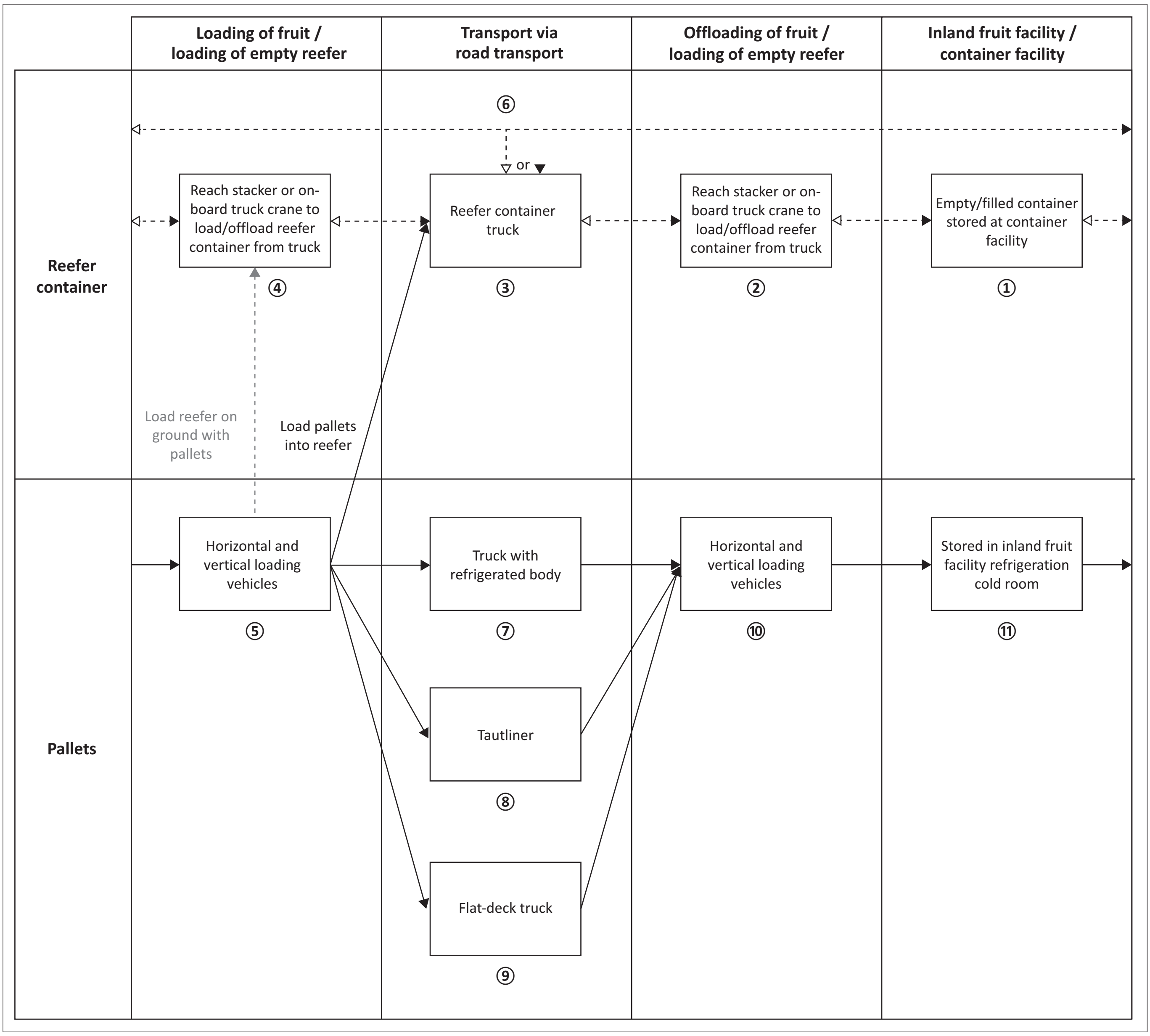


FIGURE 7: *n*-logistical facility repetitions.

generic distribution chain responsible for exporting fruit via *n*-inland facilities to an Airport of export.

