A Carbon Mapping Framework for the International Distribution of Fresh Fruit

by

Martin Johannes du Plessis

Dissertation presented for the degree of

Doctor of Philosophy

in Industrial Engineering in the Faculty of Engineering at

Stellenbosch University

Supervisor: Prof Joubert van Eeden
Co-Supervisor: Prof Leila Goedhals-Gerber

March 2023

DECLARATION

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This dissertation includes [5] original papers published in peer-reviewed journals or books and [0] unpublished publications. The development and writing of the papers (published and unpublished) were the principal responsibility of myself and, for each of the cases where this is not the case, a declaration is included in the dissertation indicating the nature and extent of the contributions of co-authors.

Date: March 2023

ABSTRACT

The emissions impact of distributing goods such as fresh fruit is increasingly attracting attention due to the heightened awareness of greenhouse gas (GHG) emissions. However, despite the importance of freight logistics, assessing how transportation, handling, and storage of goods produce emissions, is largely an underdeveloped field. This is predominantly the result of a lack of practical industry guidance. The distribution of fresh fruit exported from South Africa is one such process that requires a standardised and accurate method to determine GHG emissions.

The primary aim of this dissertation was to develop a carbon mapping framework and emission intensity factors for the international distribution (transportation, handling, and storage) of fresh fruit from South Africa. The framework and factors should enable any stakeholder with reasonable knowledge to calculate the carbon footprint (kg CO_2e/kg of fruit) and the total emissions (kg CO_2e) produced by the various distribution activities from a packing facility up until the port of discharge.

To achieve this primary aim, several research objectives (ROs) were satisfied using a well-defined mixed methods research approach. This mixed methods approach was ideal since it enabled the triangulation of quantitative and qualitative input data. The sources of data included literature, observations, emission intensity factors developed from primary data collected from industry, distribution chain diagrams, semi-structured interviews with subject matter experts (SMEs), collaboration with the fruit export industry, and the iterative application of the framework to validate typical distribution scenarios by which fresh fruit is exported. The large number of different inputs enabled constant and continuous verification of each part of the research, thereby ensuring the subsequent results' validity and research rigour. Apart from the validation of each part of the research by SMEs, the validity of the research was also confirmed by the five journal articles included in the dissertation document.

The application of the developed carbon mapping framework and associated emission intensity factors showed that the carbon footprint for scenarios where deep-sea ocean transport is used as mode for the main carriage varies between 0.31 and 0.84 kg CO_2e/kg of fruit. If air transportation is used as mode for the main carriage, the carbon footprint can be up to 11.35 kg CO_2e/kg of fruit. These results are, however, scenario-specific and depend on the transportation mode, the number of activities performed during the pre-carriage phase, the duration of storage, the packaging configuration of fruit, the transportation distances, and the origin-destination pair, amongst other things. However, it is certain that the distribution of fresh fruit, like many other commodities, emits a significant amount of emissions, necessitating urgent decarbonisation.

The carbon mapping framework and emission intensity factors developed in this research not only set a standard for the South African fruit export industry to estimate distribution emissions but also provides other commodity groups with guidance to develop a similar emission accounting standard. With global freight volumes growing due to globalisation and economic progress, practical tools such as this framework are now more important than ever for understanding the emission impact of logistical decisions and freight distribution.

OPSOMMING

Kweekhuisgasvrystellings as gevolg van die verspreiding van produkte soos vars vrugte, lok toenemend meer aandag en belangstelling vanweë die algemene bewustheid oor die effek van kweekhuisgasse. Ten spyte van die rol en belangrikheid van vraglogistiek is daar weinig navorsing rakende die emissies wat vervoer, hantering en stoor van goedere produseer. Dit is hoofsaaklik vanweë 'n gebrek aan praktiese en toepaslike leiding vir die industrie. Die internasionale verspreiding van vars vrugte wat vanaf Suid-Afrika uitgevoer word, is een proses wat 'n gestandaardiseerde en akkurate metode benodig om kweekhuisgasvrystellings te bepaal.

Die primêre doel van hierdie verhandeling is die ontwikkeling van 'n koolstofkarteringraamwerk en emissie-intensiteitsfaktore vir die internasionale verspreiding (vervoer, hantering en stoor) van vars vrugte wat vanaf Suid-Afrika uitgevoer word. Die raamwerk en faktore behoort enige belanghebbende met genoegsame kennis in staat stel om die koolstofvoetspoor (kg CO_2e/kg vrugte) en die totale emissies (kg CO_2e) wat deur die verskillende verspreidingsaktiwiteite geproduseer word vanaf 'n pakstoor tot by die hawe van invoer te kan bereken.

Om hierdie primêre doel te bereik, is verskeie navorsingsdoelwitte bevredig deur die gebruik van 'n goed gedefinieerde gemengde-navorsingsmetode. Hierdie gemengde-navorsingsmetode was ideaal, aangesien dit die triangulasie van beide kwantitatiewe en kwalitatiewe insetdata gebruik het. Dit het die volgende ingesluit; literatuur, waarnemings, die emissie-intensiteitsfaktore wat bepaal is deur industrie, die verspreidingskettingdiagramme, semi-gestruktureerde onderhoude met vakkundiges, noue samewerking met die vrugte-uitvoerbedryf, sowel as die iteratiewe toepassing van die raamwerk op tipiese verspreidingscenario's waarmee vars vrugte vanaf Suid-Afrika uitgevoer word. Hierdie groot verskeidenheid insette maak dit moontlik om elke deel van die navorsing konstante en deurlopende te verifieër, wat uiteindelik tot meer geloofwaardige eindresultate lei. Buiten die eksterne validering van elke deel van die navorsing deur vakkundiges, word die geldigheid van die navorsingsresultate om hierdie stelselprobleem op te los deur die vyf joernaalartikels in die verhandeling bevestig.

Die aanwending van die ontwikkelde koolstofkarteringraamwerk en gepaardgaande emissie-intensiteitsfaktore toon dat die koolstofvoetspoor vir scenario's waar diepsee-vervoer gebruik word tussen 0.31 en 0.84 kg CO_2e/kg vrugte wissel. As lugvervoer as wyse van vervoer gebruik word, kan die koolstofvoetspoor sels so hoog soos 11,35 kg CO_2e/kg vrugte wees. Hierdie resultate is egter scenario-spesifiek en is onder andere afhanklik van die tipe vervoermiddel, die aantal aktiwiteite tydens die verspreidingsfase, die tydsduur van berging van vrugte, die tipe verpakkingsmateriaal, die vervoerafstande en die oorsprong-bestemming-paar. Daar kan egter met volkome sekerheid gestel word dat die verspreiding van vars vrugte, soos baie ander kommoditeite, 'n wesenlike hoeveelheid emissies vrystel.

Die koolstofkarteringraamwerk en emissie-intensiteitsfaktore wat in hierdie navorsing ontwikkel is, skep nie net 'n standaard vir die Suid-Afrikaanse vrugte-uitvoerbedryf om kweekhuisgasvrystellings te bepaal nie, maar dien ook as riglyn vir ander kommoditeitsgroepe om 'n soortgelyke standaard te ontwikkel. In lig van internasionale vragvolumes wat groei as gevolg van globalisering en ekonomiese vooruitgang, is praktiese hulpmiddels soos hierdie raamwerk nou belangriker as ooit om die emissie-impak van logistieke besluite en vragverspreiding van produkte te verstaan.

ACKNOWLEDGEMENTS

- Prof Joubert and Prof Leila – thank you for the guidance, meticulous attention, resources, and time you have invested in me. You have shown me a different perspective of academics in the past three years, where the student becomes like family and not the means to an end. This project would not have been possible without you. Prof Joubert, thank you for being more than my supervisor. You have become a mentor who has shown me how to walk this world according to His ways.
- My parents and family – you have set an example of how to work hard for what you want and never give up on that dream. Thank you for always being there for me.
- To my grandfather, Martin van Niekerk – you will forever be remembered by all who loved you dearly.
- Friends who have supported and encouraged me throughout this journey.
- The Department of Industrial Engineering staff and fellow students – tannie Karina, Amelia, Dean, Elise, Melissa, Frederick, Jana, and Minette. Thank you for making it worthwhile to come to the office each morning.
- Industry partners and individuals who made the research a reality.
- Reviewers and editors. I can confirm that diplomacy has become one of my newly acquired skills.

DEDICATION

For from Him and through Him and to Him are all things. To Him be the glory forever. Amen

– Romans 11:36

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LIST OF ACRONYMS/ABBREVIATIONS

A/E	Auxiliary Engine
CCWG	Clean Cargo Working Group
CDP	Carbon Disclosure Project
CF	Carbon Footprint
CGA	Citrus Growers Association
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
EU	European Union
FDM™	Freight Demand Model
FEU	Forty-foot Equivalent Unit
FPEF	Fresh Produce Exporters Forum
GCM	Gross Combination Mass
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
GVM	Gross Vehicle Mass
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
IPPC	Intergovernmental Panel on Climate Change
JCSE	Johannesburg Centre for Software Engineering
JETP	Just Energy Transition Plan
JTSCM	Journal of Transport and Supply Chain Management
LNG	Liquified Natural Gas
LSP	Logistics Service Provider
M/E	Main Engine
MGO	Marine Grade Oil
NF_3	Nitrogen trifluoride
NH_3	Ammonia
NMVOCs	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen oxides
N_2O	Nitrous Oxide
nm	Nanometre
NM	Nautical Miles
O_3	Tropospheric Ozone
OD	Origin-Destination
PFCs	Perfluorocarbons
PM	Particulate Matter
PPECB	Perishable Products Export Control Board
ROs	Research Objectives
RQs	Research Questions
SA	South Africa
SAAGA	South African Avocado Growers Association
SADC	Southern African Development Community
SAGERS	South African Greenhouse Gas Emissions Reporting System
SAJIE	South African Journal of Industrial Engineering

SATI	South African Table Grape Industry
SC	Supply Chain
SDGs	Sustainable Development Goals
SF_6	Sulphur hexafluoride
SFC	Smart Freight Centre
SH	Southern hemisphere
SLR	Systematic Literature Review
SME	Subject Matter Expert
SO_2	Sulphur dioxide
TEU	Twenty-foot Equivalent Unit
TFR	Transnet Freight Rail
TNPA	Transnet National Port Authority
TPT	Transnet Port Terminals
TTW	Tank-to-Wheel
ULSFO	Ultra Low Sulphur Fuel Oil
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UN/LOCODE	United Nations Code for Trade and Transport Locations
USA	United States of America
VLSFO	Very Low Sulphur Fuel Oil
WBCSD	World Business Council for Sustainable Development
WRI	World Resource Institute
WTT	Well-to-Tank
WTW	Well-to-Wheel

1. Introduction

This chapter of the dissertation provides an introduction to the research project. The first section sets the scene by discussing the project's background, whereafter the problem statement is defined in Section 1.2. Section 1.3 defines eight research objectives guiding the research project to solve the problem statement in the previous section. The rationale for conducting the research is discussed in Section 1.4, which iterates the importance of the project and associated results. Section 1.5 defines six research questions, while Section 1.6 elaborates on the scope and limitations of the project. Finally, the research design for the project is described in Section 1.7, after which the structure of the dissertation document is explained.