Discussion

Analysing the five generic distribution chain diagrams (Figures 5, 6 and Figures B.1-A1–B.3-A1) reveals many distribution possibilities between a packing facility and a port of export. This variation is because of the unique characteristics of each fresh fruit shipment. Factors such as the volume of the shipment, geographical location, contractual agreements between exporters, importers and shipping lines, regulatory requirements by the country of import, operational factors, transport mode and vehicle types dictate which distribution scenario is most applicable. Furthermore, unforeseen circumstances and the subsequent managerial decisions in reaction to these events lead to considerable variation in the distribution chain between different shipments of fresh fruit. However, the five diagrams that were developed capture all the hypothetical and real-life scenarios of international fresh fruit distribution from South Africa in detail. This was confirmed by four industry experts with a wealth of experience in fruit exports.

All possible activities performed during distribution can be classified into one of four categories: loading, transport, offloading and storage. These four categories will always recur in this order in the *n*-facility repetition section – irrespective of the number of logistical facilities the fruit moves through.

The main difference between the two defined distribution scenarios, Scenario A and Scenario B, is the number of logistical facilities (*n*) visited during either the upstream or the downstream distribution process. These repetitions, shown in Figure 7, lead to considerable complexity in mapping the standard distribution strategies and allocating a standard emissions value to any fruit product. Each activity in the distribution chain identifies a single emissions calculation. Collectively, the sum of the emissions calculated for individual activities results in the overall distribution chain emissions. Thus, the generic distribution chain diagrams can form the input basis of all emissions estimation projects for the shipment of fresh fruit. The diagrams prescribe for which activities emissions must be calculated.

Although the diagrams capture the real-life distribution scenarios of fresh fruit in South Africa, the same activities and diagrams are applicable to other southern hemisphere countries such as Chile, Peru, Argentina and Brazil. The diagrams can also be used to map the emissions of their fresh fruit distribution chains. However, validation interviews would be needed to confirm whether specific distribution scenarios are possible, such as rail linkages to airports or long-term storage at the port of export.

In addition, it is also possible that other product types, such as frozen foods or vegetables, follow similar distribution processes. This implies that the carbon footprint of products with a similar distribution chain can also be calculated using this outcome.

Implications for managerial practice

The five generic distribution chain diagrams form the blueprint of seven important emission-related managerial practices:

1. They enable stakeholders with reasonable industry knowledge to identify the specific scenario (A or B) that correctly represents the distribution of a shipment of fruit. Defining the process increases visibility in the SC, which improves transparency and communication between producers, buyers and logistical service providers, as a common basis of understanding is shared amongst all stakeholders.
2. An analysis of the distribution chain enables stakeholders to analyse the consequences of logistical decisions such as choice of transport mode and storage duration, as well as how these choices affect the carbon footprint of the final product. Without the generic diagrams, it would be difficult to determine accurate distribution emissions per kilogram of a specific fresh fruit shipment.
3. The diagrams allow controllers or fruit export companies to identify alternative distribution options if the planned distribution scenario fails. Thus, diagrams visually guide users to select a different alternative distribution strategy to reduce excess movement and related emissions. Liu et al. (2021) confirm the need for proactive network design to increase competitiveness and bolster performance.
4. The research identifies possible redundant activities performed during the distribution process. This enables stakeholders to redesign their current distribution chain to a more streamlined process.
5. The research also allows stakeholders in the logistics sector to allocate cost, time, emissions and resources in a structured manner, enabling better planning as cost, time, emissions and resources are estimated for each individual activity versus the conventional overall distribution chain.
6. The diagrams enable comparison between different distribution strategies in a consistent way for each activity or the overall distribution process in terms of cost, time, risk, temperature deviation, emission, etc. This facilitates selecting the best possible distribution strategy.
7. The diagrams capture the various methods by which fresh fruit is currently being exported from South Africa. This allows inexperienced logistical service providers to verify that all the distribution activities have been planned, arranged and paid for.

Contribution to scholarly knowledge

This article introduced the readers to various distribution activities in a fresh fruit SC that collectively form the distribution chain. It addressed the four research questions set out in the 'Methodology' section:

What are the individual distribution activities and the variations of these activities?: All distribution activities in the fresh fruit distribution chain fall into one of four categories: transport, loading, offloading and storage. Several different variations of a single distribution activity exist because of types of vehicles or equipment used, the method of operating the equipment or vehicles and finally, the market element, which introduces a time variable to distribution activities.

How is the overall distribution structure of a fresh fruit supply chain configured?: The distribution structure or sequence of distribution activities by which the fresh fruit is exported is always configured in one of two scenarios, Scenario A or Scenario B. The major difference between these scenarios, apart from the difference in transportation vehicles, is the introduction of movement via *n*-logistical facilities. The two scenarios were expanded to create five generic distribution chain diagrams describing the standard scenarios for exporting fresh fruit.

How can the analysis of distribution chain activities facilitate the calculation of the carbon footprint of export fruit?: The distribution chain diagrams developed identify all emission-contributing activities in a distribution chain. This ensures that independent carbon-footprinting projects can analyse the same set of activities and produce comparable results. It thus eliminates the personal interpretation of boundaries and exclusion of relevant activities in these projects. This allows for product benchmarking amongst various stakeholders, leading to pressure towards a net product emissions reduction. The five generic distribution chain diagrams could be used as models for future emissions estimation projects focusing on distribution not only from South Africa but also other southern hemisphere countries.

In addition, the individual activities in the diagrams identify the various activities for which data are needed in emissions estimation projects. As explained in the 'Results' section, individual activities prescribe the data and emission intensity factors necessary for any calculation. From the generic diagrams, it is evident that emission intensity factors for several transport modes, configurations within the mode and logistical facilities are required.

What other potential contribution can the diagrams make?: Finally, apart from mapping the various distribution scenarios for emissions calculation purposes, the generic distribution chain diagrams can also be used as the basis for countless simulation projects analysing and/or optimising the distribution chain and associated activities. Simulation studies could investigate the distribution chain to suggest the optimal strategy in terms of time, cost, emissions, risk, temperature deviations and process capacity, amongst others.

Conclusion

This article analysed the processes and activities involved in exporting fresh fruit from South Africa. In terms of emission assessment, the research conducted (1) identified individual emission-generating distribution activities in fresh fruit shipments and activity variations, (2) described five generic distribution chain diagrams depicting the distribution process of exported fresh fruit and (3) discussed how the analysis of distribution activities facilitates assessment of the carbon footprint. The article also discussed seven implications for emission-related managerial practice when dealing with SCs and explained how the diagrams can be used in other simulation projects.

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Competing interests

The authors have declared that no competing interest exists.

Authors' contributions

M.J.D.P. primarily executed the data collection and analysis and was responsible for the initial write-up and editing. J.V.E. and L.L.G.-G. were involved significantly in the conceptualisation, design and oversight of the research process, established industry contacts, verified results and contributed significantly towards both the editing and finalisation of the manuscript.

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Data availability

Because of the sensitive nature and privacy of the analysed data, neither the collected data nor detailed results are available for this study.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

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Appendix 1: Scenario B diagrams