1.1 Background

In 1892, the steamship *SS Drummond Castle* successfully exported the first consignment of fresh fruit from South Africa to Great Britain (de Beer, Paterson & Olivier, 2003). This consignment of 8 000 cases of peaches was a significant achievement for its time since it showed that it was possible to ship perishable produce halfway across the world while being refrigerated. However, four years after this first successful consignment in 1896, Swedish scientist Svante Arrhenius predicted the potential correlation between carbon dioxide emissions and the Earth's surface temperature (Arrhenius, 1896).

In 2022, 126 years later, global warming and climate change arising from anthropogenic activities, such as fresh fruit distribution, have been identified and acknowledged as one of the world's most significant challenges (McKinnon, 2018). Climate change due to greenhouse gas (GHG) emissions is an undeniable threat to all humanity and will continue to affect all ecosystems in detrimental ways.

Fortunately, society is becoming increasingly aware of its responsibility to act and mitigate the impact of GHG emissions. Growing pressure has resulted in governments and business organisations setting more ambitious emission reduction targets to reduce GHG emissions. Decarbonising strategies have become increasingly important, not only for an organisation's public image but also due to legislation. For example, the European Union (EU) plans to introduce the world’s first carbon emissions tariff on imported GHG-intensive goods such as cement, steel, aluminium, fertilisers, and electricity by 2026 (Abnett, 2022). Precisely how the carbon emissions of these products will be quantified is uncertain. However, within three years from now, a credible, accurate, and comparable emission standard for these products must be developed, otherwise these products will not have access to markets in the EU.

Having visibility of a product such as fresh fruit’s carbon footprint is a global trend that is increasing in popularity due to GHG emissions and climate change being the "latest trend". However, determining a product's total life cycle emission is a complex macro systems problem due to the complexity and interrelatedness of supply chains (SCs). Further, the lack of guidance and tools to estimate SC emissions accurately also impedes industry adoption and implementation.

According to du Plessis, van Eeden and Goedhals-Gerber (2022a), one element neglected in current life cycle emission assessments of products is the emissions contribution of distribution (transport, handling and storage) in SCs. This is particularly true for perishable products due to the energy intensiveness of refrigeration.

Distribution of fresh fruit exported from South Africa is one such process that requires a standardised and accurate method to determine GHG emissions. 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. The distribution of finished packed fruit (i.e. fruit ready for shipment) from the gate of a packing facility to the port of import in the country of discharge is, however, a complex macro systems problem since it entails large shipment distances and multiple modes of transport while being continuously refrigerated.

A "complex macro systems problem" is defined as a type of problem that arises from the interaction of multiple, interconnected systems at a large scale. Fruit distribution is "complex" because it involves multiple interacting distribution activities performed by different stakeholders – each with its unit and method of analysis. The problem is a “macro problem” because fruit export occurs on a large scale, and the resulting anthropogenic GHG emissions significantly impact society and export markets.

This research project solves this complex macro systems problem for the South African fruit export sector by developing an industry-specific carbon mapping framework. This framework enables any stakeholder with reasonable knowledge of the industry to accurately determine the carbon footprint (kg CO_2e/kg of fruit) and the total emissions (kg CO_2e) due to the distribution of their fresh fruit. This research is not only important for the industry to remain relevant in the global market but empowers the industry to understand how logistical decisions influence emissions.

1.2 Problem statement

The global distribution of fresh fruit is carbon intensive, resulting in fruit on international retail shelves having a large carbon footprint (kg CO_2e/kg of fruit). There is, however, no standard framework that enables the consistent, accurate and transparent quantification and allocation of such emissions. The absence of a carbon mapping framework makes it even more difficult to calculate emissions for various distribution scenarios. This lack of a framework allows for personal interpretation of boundaries of which activities to assess and this leads to inconsistent application of vaguely relevant international level standards. This ultimately leads to emission assessment results that are not comparable or accurate.

Apart from the lack of a framework, there is a need for suitable and accurate emission intensity factors used in the calculation steps of such a framework. The absence of such factors often leads to the incorrect use of alternative values, which are not relevant to refrigerated distribution. In addition, no relevant factors exist that are specifically focused on South Africa's fresh fruit export industry. The erroneous use of these incorrect emission intensity factors could lead to a skewed emission profile that is not a true representation of the relevant distribution process emissions. The combined effect of the lack of a framework and a lack of emission intensity factors needed for the calculation step results in the avoidance of carbon estimation projects by researchers and the industry.

In principle, these two problems may be summarised as follows:

1. There is no carbon mapping framework for fruit exports that can be used as an industry standard;
2. Insufficient emission intensity factors for distribution activities exist, which are needed in the calculation process.

1.3 Research aim and objectives

This study aims to develop a carbon mapping framework and emission intensity factors for the international distribution of fresh fruit from South Africa. The research is therefore focused on determining the greenhouse gas emissions of the transportation, handling, and storage component of fresh fruit supply chains. The framework and factors should enable any stakeholder with reasonable knowledge to calculate the carbon footprint (kg CO_2e/kg of fruit) produced by the various distribution activities in a shipment. The framework must also quantify the distribution process's total emissions (kg CO_2e) from a packing facility up until the port of discharge. To achieve this aim, several research objectives (ROs) need to be satisfied, which include:

RO1: To conduct a thorough literature review to:

(a) *Establish* a profile of the South African fruit export sector;
(b) *Identify and assess* existing carbon mapping frameworks used for general freight and fresh fruit distribution;
(c) *Identify* and *establish* fuel emission factors that are specific to South Africa and discuss the potential use of these factors for the remainder of the project;
(d) *Identify* and *assess* existing emission intensity factors relevant to fresh fruit distribution.

RO2: To *identify* and *describe* all the physical emission-generating distribution activities performed during the distribution of fresh fruit from South Africa.

RO3: Based on RO2, c*reate* distribution chain diagrams that *define* the structure of fresh fruit distribution. These diagrams should represent all possible distribution scenarios by which fresh fruit can be exported from South Africa.

RO4: *Verify* and *validate* the created distribution chain diagrams developed in RO3.

RO5: *Establish* and *calculate* emission intensity factors associated with each activity defined in RO2.

RO6: *Verify* and *validate* the emission intensity factors calculated during the project.

RO7: *Develop, verify* and *validate* a carbon mapping framework for the international distribution of fresh fruit.

RO8: *Apply* the developed carbon mapping framework to typical validated distribution scenarios.

1.4 Rationale

An industry-specific framework and factors would **simplify the carbon mapping process** for all stakeholders. The framework will avoid confusion and personal interpretation in independent projects since the same set of base rules is consistently used. If the same methodology is universally applied to carbon estimating projects, the results of similar studies are comparable. This allows benchmarking amongst different exporters, markets and industry role players, ultimately leading to visibility and focused projects on net emission reduction to remain relevant in the market.

Customers, businesses and governments are increasingly **demanding visibility on value chain emissions. Carbon-labelled products** will become increasingly important in the future. A numerical value on a product's packaging allows a consumer to make an informed decision about the environmental impact of purchasing a product. Ideally, if all products' carbon footprints were displayed on the packaging, the consumer could decide between similar products based on this additional variable. Organisations will subsequently be compelled to reduce their emissions to remain relevant and competitive in the market. This results in free market factors becoming the driving force in reducing emissions. The industry is, therefore, increasingly compelled to achieve sustainability goals and objectives. South Africa is also facing significant **trade risks** if the country does not show commitment to global emission reduction efforts.

In the foreseeable future a **product carbon tax** might be introduced by international markets on imported goods such as fresh fruit. This, however, requires a lifecycle assessment (LCA) of the total emissions of a product – of which one element is distributional emissions.

The research also gives the South African fresh fruit industry a head-start over other southern hemisphere fruit exporting countries such as Chile, Peru, Uruguay, Argentina, Brazil, New Zealand, and Madagascar to assess environmental sustainability. This could potentially give the **South African export sector a market advantage** in existing or new markets. In the scenario that **carbon legislation** is introduced at a product level to enforce a **non-tariff barrier or a carbon barrier**, this research might provide market access to the SA fruit export industry.

Further, business organisations can include emissions due to the distribution of their products as a **variable in the organisation's sustainability reporting**. Therefore, an organisation's total fuel consumption (diesel, petrol, and electricity) is no longer the only category assessed. The framework allows for creating a baseline enabling the comparison of alternative distribution scenarios. The framework thus assists organisations in quantifying the carbon reduction progress, or the lack thereof. It might be financially beneficial for companies to state the emissions because of the distribution of their product since this differentiates their company from competitors.

The research is also important since it **promotes** and **enables a fundamental shift in carbon accounting methodology**. The global status quo is to draw an imaginary boundary around a business entity and only account for the emissions directly associated with the organisation's activities (Scope 1 and 2 emissions). Scope 3 emissions, which include transportation and distribution, are voluntary. This leads to voids in carbon accounting values since not all organisations, and in particular logistics companies, report emissions. Further, outsourcing carbon-intensive activities such as transportation and refrigerated storage are common to reduce “internal” company emissions. Although the company's emissions have been reduced, the net SC emissions have not changed. The blame is thus shifted from one stakeholder in the SC to another. A more transparent method is to account for all the SC emissions – irrespective of the emitter. This ensures that all emissions are accounted for in a just and fair manner.

On a more practical level, the research **identifies areas for possible improvement *in the distribution chain***. The emissions are calculated for each activity (transportation and storage) in the distribution process. This enables the quantification of each step's emissions. Thus, the framework and factors empower stakeholders to understand the consequences of logistical decisions such as modal choice and duration of storage and how these choices affect the final product's carbon footprint.

Ultimately, the research provides a platform for future improvement and aids in achieving goal 13 of the United Nations (UN) sustainable development goals (SDGs), focusing on emissions and climate change.

1.5 Research questions

The following six research questions (RQs) in Table 1.1 form the cornerstone of the study. Each RQ in Table 1.1 is aligned with the corresponding RO(s) from Section 1.3 that will answer the RQ and the specific chapter or section where this is achieved.

Table 1.1: The various research questions (RQs) aligned to the corresponding research objectives (ROs)

Research Questions (RQs)	Research Objective (ROs)	Chapter or section
RQ1: What is the importance of fruit production and export in a country like South Africa?	**RO1(a)**	Chapter 2, Section 2.1
RQ2: What carbon mapping framework(s) are currently used for freight distribution and distribution of fresh fruit?	**RO1(b)**	Chapter 2, Section 2.3
RQ3: How does a generic distribution chain for fresh fruit look?	**RO2, RO3,** and **RO4**	Chapter 3, Section 3.3
RQ4: How is the carbon footprint of freight distribution activities determined, and how can this be done accurately for the South African context?	**RO1(c)**	Chapter 4
RQ5: How would a carbon mapping framework for the distribution of fruit types look?	**RO1(d), RO5, RO6, and RO7**	Chapters 5, 6 and 7
RQ6: How can stakeholders use this carbon mapping framework to determine the carbon footprint due to the distribution of fruit?	**RO8**	Chapter 8

1.6 Research limitations and scope

The framework and associated factors **cover the distribution of the six fresh fruit categories** in Table 1.2. The different fruit categories and fruit types are stated in decreasing order of export volume. These fruit types are the major contributors to the SA export fruit industry (>95% of volume); therefore, the research focuses on these fruit types.

The project will **only analyse the distribution of packed fruit from a South African packing facility up until the international port of discharge**, as shown in Figure 1.1. Thus, from the gate of the packing facility to the port of import in the country of discharge. The framework does not include the offloading of fruit at the port of discharge or any further distribution activities towards the point of retail.

The reason for excluding all SC emissions prior to loading of fruit at a packing facility is due to the existing work done by Blue North Sustainability. An interview was held with Anel Blignaut from Blue North Sustainability, during which the methodology of the *EcoInvent Fruit Carbon Calculator* was demonstrated. The production and packaging phases of the calculator are of a high standard since they can be ring-fenced and calculated relatively easily. However, the interview revealed that the distribution process is neglected because of the complexity and variability in estimating logistical activity emissions.

All distribution activities after arrival at the port of discharge are explicitly excluded to reduce the project's scope and complexity. The primary researcher and their supervisors deemed it more appropriate to focus on the pre- and main-carriage phases of distribution and ensure that they are comprehensively explained. Further, the exclusion is deemed necessary due to each country of imports' unique local distribution processes to the point of retail, modal availability, vehicle type and configuration, and different fuel emission factors. To include the country of import’s port handling and domestic distribution activities would add a level of complexity beyond the possibility of a single dissertation.

Table 1.2: The six fruit categories and types of fruit that the study focuses on, as well as the associated volume exported

Fruit category and year of statistics	Fruit type	Exported volume in tonnes (t)
1) Citrus Fruit (2021)	Oranges	1 150 000
	Soft citrus	460 000
	Lemons	460 000
	Grapefruit	255 000
2) Pome Fruit (2021)	Apples	550 000
	Pears	227 500
3) Table Grapes (2020/21)	Table grapes	319 500
4) Subtropical Fruit (2021)	Avocados	60 800
5) Stone Fruit (2020/21)	Plums	78 750
	Nectarines	16 250
	Peaches	6 125
	Apricots	3 325
6) Exotic Fruit (2020/21)	Blueberries	15 000

Adapted from (FPEF, 2022) and (CGA, 2022).

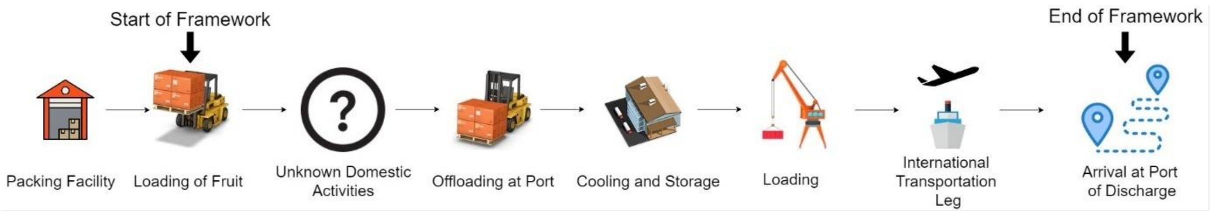

Figure 1.1: Extent of the distribution activities covered in the framework

Only direct emission-generating activities associated with the distribution process of the produce are assessed. Each activity's operational or use-phase emissions are assessed on a Well-to-Wheel (WTW) or complete fuel life cycle basis. Therefore, all other activities and emissions associated indirectly with the distribution process and SC are not considered. Apart from the abovementioned activities, the study excludes the following:

<u>Distribution activities out of scope:</u>

- Transport from the orchard to the packing facility;
- Cold storage of fruit before packaging commences;
- Cold storage of the fruit at the packing facility after the packaging process but prior to loading;
- Fresh fruit distribution to SADC countries;
- Repositioning of vehicles such as trucks or ships carrying other types of cargo;
- Distribution activities after arrival at the port of discharge;

Types of goods not included:

- Distribution of grain or vegetable produce;
- Fresh fruit distribution intended for the domestic market;
- Agricultural processed products such as dried fruit or juice pulp;
- Bulk fresh fruit distributed in crates or bins;
- Wine grapes or related alcoholic products;

Other exclusions:

- Infrastructure development such as roads, and ports of export;
- Vehicle and transport equipment manufacturing, maintenance, and decommissioning;
- Admin activities associated with controlling freight movement;
- Leakage of refrigerants on a vehicle or facility level;
- Short-term assistance of vehicles for security or movement reasons;
- Operator and admin personnel commute to and from work.

1.7 Research design

Saunders, Lewis and Thornhill's (2019) book titled *Research Methods for Business Students* provides a helpful diagram called the *research onion* to explain the project's overall research design. Since the project consists of various parts (journal articles and dissertation sections), each having its own methodology, it is vital to state the overall research approach used to steer the entire project. Figure 1.2 shows the research onion, which consists of six layers that need to be 'peeled' from the outside inwards. With each layer, the project's overall research design is defined in further detail.

According to the first layer of the research onion, the researcher must state their philosophical grounding or research paradigm before conducting a project. Saunders et al. (2019) state that three concepts influence each research philosophy in Figure 1.2: how the primary researcher perceives the world or the nature of reality (ontology), how the researcher collects knowledge and what should be regarded as acceptable knowledge (epistemology); and the values and ethics of the researcher (axiology). These concepts (ontology, epistemology, and axiology) collectively form a research paradigm that creates the first layer of the onion. For this project, the researcher followed a **critical realist paradigm** as philosophy, which implies that the environment and the researcher are independent and that the primary researcher needed to look for a "bigger picture" of which one only observes a small part (Saunders et al., 2019). Realism believes that scientific methods are not perfect and that theories can be continually researched with newer methods. Thus, realism ideally uses a mixed methods research approach to try to triangulate results to improve the chance of a reliable outcome and non-biased results.

After the first layer is peeled away, the second layer can be analysed. This layer is concerned with the approach the primary researcher followed. Three approaches are possible: deductive, inductive, and abductive. The deductive approach relies on previous theories to create new data, while the inductive approach focuses on creating new theories through data. In this project, an **abductive method** was used since both a deductive and inductive approach were used interchangeably. The research project used existing literature, such as emission accounting standards, the GLEC framework, and publicly available data in the body of knowledge for specific elements of the research to deduce the required data. However, since current literature was insufficient in providing accurate or the required data, primary data was collected from industry partners to develop and induce new theories. Subsequently, the abductive method was used throughout the research project to answer the RQs and achieve the ROs.

The third layer in the research onion entails selecting a methodology that was used to gather and analyse qualitative or quantitative data. For this project, the primary researcher used a **mixed methods approach** since both quantitative and qualitative methods were employed. This mixed methods approach is ideal since qualitative methods, such as interviews or feedback from journal reviewers, can validate the quantitative primary research results and vice versa. This ensured that a broad spectrum of data was collected and analysed for triangulation of the research results to ensure validity.

Level four of the research onion is concerned with the research strategies used to execute the project. This strategy is the "plan of action" to achieve the research aim. In this research project, the primary researcher used a **case study strategy** and **archival research** to achieve each of the ROs. A case study strategy investigates a contemporary phenomenon, such as fruit exports from SA, in its real-life context, using multiple sources of evidence to understand and assess how the process occurs. Archival research is used in parallel to ensure the case study strategy produces realistic and valid results. Note that ethical clearance to conduct the study was obtained from the University of Stellenbosch, Social, Behavioural and Education Research Ethics Committee (ref. no. 19464).

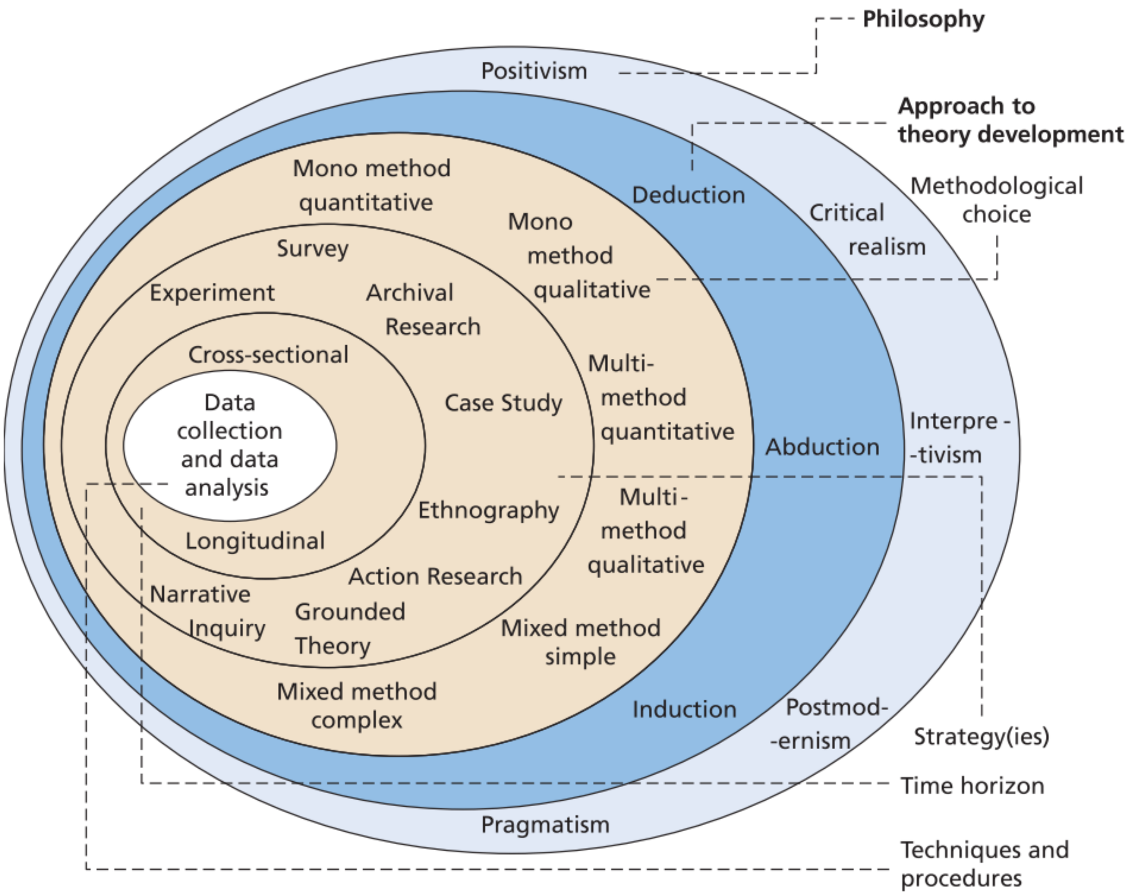

Figure 1.2: The research onion depicting the different layers of research (Saunders et al., 2019)

The fifth layer attempts to analyse the time horizon of data in the study. A cross-sectional time horizon only analyses a single point or "snapshot" in time, while a longitudinal time horizon analyses samples over a long period of time. Both time horizon techniques make use of qualitative and quantitative research. The study **employed both time horizons** through interviews (cross-sectional) and analysis of several years of primary and secondary data (longitudinal).