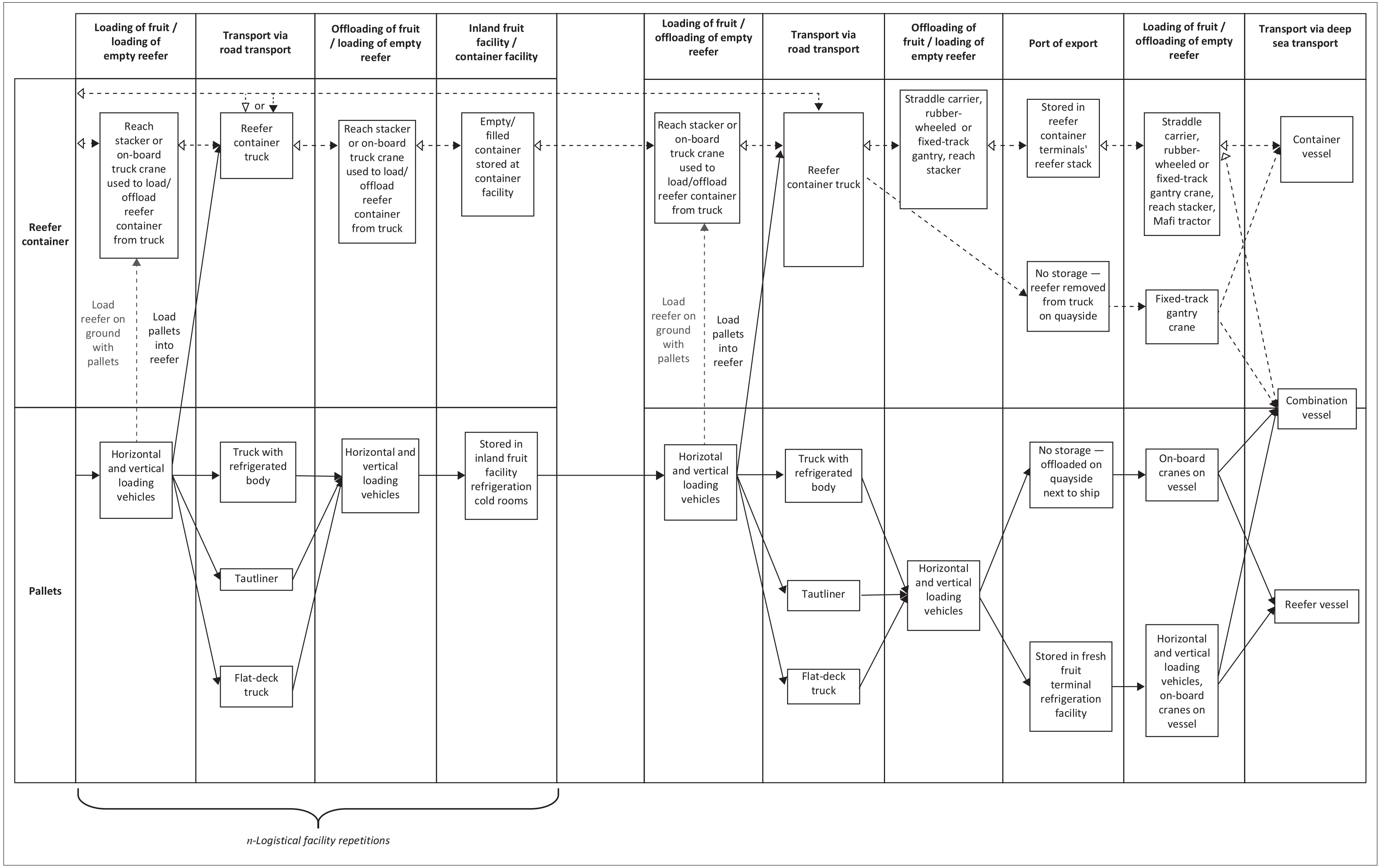

FIGURE 1-A1: Scenario B.1, where fresh fruit is transported by road to an ocean port of export via n-logistical facilities (n = 1, 2, 3...).