The sixth and final layer at the centre of the research onion represents the data collection techniques and the procedures used to assess this data. Since the project consists of various semi-independent sections**,** Figure 1.3 was developed to indicate the data collection techniques for RO2 to RO8. Note that RO1 is not included in Figure 1.3 since it only uses archival research.

An important consideration of the project is the sensitivity of the collected data and assessment results. The researchers acknowledge the sensitivity of the primary data collected from industry collaborators and the potential impact of traceability. Subsequently, all data and results were anonymised to ensure that collaborators' identities remain anonymous. Utmost care was also taken with storing, sharing, and handling this confidential data with stakeholders.

Examples of **primary data** collected from the industry include data from eight cold storage facilities, a rail terminal facility and associated rail services, several road freight transporters, fruit exporters and representative organisations, and a maritime shipping company. Primary data was also collected by means of interviews with stakeholders or subject matter experts (SMEs) in the fruit export industry. Observations also played an essential role in collecting primary data since there is often a large discrepancy between facility descriptions found in literature and the real world – especially in the fruit export industry. Furthermore, these observations were important in providing a holistic view of the fruit export industry. **Secondary data** used in the project includes data from EcoInvent, the Smart Freight Centre (SFC), the Food and Agriculture Organisation (FAO) of the UN, Eskom, Agrihub data, and the Intergovernmental Panel on Climate Change (IPCC).

Using multiple data collection techniques strengthens the overall credibility of the research since results are triangulated. Regarding the assessment methods, there is a significant difference in how the collected data were assessed. Subsequently, the analysis methods used are discussed in the relevant chapters.

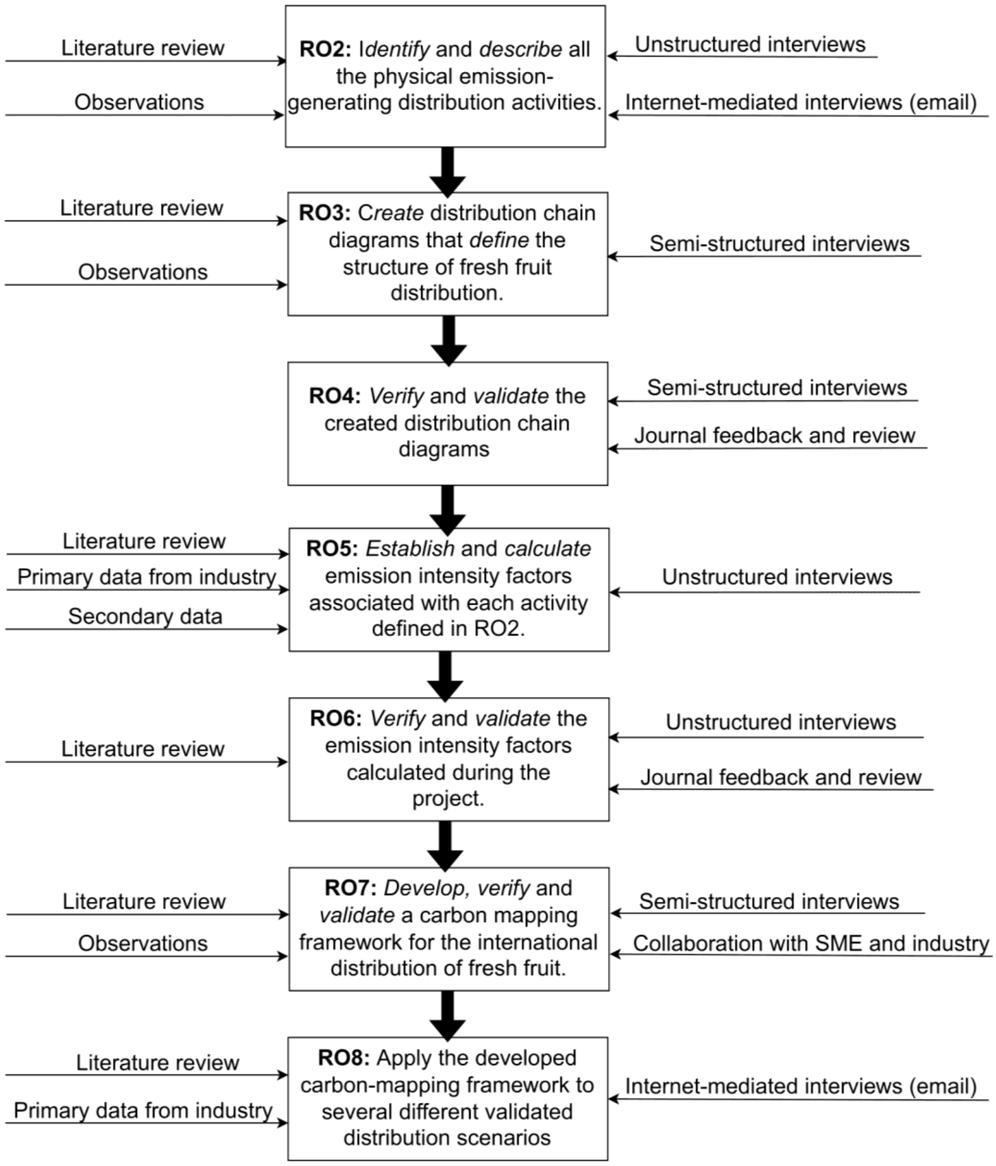

Figure 1.3: Research objectives (ROs) and the data collection method used

1.8 Structure of the document

The structure of this document is set out in Table 1.2. The dissertation ultimately consists of a combination of published and unpublished journal articles and chapters, which have been integrated through bridging text to create one coherent narrative. The four published journal articles can be found in Chapters 2, 3, 5, and 6, while the unpublished journal article is shown in Chapter 5. As shown in Table 1.2, the document is divided into six conceptual parts.

Part I (Chapter 1) provides background and defines the research project and rationale. In addition, it also states the research design and types of primary and secondary data collected to achieve the various ROs.

In **Part II** (Chapter 2), the need for the research project is confirmed by a published journal article in which a systematic literature review (SLR) was conducted to identify any relevant frameworks or prior research. Further, an overview of the South African fruit export sector and literature relevant to the study are discussed.

In **Part III** (Chapter 3), a published journal article defines various distribution chains through diagrams, which identify all the emission-generating activities. These diagrams identify the realistic combination of activities by which fresh fruit is exported from SA. Part III forms the foundation for the remaining research since this defines the activities for which emission intensity factors are required. Furthermore, these diagrams are the basis of the framework since they prescribe the activities that should be assessed.

Part IV (Chapters 4, 5, and 6) elaborates on the emission intensity factors developed in this project. Chapter 4 serves as a precursor to discuss the use of emission intensity factors. Chapter 5 discusses the emission intensity factors required for each mode of transport. This chapter consists of one published journal article (in-press) and one journal article in review. Chapter 6 elaborates on the factors developed for logistical facilities or sites. This chapter also contains one published journal article.

Part V (Chapters 7 and 8) consists of the developed carbon mapping framework and the application thereof to example distribution scenarios. Chapter 7 begins by discussing the basic emission accounting principles that form the foundation of the developed framework, whereafter the various inputs used to design and develop the framework are stated. Apart from presenting and discussing the carbon mapping framework, Chapter 7 also addresses the verification and validation of the individual steps of the framework and the framework as a whole. Chapter 8 applies the framework and developed emission intensity factors from Part IV to seven real-world distribution scenarios. Each example scenario is unique since the fruit type, functional unit (pallets of fruit or reefer containers filled with fruit), mode of transport, type of logistical facility used, and country of import are different. The in-depth examples in this chapter prove the level of intricate detail that the developed framework can assess.

Part VI (Chapter 9) serves as the formal conclusion to the dissertation. A critical review of the overall methodology is given and the achievements of the developed carbon mapping framework and emission intensity factors are reported. The unique contribution of the research project to society and the export fruit industry is also discussed. Finally, recommendations for future work in the logistics emissions realm are suggested.

Note that articles in this dissertation appear in their original format as the journal published them or in the format submitted to the journal. All articles in this document are indicated with a solid black border around the page. Caution should be taken not to confuse the page number of the dissertation document with that of the articles. Also, note that the framework in Chapter 7 is indicated with a double border and should not be confused with an article.

Table 1.3: Document structure

Chapter	Chapter content and type	Research objective	Chapter theme
Part I: Research Rationale and Definition			
1	Bridging text	NA	Research definition, rationale and background.
Part II: Setting the Scene through Literature			
2	Published article and bridging text	RO1 (a) - (b)	Overview of the SA fruit export sector, confirmation of the research problem using an SLR, high-level synthesis of related research concepts.
Part III: Generic Distribution Chains and Activities			
3	Published article and bridging text	RO2 - RO4	Identify emission-generating activities and create distribution chain diagrams that define the structure of fresh fruit distribution. Also, discuss the status quo of various modes and facilities.
Part IV: Emission Intensity Factors			
4	Chapter	RO1 (c)	As a precursor to the following chapters, explain how the emissions of distribution activities are quantified to provide context for emission intensity factors. Also, discuss the relevant SA fuel emission factors.
5	Chapter consists of two published articles and bridging text	RO1 (d), RO5 - RO6	State and explain the developed emission intensity factors for the various modes of transportation (road, rail, deep-sea, and air transport).
6	Chapter consists of a published article and bridging text	RO1 (d), RO5 - RO6	State and explain the developed emission intensity factors for various logistical facilities or sites that handle pallets and or containers.
Part V: Framework and Application			
7	Chapter	RO7	The design requirements for the framework are defined. The developed carbon mapping framework is stated, whereafter it is discussed.
8	Chapter	RO8	Apply the developed framework and emission intensity factors to seven different distribution scenarios of varying fruit types.
Part VI: Conclusion			
9	Chapter	NA	Conclude the project by discussing the methodology, achievements and unique contributions, recommended future work, and impact on society.

2. Setting the scene: Problem confirmation and related research concepts

This chapter addresses the following research objectives:

RO1: To conduct a thorough literature review to:

(a) *Establish* a profile of the South African fruit export sector;
(b) *Assess* existing carbon mapping frameworks used for general freight and fresh fruit distribution.

This chapter consists of four sections which set the scene for the dissertation and position the remaining research. Section 2.1 provides a narrative for the research through an exposition of the South African fruit export industry. Apart from discussing the importance of accessing emissions, the section also focuses on the industry's vital contributions to South Africa's society and economy. Further, Section 2.2 discusses research concepts such as sustainability, emissions and the various levels of accounting for them, the importance of holistic SC sustainability, and the food miles debate, which are essential for the research project. This is followed by a published, peer-reviewed journal article in *Global Food Security,* which performs a systematic literature review (SLR) to identify and assess existing carbon mapping frameworks used for general freight and fresh fruit distribution. The SLR article in Section 2.3 confirms the need for an industry-specific framework. Finally, Section 2.4 provides a conclusion to the chapter.

2.1 The South African fruit export sector

This section provides a holistic overview of the South African fruit export industry. It also discusses the industry's importance to South Africa's society and economy. Finally, the significance and importance of assessing emissions related to fruit exports are explained.

2.1.1 Industry overview

South Africa is world renowned for producing and exporting a large variety of fresh fruit. The country is the biggest exporter of fresh fruit by volume in the southern hemisphere and the second largest citrus exporter in the world (CGA, 2022; FPEF, 2022). Based on data from the Fresh Produce Exporters Forum (FPEF) and the Citrus Growers Association (CGA), the country exported more than 3.6 million tonnes of fresh fruit during the 2020/21 season for the six fruit categories analysed (see Section 1.6). This equates to 180 000 40-foot (FEU) integral reefer containers, each filled with 20 t (nett weight) of fruit. Regarding the proportion of the total TEUs exported from SA, fresh fruit represented approximately 30% of all exports for the 2020 calendar year (calculated by the primary researcher from TNPA data).

In addition to being well established, the fruit export industry is also growing at a significant rate, which is not expected to change in the foreseeable future. In the past five years (since the 2016/17 season), the total amount of fruit exported from SA has increased by 26.4%. This equates to an average industry growth rate of nearly 6.2% per year. This growth is confirmed by the Department of Agriculture, Forestry and Fisheries (2019), which estimates that the agricultural sector (including forestry and fisheries) has grown an average of 7.6% per year since 1994.

Furthermore, apart from replacing older orchards with newer high-yield cultivars and increasing planting densities, producers continuously increase their production capacity by establishing new orchards on "virgin" land. The most significant expansion is in the citrus industry, where 9 500 hectares of new citrus orchards (new hectares) were established in 2020 and 2021 (CGA, 2022). This expansion represents a 10% increase in the total hectares planted with citrus in SA. Other fruit commodities, such as avocados, are also expanding rapidly due to increased consumer demand, resulting in nearly 800 hectares of new plantings each year since 2009 according to the 2020 avocado census (Donkin, 2022). Likewise, the blueberry export industry is also expanding rapidly - from a modest 7 000 t in 2017 to nearly 25 000 t in the 2021/22 season (Pienaar, Smit, Hattingh & Cloete, 2022). Pienaar *et al.* (2022) estimate that blueberry exports could increase to 42 000 t in 2031; however, this scenario depends on European market prices. It should be noted that the proportional tonnage contribution of expansion in the blueberry industry is small compared to other fruits such as citrus and avocados. As for stone fruit, table grapes, and pome fruit, there has been no significant increase or decrease in the total area planted (HORTGRO, 2021; SATI, 2022). The abovementioned growth in the fruit export industry is, however, only realistic if there is no significant change in the status quo of labour, input costs, market prices, demand, and the political landscape.

The SA fruit industry is export-orientated and approximately 60% of the country's fresh produce is exported to nearly 110 countries (SA Fruit Journal, 2020). The destination and percentage of total SA exports for the years 2013 to 2018 are indicated in Figure 2.1. It is important to note that most (>95%) of the of export markets for SA fresh fruit are located in the northern hemisphere. 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.

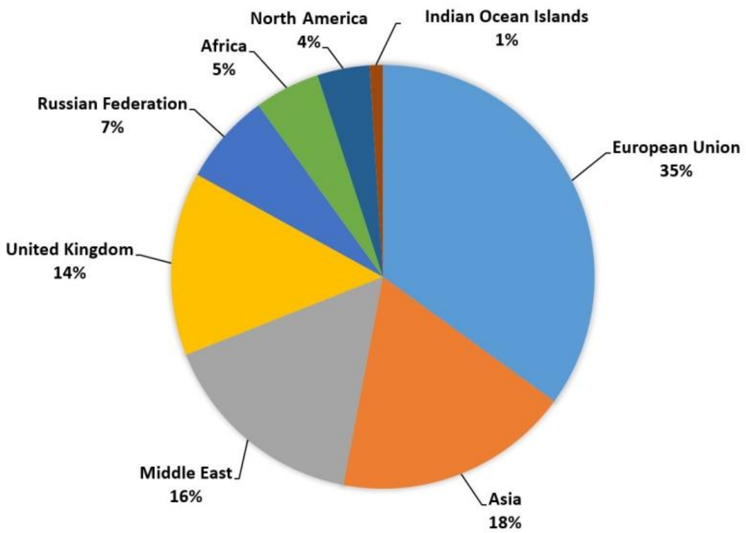

Figure 2.1: Major export regions for fresh fruit from SA for a five-year period

(adapted from Department of Agriculture, Forestry and Fisheries, (2018))

It is also important to understand the scale of the SA fruit export industry compared to other southern hemisphere exporting countries such as Chile, Peru, Uruguay, Argentina, Brazil, New Zealand, Australia, and Madagascar. These countries compete for the same importing markets as the SA industry, resulting in strong competition for market domination going back several decades (van Niekerk, 2020). Table 2.1 states the total volume (tonnes) of each fruit type exported from the southern hemisphere. In addition, the largest exporter in the hemisphere and rank and percentage that SA produces are also stated. Note that potential anomalies exist between the different datasets used in Table 2.1 as the author compiled the table from various sources, choosing the most credible and realistic value for each fruit type. Nevertheless, Table 2.1 shows that the SA citrus industry is responsible for a significant proportion and volume of fruit exports from the southern hemisphere. Proportionally, SA is also a prominent exporter of other fruit types such as plums, apricots, apples, pears and table grapes, and is undoubtedly, a country that has considerable influence on the global supply of fresh fruit to the northern hemisphere.

Table 2.1: Southern hemisphere (SH) fruit production overview for various fruit types

Fruit type	Total SH exports (t)	Largest exporter in SH	SA rank in SH	SA's proportional contribution to total SH exports
Stone fruit (2020/21)				
Peaches and Nectarines	157 020	Chile	2	19,14%
Plums	226 029	Chile	2	36,27%
Apricots	3 943	South Africa	1	69,69%
Pome fruit (2021)				
Apples	1 880 688	Chile	2	31,33%
Pears	710 706	Argentina	2	34,77%
Table grapes (2021/2022)				
Table grapes	1 498 500	Chile	3	22,52%
Citrus fruit (2020/21)				
Oranges	1 738 264	South Africa	1	72,47%
Lemons and limes	971 552	South Africa	1	47,13%
Grapefruit	264 352	South Africa	1	92,43%
Soft Citrus	913 037	South Africa	1	42,65%
Subtropical (2020)				
Avocados	598 060	Peru	3	7,90%
Blueberries (2020)				
Blueberries	420 000	Peru	3	4,76%

Compiled from (FAO, 2022; Pienaar *et al.*, 2022; SATI, 2022; and Trademap, 2022).

In terms of the profile of fruit exports from SA, Figure 2.2 shows the different fruit types and percentage contributions to the total exports from SA during the 2020/21 season. Citrus fruit represents the largest proportion (63%) of the total weight of fruit exported from SA, followed by pome fruit and table grapes. The remaining three fruit types (stone fruit, subtropical fruit, and exotic fruit) collectively represent 5% of the total tonnes. Note that the financial contribution of each fruit category is not necessarily related to the volume exported since commodities such as blueberries are more expensive than pome fruit per kilogram.

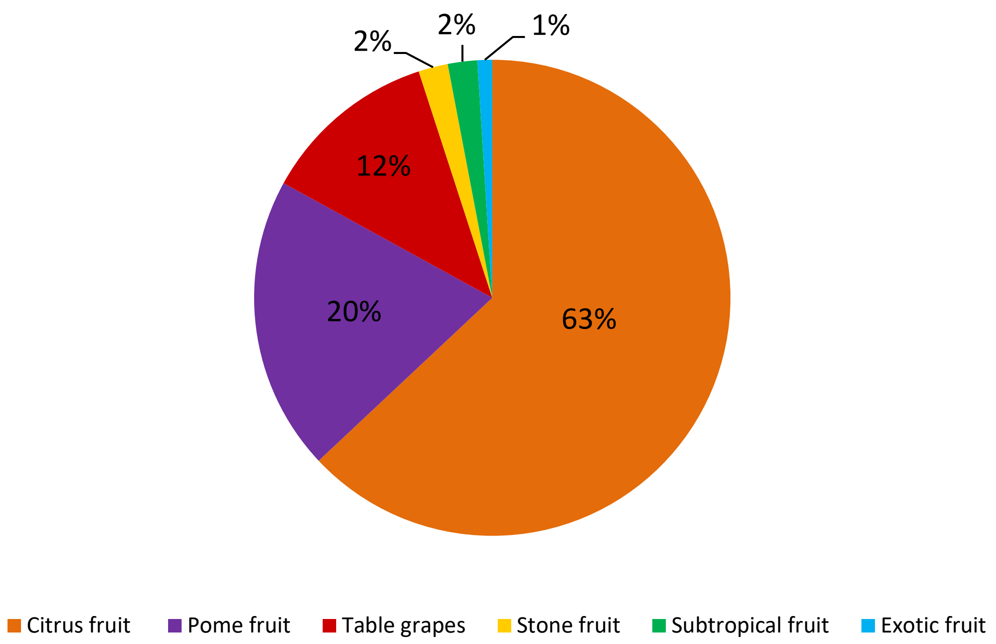

Figure 2.2: SA fresh fruit export profile for the year 2020/21

(Adapted from (FPEF, 2022))

2.1.2 Importance and contribution of the industry

The importance of the South African fruit industry can be categorised into four sectors: economic contribution, the impact on food security, employment, and other miscellaneous reasons. These four domains are briefly discussed below.

2.1.2.1 Economic contribution

The agricultural sector, which includes forestry and fisheries, directly contributes a mere 2–3% to the gross domestic product (GDP) of SA but can be extrapolated to 12% of GDP if the entire value chain of the agricultural sector is considered (Kuschke & Cassim, 2019). The total gross value of all agricultural production in SA for 2018/19 is estimated to be R277 billion (Department of Agriculture, Forestry and Fisheries, 2019). Of this gross value, the horticulture industry accounted for 19.8% of the total income in 2017 (Statistics South Africa, 2017). Despite the seemingly small contribution of horticulture, the net revenue generated is considerable. The SA citrus industry, for example, generated more than R26.1 billion of revenue through sales in 2021 alone (CGA, 2022). It is a significant amount of money considering that production regions are predominantly located in rural areas with minimal other industries apart from agriculture and related value chain activities. Apart from the direct economic contribution, the sector's impact on other value chain activities in these production regions should not be forgotten. The agricultural industry is essential for the country's economic sustainability, particularly in the rural areas where these industries are located. Furthermore, the fruit export industry is also an important foreign exchange earner for the country (DALRRD, 2020).

2.1.2.2 Food Security

Food security is increasingly becoming a topic of concern and discussion (World Bank, 2022). This is especially true after the Russia-Ukraine conflict escalated, leading to severe global supply chain disruptions and shortages of some food commodities (World Food Program, 2022). Furthermore, rapid food inflation, political unrest, adverse weather conditions, natural disasters, and climate change reiterate the importance of having multiple countries or regions that can supply produce. The SA fruit export industry is not only important for the food security of First World importing countries but also for food security in SA and the broader Southern African region. Since only class 1 and 2 produce is exported to the northern hemisphere, an increase in fruit production for export would inevitably lead to an increased supply of fruit in the entire Southern African market since not all fruit is export quality. Apart from skin blemishes or size and weight variations, these fruits are similar to the ones exported. However, this fruit is sold at a lower price, which will inevitably also increase food access. Since SA is a significant producer of various fruit commodities, the country's fruit industry will become increasingly important for food security globally.