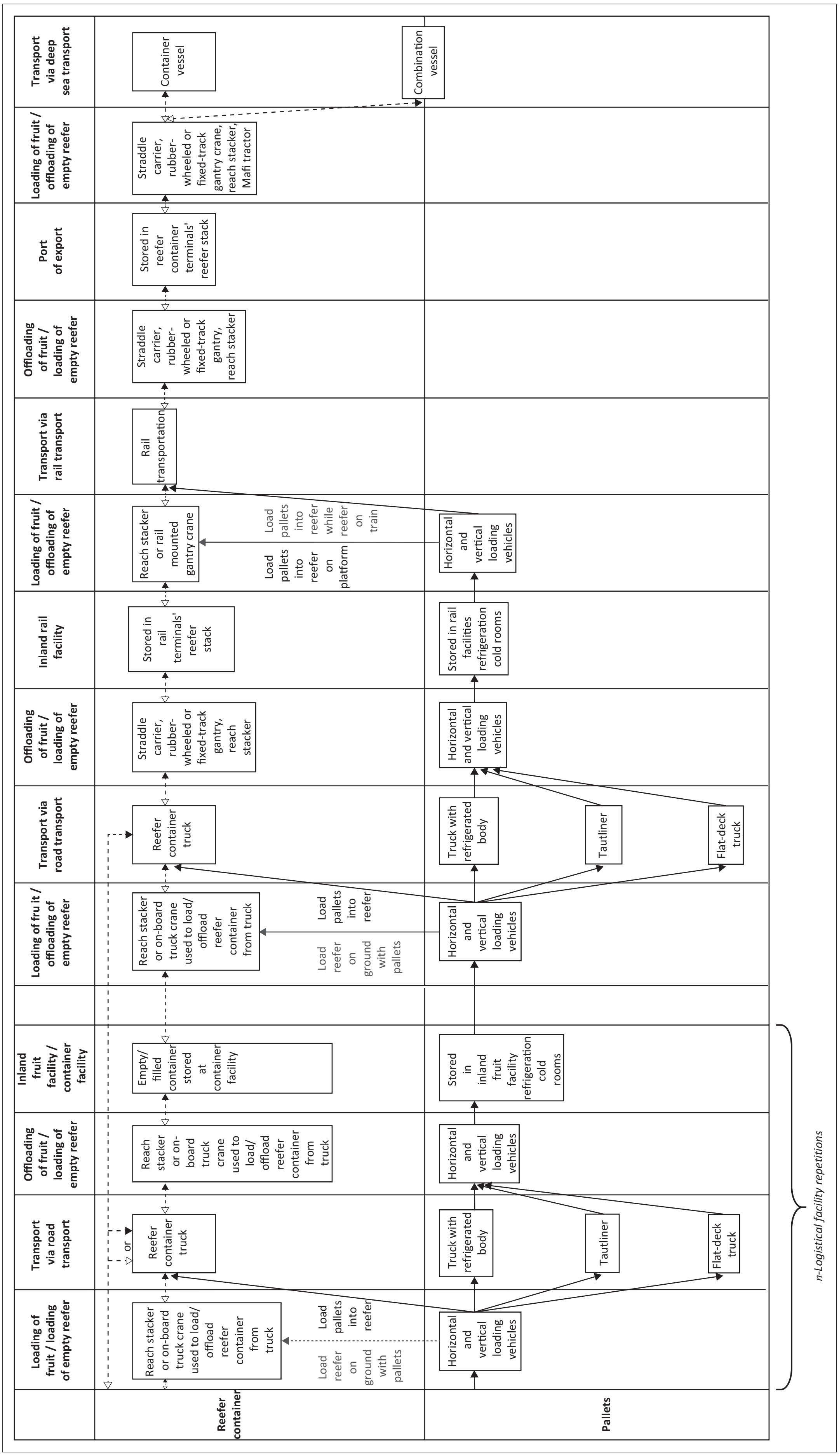

FIGURE 2-A1: Scenario B.2, where fresh fruit is distributed by rail and road to an ocean port of export via n-logistical facilities (n = 0, 1, 2...).

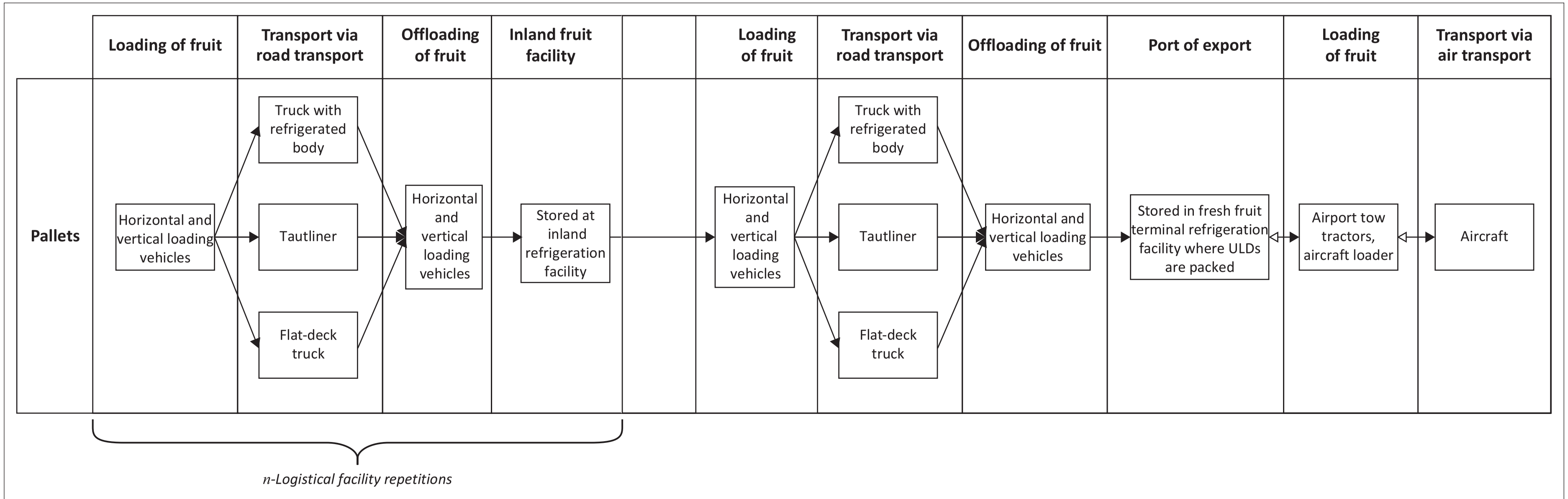

FIGURE 3-A1: Scenario B.3, where fruit is shipped by road to an airport of export via *n*-logistical facilities (n = 1, 2, 3...).