2.1.2.3 Employment

Apart from producing food for basic human livelihood and ensuring food security, agriculture also provides much-needed employment. Table 2.2 shows the number of permanent employees and the associated number of dependants of the SA fruit industry. Note that these estimated employment figures do not include seasonal labourers required in the harvest season of the respective fruits. Table 2.2 shows that approximately 270 000 permanent jobs are created directly through the fruit industry and that up to 1.6 million people's livelihoods depend on the industry. Each permanent employee financially supports between four (HORTGRO, 2021b) and nine people (primary researcher’s calculation from collected data). The large number of dependants reliant on a single breadwinner in a household emphasises the vulnerability of South African society and the importance of the agriculture sector to provide jobs. Other authors such as Cousins, Genis and Clarke (2018) estimate that the entire agricultural sector (horticulture, grains, forestry, and fisheries) directly employs approximately 840 000 workers or 5% of total employment in SA.

Note that none of the abovementioned employment figures incorporate other activities in the value chain of agricultural produce, such as supporting services. This includes services rendered to the agricultural industry, such as machinery sales and repairs, financial services in the agricultural sector, and the sale of essential products like fuel, fertilisers, and other consumables. However, the exact number of jobs created indirectly by the agricultural industry is difficult to estimate.

Table 2.2: Employment and the potential number of dependants in the South African fruit sectors

Fruit category	Fruit type	Estimated number of permanent equivalent employees	Dependants
1) Citrus Fruit	All	113 650 to 125 000	480 000 to 1 000 000
2) Pome Fruit	Apples	28 200	112 799
	Pears	12 361	49 445
3) Table Grape	Table grapes	78 660	314 680
4) Subtropical Fruit	Avocados	5 938	23 752
5) Stone Fruit	Plums	7 059	28 238
	Nectarines	2 848	11 391
	Peaches	7 066	28 265
	Apricots	1 969	7 875
6) Exotic Fruit	Blueberries	8 000	32 000

Fruit category	Fruit type	Estimated number of permanent equivalent employees	Dependants
	Total	**265 751 to 277 101**	**858 445 to 1 608 445**

Compiled from (Dlikilili & van Rooyen, 2018; DALRRD, 2020; Fruit South Africa, 2021; Chisoro-Dube & Roberts, 2021; HORTGRO, 2021b; Schutte, 2021 and SAAGA, 2022).

2.1.2.4 Miscellaneous

An often-overlooked contribution of the agriculture industry is the stability that agriculture brings to rural society and SA as a whole. Agriculture is the economic and social lifeline of numerous small towns in SA. In many cases, a rural area's entire economy depends on the well-being of the agricultural sector. In many of these rural areas, the only source of stable employment is in the agricultural sector and related value chain activities. A change in the status quo would therefore be detrimental. In addition, unique and challenging conditions in SA force producers, agri-enterprises, and other stakeholders to perform the role of civil servants or governmental bodies. These include ensuring rural safety, the upkeep of basic infrastructures such as roads, housing for workers, and basic service delivery in some areas.

2.1.3 Importance of accessing emissions

From Section 2.1.2, it is evident that a sustainable, prosperous, and thriving agricultural sector is of vital importance not only for SA but also for the global community. One factor that might potentially inhibit future industry growth or even limit market access to some importing countries is GHG emissions. This comes as consumers, corporations, and governments are increasingly becoming aware of the impact of climate change due to emissions (IPCC, 2007). Subsequently, decarbonising has become a significant business driver in recent years (McKinnon, 2010) since all spheres of society and many countries are adapting or transforming to become more environmentally sustainable. The importance of assessing emissions due to fresh fruit distribution can be summarised as follows:

- Enables the industry to benchmark emissions for future comparison and develop decarbonisation strategies;
- Provides a baseline for institutional bodies such as SATI, HORTGRO, CGA, SAAGA, and BerriesZA to impose recommended maximum emission standards for distribution;
- Proves to international markets and consumers that the South African fruit industry is determined to reduce emissions;
- Potentially provides a competitive advantage when compared to other exporting countries;
- This research might provide market access if non-tariff barriers such as a maximum allowable carbon footprint are imposed in future scenarios.
- Carbon-labelling will potentially place a premium on the price of SA fruit compared to other countries.

2.2 Research concepts

The following sections discuss and explain important research concepts used in the remainder of the dissertation.

2.2.1 Sustainability

The term *sustainability* or *sustainable development* is not a new concept or buzzword. The idea of sustainability can be traced back to the ancient Mesopotamian, Greek, Egyptian, and Roman societies, where Plato, Aristotle, and Strabo philosophised about different environmental problems (Du Pisani, 2006). However, these societies' discussions only focused on environmental problems such as soil degradation, deforestation, etc.

Several modern-day definitions exist for the term, depending on the context of use as shown in Arora (2014). Of the eight definitions of sustainability stated in (Arora, 2014), three overlapping dimensions are evident: social, environmental, and economical. The concept of sustainability has thus evolved from a purely environmental focus in the days of early philosophers to include a combination of environmental, social, and financial aspects. This new definition gave rise to the concept of the Triple Bottom Line, also referred to as People, Planet and Profit by Hu (2014) and Despoudi (2020). The most suitable modern-day definition of *sustainable development* is stated in *The Brundtland Report* by Keeble (1988, p. 41), which combines all three dimensions of sustainability into a single entity:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Sustainability can, therefore, be summarised as the delicate balance between economic progress, environmental safeguarding of the planet and its natural resources, and the improvement of people's livelihood during the process. Sustainable development is, thus, only possible if a compromise is made between all three dimensions.

2.2.2 Emissions

Emissions are defined by the United States Environmental Protection Agency (2016) as any particle or gaseous substance that is emitted into the air. Emissions are classified according to the source of origin, as indicated in Figure 2.3, which can be either natural or anthropogenic. Natural systems' emissions are produced by naturally occurring activities or processes such as forest fires or the respiration by bodies such as oceans, wetlands, and volcanoes, which are not directly attributed to humans. Anthropogenic emissions are, however, emissions that are produced or caused as a result of human activities. Natural processes can also emit aerosols and greenhouse gases, but the remainder of this section focuses on anthropogenic emissions only.

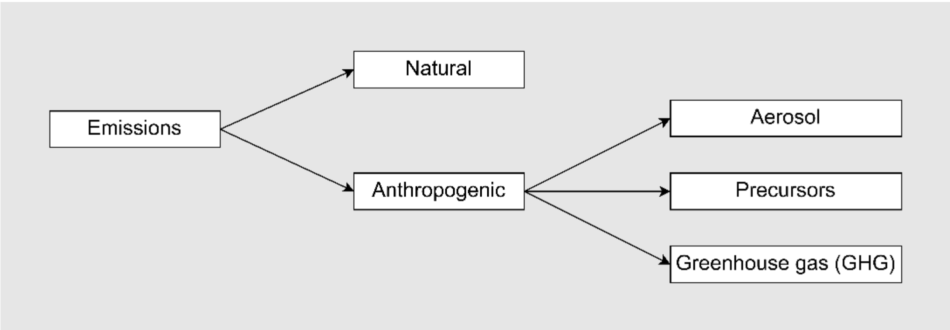

Figure 2.3: Classification of emissions based on the origin – adapted from (IPCC, 2014)

Anthropogenic emissions are classified according to the three categories identified in Figure 2.3. *Aerosols,* also referred to as aerosol particles or particulate matter (PM), are defined by (Allwood et al., 2014) as a mixture of liquid and solid airborne particles with a relatively small size of between a nanometre (nm) and 10 micrometres (µm). These particles are present or suspended in the earth's atmosphere for at least a few hours. Examples of aerosols include smoke, dust, fog, mist, and black carbon or soot (IPCC, 2007). Most aerosols originate from natural pathways, but some originate due to anthropogenic activities. Irrespective of anthropogenic or natural origin, aerosols are created or emitted by two possible processes – combustion of fossil fuel or the burning of biomass.

The second type of anthropogenic emission is unique since it is not classified as a greenhouse gas (GHG) or an aerosol. *Atmospheric precursor compounds,* however, directly impact the physical and chemical processes that regulate the destruction or production of GHGs and aerosols (Allwood et al., 2014). The Netherlands Environmental Assessment Agency (2010) states that examples of precursor gases include Carbon monoxide (CO), Nitrogen oxides (NO_x), Sulphur dioxide (SO_2), Ammonia (NH_3), and non-methane volatile organic compounds (NMVOCs). These five precursor gases help to produce tropospheric ozone (O_3), a natural GHG found in the earth's atmosphere, as well as methane (CH_4) (Reilly, Jacoby & Prinn, 2003).

The final type of anthropogenic emission is *greenhouse gases (GHGs)* – the focus of this research project. With the ever-increasing emphasis on reducing GHG emissions, it is important to clarify what these gases are. According to Mann (2009) and Allwood et al. (2014), GHGs are anthropogenic or natural gaseous constituents in the earth's atmosphere that absorb and emit infrared radiation (heat energy) released by the earth's surface, clouds or the atmosphere itself. These GHGs trap infrared energy in the atmosphere by radiating the absorbed heat back towards the earth in a phenomenon known as the greenhouse effect (Allwood et al., 2014).

Since a definition of GHGs and their effect has been established, it is appropriate to identify the different GHGs. The United Nations Framework Convention on Climate Change Kyoto Protocol (UNFCCC, 1997) initially identified six compounds as the significant GHGs. However, due to its potential impact and scale, a seventh "missing" gas (Nitrogen trifluoride) has been added to the list of GHGs in the Kyoto Protocol (Prather & Hsu, 2008; IPCC, 2014). Nitrogen trifluoride is also included as a standard GHG in the emission assessment of distribution activities, as shown in the GLEC framework and numerous other standards. The complete list of Kyoto Protocol GHGs is as follows:

- Carbon dioxide (CO_2);
- Methane (CH_4);
- Nitrous Oxide (N_2O);
- Hydrofluorocarbons (HFCs);
- Perfluorocarbons (PFCs);
- Sulphur hexafluoride (SF_6);
- Nitrogen trifluoride (NF_3).

These seven GHGs are the basis for all emission projects, protocols, frameworks, and standards, such as the GHG Protocol Corporate Accounting and Reporting Standard (WBCSD & WRI, 2004), the Global Logistics Emissions Council (GLEC) framework (Smart Freight Centre, 2019), carbon footprinting of products (BSI, 2019), and life cycle assessments (ISO, 2006). Thus, all GHG projects that aim to quantify emissions assess these seven gases as a minimum. However, note that there are numerous other gases which are also classified as GHGs.

To understand the effect and potency of different GHGs, and to avoid the nuance of analysing each gas separately, all GHGs are compared relative to carbon dioxide (CO_2). Each GHG has a Global Warming Potential (GWP), as indicated in Table 2.3, which describes the efficiency of the specific gas to trap heat during its atmospheric lifetime when compared to one unit of CO_2 (Myhre, Shindell, Bréon, Collins, Fuglestvedt, Huang, Koch, Lamarque, Lee, Mendoza, Nakajima, Robock, Stephens, Takemura, Zhan & Zhang, 2013). This reference to a common basis scales non-CO_2 gases to carbon dioxide allowing for easy and meaningful comparison. Using CO_2e allows for the easy quantification of all GHGs through one unit of analysis. Note that various time horizons (20, 100 or 500 years) are potentially used to estimate the GWP of gases. However, a 100-year period or horizon is standard practice in most transportation realm assessments and is therefore used in this dissertation. Table 2.3 also iterates the potential impact that non-CO_2 GHGs have in terms of their efficiency in acting as a GHG. It is, therefore, fundamental for completeness to include emission-generating activities that use or emit any of these high GWP gases in any assessment.

Table 2.3: Global Warming Potential (GWP) of the seven GHGs covered in the Kyoto Protocol

Greenhouse gas (GHG)	100-year GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310
Hydrofluorocarbons (HFCs)	140 – 11 700
Perfluorocarbons (PFCs)	6 500 – 9 200
Sulphur hexafluoride (SF_6)	23 900
Nitrogen trifluoride (NF_3)	16 600

Adapted from (UNFCCC, 2017).

2.2.3 Emission accounting: the various levels

Greenhouse gas emissions can be assessed and reported at three different levels: a national level, a corporate level, or a carbon footprint level. These levels define the various entities around which an imaginary border is drawn to state the scope of an assessment. The remainder of this section discusses the holistic methodology and overall process used by each of the three levels with a specific focus on South Africa.

2.2.3.1 National emission inventories

At this level of accounting, an entire country’s emissions and removal from the atmosphere are determined for a calendar year or a sequence of years. A national inventory (also referred to as a geographical inventory) includes all emissions generated in a nation's territories and offshore areas that the country controls. The Intergovernmental Panel on Climate Change (IPCC) *Guidelines for National Greenhouse Gas Inventories* provides comprehensive methodological guidance in accounting for national emissions. National inventories are divided into four categories and numerous smaller subcategories, as shown in Table 2.4. A national inventory is thus constructed on a subcategory level since it allows for more accurate estimations and provides policymakers with useful data. These sectoral values are then summed to yield the national emissions inventories of a country.

Table 2.4: Categories and subcategories used to estimate national emission inventories

Category	Subcategories level
Energy	• Stationary combustion emissions; • Mobile combustion emissions; • Fugitive emissions; • CO_2 from transport, injection and geological storage.
Industrial Processes and Product Use	• Emissions from the mineral industry; • Emissions from the chemical industry; • Emissions as a result of the metal processing industry; • Non-energy products derived from fuels, as well as solvent use; • Emissions from the electronics industry; • Emissions of fluorinated substitutes for ozone-depleting substances; • Other manufactured products and the use thereof.
Agriculture, Forestry and other Land Use	• Forest land; • Grassland; • Cropland; • Wetlands; • Settlements; • Other land use emissions; • Emissions from livestock and manure management; • N_2O emissions from managed soils in agriculture, and CO_2 emissions from urea and lime application on fields; • Harvested wood products.
Waste	• Emissions due to solid waste disposal; • Biological treatment of solid waste products; • Incineration and open burning of waste; • Wastewater treatment and discharge emissions.

From (IPCC, 2008).

After compiling national emission inventories, they are submitted to the United Nations Framework Convention on Climate Change (UNFCCC). All Parties to the Convention should periodically develop, update, and submit their national emission inventories to the UNFCCC. However, the original UNFCCC was not legally binding and did not state any numerical goals, as with other agreements (United Nations, 1992). This, however, changed after the 1997 Kyoto meeting of the Parties (Allwood, Bosetti, Dubash, Gómez-Echeverri & von Stechow, 2014). The Kyoto Protocol, adopted in 1997, only came into effect in 2005 and legally bound committed nations to reduce their greenhouse gas emissions by at least 5% below the 1990s level from 2008–2012 (Allwood *et al.*, 2014). The Kyoto Protocol was focused on reducing GHG emissions at a national level by providing nations with flexible mechanisms, referred to as the Kyoto Mechanisms, to help reduce emissions. This involved emission trading, where nations trade with GHG emissions, clean development mechanisms (CDM), where green projects are financed, and joint implementation schemes where investors may fund and implement shared projects that reduce emissions or serve as emission sinks. Note that this Protocol was also the standard for defining the seven GHGs mentioned in Section 2.2.2.

The most recent significant climate accord, held in 2015, is the Paris Agreement. This was the twenty-first meeting of the Parties (countries who initially participated in the 1992 UNFCCC) and is, therefore, referred to as the Conference of the Parties (COP) 21. The Paris Agreement aims to limit the average global temperature increase to below 2 °C and cap the temperature increase to 1,5 °C compared to pre-industrial levels (United Nations, 2015). The Paris Agreement was thus the first-ever international accord that specified numerical goals regarding a temperature increase.

The main difference between the Paris Agreement and the Kyoto Protocol is that each country is responsible for setting its own emission targets. The Agreement is, however, similar to previous ones since there was an emphasis on reducing emissions at a country level. Furthermore, all parties participating are under commitment, but the level of commitment (net-zero before, by, or post-2050) varies according to the country's development profile. Developed nations are more responsible for setting and achieving their reduction efforts since they are better equipped to transform to greener economies and processes than developing nations. According to Article 14 of the Paris Agreement (United Nations, 2015), the first global "stocktake" of emissions will occur in 2023 and, after that, every five years. Apart from enhanced monetary assistance, the Paris Agreement is, to a large extent, similar to the Kyoto Protocol.

According to the World Trade Organization (2022), estimating the emissions of an entire country is, at best, a guessing game due to a lack of accurate and comprehensive data across all estimation categories listed in Table 2.4. Further, the sheer scale of such projects and the number of stakeholders involved complicates the assessment. Apart from the complexity and lack of country-specific data when determining national-level emissions, there are certain fundamental issues with accounting for emissions at a national level, such as carbon offshoring. *Carbon offshoring,* or *carbon leakage,* is a process whereby countries move carbon-intensive processes such as manufacturing, petroleum refinement, fuel purchasing, and other industrial activities to less developed countries to reduce their national emissions (Dussaux, Vona & Dechezleprêtre, 2020; World Trade Organization, 2022). Inevitably, this leads to a reduction in one country's emissions but a direct increase in those of another, and thereby, no net reduction occurs globally.

Further, there are significant voids in accounting for transportation-related emissions when using the national inventory level. According to the IPCC (2008), emissions from aircraft or vessels in international transport are excluded from national totals meaning no country takes responsibility for international transportation. Also, emissions of road vehicles should be accounted for in the country where fuel is sold, leaving considerable room for interpretation in cross-border transport.

Although the concept of calculating emissions at a national level is not perfect, and numerous loopholes exist, it is a considerable step toward reducing global GHG emissions and combating climate change. The method places diplomatic pressure on nations to commit to decarbonisation efforts, hopefully leading to a systematic decrease in global emissions to achieve a net-zero emission scenario.

In SA, the Department of Environmental Affairs recently prepared and submitted a national GHG emission inventory report for SA to the UNFCCC. The 514-page report not only illustrates the complexity, scale, and volume of ongoing research in the realm but also confirms the scale of GHG emissions from SA. According to the report (Department of Environmental Affairs, 2020), the total GHG emissions across all categories mentioned in Table 2.4 during 2017 is estimated to be 516 Mt CO_2e. According to a Climate Transparency report (2021), SA's emissions have increased by 47.7% from 1990 to 2018 and stood at 557 Mt CO_2e in 2018.

With SA being estimated as the thirteenth biggest polluter in the world (Global Carbon Project, 2023), no net-zero emission commitment, a low observed adaption readiness to emission policies, and a considerable reluctance by the government to decarbonise the country's economy, this could be a significant trade risk for the country (Climate Transparency, 2021; Phillips, 2022). With the global commitment to emission reduction by 2050 increasing rapidly – from 16% of the global economy in 2019 to 68% in 2021 (Phillips, 2022) – this places SA in an unfavourable position. Further, the country is not on track to achieve the Paris Agreement of 1.5 °C (Climate Transparency, 2021), resulting in SA being under the spotlight at the COP27 meeting to do more to achieve the Paris Agreement (Manoko, 2022). South Africa, however, also drew attention due to the announcement of the Just Energy Transition Plan (JETP) – an ambitious world-first energy transition plan to move away from fossil fuels to increase the use of renewable energy sources (Boussion, 2022). The JETP ultimately aims to increase energy access, improve energy security, create jobs, reduce GHG emissions, and promote economic development.

Interesting to note is that all sectors, except transportation, form part of the National Climate Change Adaption Strategy in SA (Climate Transparency, 2021). According to Climate Transparency (2021), all sectors, except for transport, must monitor and evaluate progress through annual reporting and strategy updates every five years. The transportation sector is not included in this strategy because other sectors, such as infrastructure and energy, cover it.

2.2.3.2 Corporate emissions inventories

The second level of accounting is at an organisational level. Corporate GHG emission inventories account for all the emissions due to or associated with a company's activities (Kauffmann, Tébar Less & Teichmann, 2012). Reporting emissions on a company level has become part of a well-devised business strategy since consumers and investors are very aware of the environmental impact of a business (Goodarzi, Fahimnia & Sarkis, 2019). The *GHG Protocol Corporate Standard* is the leading international standard used by organisations to prepare corporate-level inventories. The Greenhouse Gas Protocol (Freeman, 2022) estimates that 92% of Fortune 500 firms that report emissions to the Carbon Disclosure Project (CDP) used the Corporate Accounting and Reporting Standard indirectly or directly in 2016. Nevertheless, a corporate accounting level is similar to the national level in that boundaries are set, and emissions are determined for the entity inside the system boundary.

In corporate reporting, emissions can be calculated either in terms of the amount of control a firm has over operations, known as the *control approach*, or the degree of ownership, known as the *equity share approach* (WBCSD & WRI, 2004). In the scenario of an equity share approach, emissions are determined by the percentage of equity the company has in the accounting entity. If Company A is wholly owned by Company B, Company B must report 100% of Company A’s emissions in their corporate emissions profile. The equity share approach thus directly reflects economic interest. In the control approach, a firm must account for 100% of the emissions from operations over which it has direct control. This control can either be *financial* or *operational*. Thus, if Company B has financial control that can influence Company A’s daily operational activity and policy, Company B must include 100% of the emissions. Likewise, if Company B has the ability to influence the day-to-day operations of Company A, Company B should account for 100% of Company A’s emissions.

Apart from the complex approaches used above to identify the business entity responsible for ownership of the emissions, a corporate level also categorises emissions according to three scopes, as shown in Figure 2.4. *Scope 1* emissions refer to all the direct emissions that originate from sources controlled or owned by the company, such as vehicles, equipment, and processes. For a logistics service provider (LSP), the Scope 1 emissions would be all the emissions released by fuel combusted in vehicles owned by the LSP, as well as emissions due to generators, forklifts, or other handling, cooling and storage activities, given that the transporter owns these assets. *Scope 2* emissions refer to indirect GHG emissions emitted when purchasing energy, such as electricity, steam, or heating and cooling. For the LSP, this would be the emissions due to electricity used. *Scope 3* emissions are all other indirect emissions that contribute to the operations or activities but are not owned by the organisation. The reporting of Scope 3 emissions is optional and, therefore, voluntary. For the LSP, Scope 3 emissions are employee commuting, business travel, emissions due to leased assets such as vehicles or equipment, subcontracted transport services, capital goods (vehicle manufacturing, outsourced servicing of vehicles, etc.), and fuel and energy-related activities.

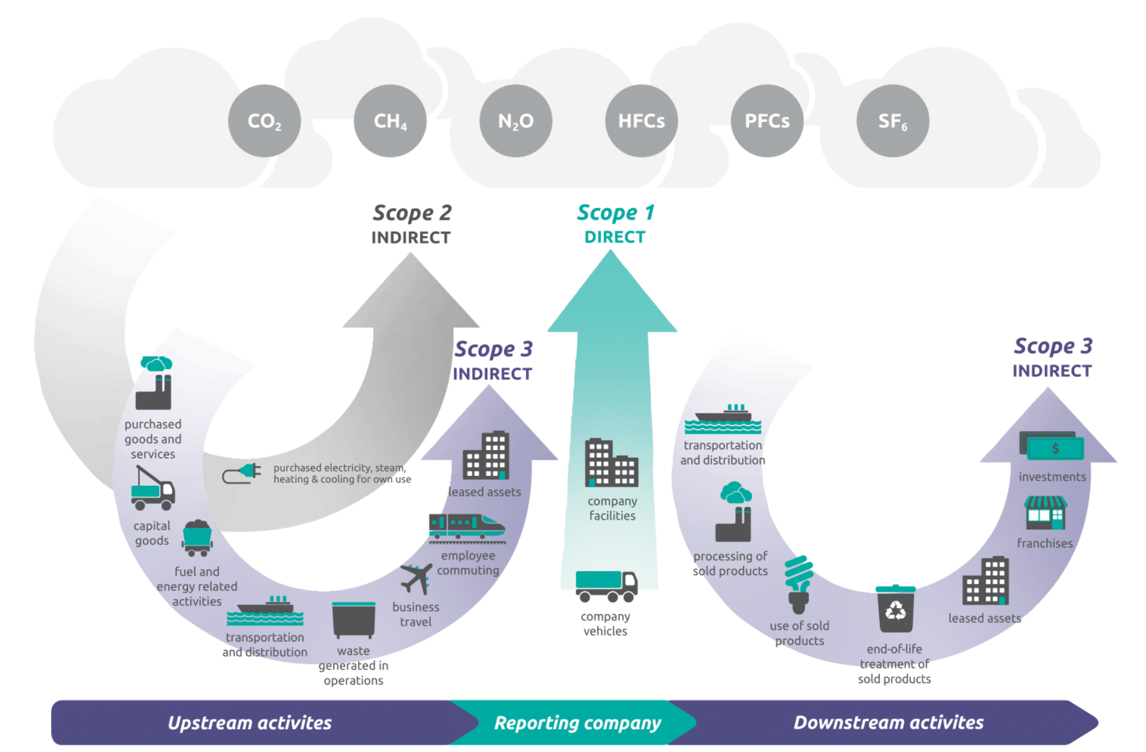

Figure 2.4: The various scopes and emission sources across a value chain

From (Bhatia, Cummis, Rich, Draucker, Lahd & Brown, 2011).

As a bare minimum, the GHG Protocol Corporate Standard requires an organisational carbon inventory to cover at least Scope 1 and 2 emissions (WBCSD & WRI, 2004). The total emissions for an organisation are thus determined for each scope and then summed to yield the total emissions. Note that the emissions due to the transportation and distribution of products are categorised as Scope 3 emissions and, therefore, it is not compulsory to include them in a corporate emissions inventory.

As with national inventories, quantifying corporate inventories has some fundamental flaws. One such flaw is that companies are selective about what they report (Tang & Demeritt, 2018; Bolton & Kacperczyk, 2021). Furthermore, carbon-intensive processes are often outsourced to other organisations to reduce the company's emissions value. This leads to a "shifting" of responsibility elsewhere in the SC. In addition, governments are weary of placing pressure on firms to reduce their emissions since the firm may move its operations abroad, reducing the tax basis.

Although not perfect, estimating the emissions in terms of an organisational boundary is an excellent start to identifying the corporations responsible for the majority of global emissions. According to a CDP report by Griffin (2017), 25 corporations or state-owned enterprises are responsible for 51% of global GHG emissions. Furthermore, the 100 largest firms are responsible for 71% of the world's industrial GHG emissions. The report also confirms that the current global emissions profile directly results from a few companies in the energy sector. In addition, corporate emission projects provide companies with an emissions profile and identify emission "hotspots" where the organisation could reduce emissions. Governments impose these mandatory regulations since this induces organisations to reduce their emissions. It also supports governments in creating national emission inventories since emission values at the firm level provide granular data and insight into sectoral emissions profiles.

Once a firm has calculated its corporate emissions inventory, it is verified internally or via third-party institutions to ensure that the inventories are correct and represent the company's emissions (Kauffmann *et al.*, 2012). The verification level, however, depends on the intended use of the inventory. Several third-party institutions exist, the most notable being the Carbon Disclosure Project (CDP) and the Global Reporting Initiative (GRI) that can assist firms with performing, validating and reporting emission inventories. According to Kauffmann *et al (*2012) and Tang & Demeritt2018), there is a global increase in the number of organisations or firms that report their carbon emissions. As of 2021, the CDP recorded the disclosure of more than 13 000 corporations with a combined global market capitalisation of 64% (CDP, 2021). However, Dexter Gavin from the CDP states that an estimated 17 000 corporations with a combined worth of USD21 trillion still fail to report their emissions (CDP, 2021).

This is, however, changing with governments introducing mandatory reporting for companies registered or operating within their borders. According to the World Resource Institute (WRI), as of 2015, more than 40 countries worldwide have made it mandatory for organisations to report their emissions (Singh & Longendyke, 2015). In SA, for example, the National Greenhouse Gas Emissions Reporting Regulations (Notice 275 of 2017) compel South African persons or companies emitting more than 0.1 Mt CO_2e annually due to a process or activity to report these emissions.

These mandatory inventories must be reported to the South African Greenhouse Gas Emissions Reporting System (SAGERS). In terms of voluntary reporting in SA, a recent PWC report shows that only 20% of CEOs indicated that their organisations had made a carbon-neutral[1] commitment, while only 30% are working towards a commitment (PwC, 2022). However, according to the same report, 17% of SA companies have made a net-zero[2] commitment, while 50% are working towards a commitment. This corporate level commitment undeniably portrays SA corporations in a better light than the national level commitment does.

2.2.3.3 Carbon footprint

The term carbon footprint (CF) has been used extensively by policymakers, the general public, governments, and businesses to make decisions regarding the environmental consequences of a product, activity, or other accounting entity (Goodarzi *et al.*, 2019). The media have especially used it in the public debate regarding the responsibility of abatement action towards the ever-growing climate change threat. However, this leads to the question: *what is the definition of carbon footprint?* Several examples of definitions are listed below.

- Shi and Yin (2021) define CF as a product's total life cycle carbon emissions for which the consumer is directly responsible.
- Wiedmann and Minx (2008, p.4) propose that CF be defined as: *"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."*

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[1] All GHG emissions emitted are removed or offset elsewhere through abatement mechanisms.

[2] Produce little or no GHG emissions from the start through a fundamental reduction of GHG emissions from sources.

- Blanchard (2010), however, defines CF as the amount of GHG emitted or produced by an organisation, individual, or the processes during the manufacturing and distribution of a product.
- Arora (2014) states that CF is the emissions associated with a value chain of a specific product or the emissions associated with a process in the SC.
- APICS (2013, p.23) defines CF as: *"A measure of carbon emissions from a person, organization, building, or operation."*
- Bertini, Buehler, Halbheer and Lehmann (2020), however, define CF from a product perspective to include the cradle-to-gate Scope 1 and Scope 2 emissions associated with a product's production and purchased energy emissions.

What is evident from these few examples is that several conflicting elements or aspects exist in the current definitions. Wiedmann et al. (2008) state that although the buzzword 'carbon footprint' is regularly used and thrown around in the literature, there is still considerable confusion about what the term truly means. However, the definitions discussed have three similarities:

- A type of gaseous substance (GHG) is measured;
- Something such as a product, service, activity, company, country, city, or SC or part thereof is assessed, and a boundary around this defines the scope of assessment.
- A functional unit of measurement, such as the total emissions (*x* tonnes CO_2e) or the emission intensity (*x* tonnes CO_2e per unit), is applicable.

It can, therefore, be concluded that the definition of CF is dependent on the context of use. The term CF can thus refer to either the total amount of GHG emissions (*x* tonnes CO_2e) or the GHG emission intensity (*x* tonnes CO_2e per unit) of a product, service, activity, company, country, city, project, or SC or part thereof. In this dissertation, however, CF refers to the GHG emission intensity of fresh fruit distribution measured in a unit as: kg CO_2e per kg of fruit.

Important to note is that CF is merely the analysis of a single impact category in a life cycle assessment (LCA), which assesses the overall environmental impact that a product, process or service has across its various life stages (APICS, 2013). An LCA, thus, determines the environmental impact of either global warming, eutrophication, human toxicity, water pollution, acidification of soil, or air pollution embedded in a product or service from the cradle to the grave. The various life stages for which a product LCA can be performed are raw material extraction, the processing thereof, manufacturing of the product, distribution, maintenance of the product, use thereof, repair, and finally, the recycling or disposal of the product. The CF of a product can, therefore, be determined for various stages of a product's life span. This dissertation performs a gate-to-gate LCA of all emission-generating activities in fresh fruit distribution.

2.2.4 The importance of overall supply chain sustainability

The importance of overall SC sustainability is crucial to achieving any of the 17 SDGs set by the United Nations (2017). With an ever-increasing global population, a rise in living standards, a change in consumption patterns, and an evolution in consumers' needs, a holistically environmentally sustainable SC is more important than ever (Sala, Anton, McLaren, Notarnicola, Saouter & Sonesson, 2017; United Nations, 2017). Globally, current environmental efforts, initiatives, and media coverage focus predominantly on GHG emissions, resulting in emissions and climate change being the "current big thing". This has resulted in mounting pressure by both the market and governments, forcing organisations to reduce, innovate and evolve to reduce emissions.

This evolution to be more sustainable has become critical for market access globally. Failing to adjust to the marketplace or governmental requirements will render an organisation, entire SC, and even all goods from a country irrelevant (Lewis, 2015). With EU plans to introduce a carbon emission tariff on products such as cement, steel, fertilisers, aluminium, and electricity by 2026 (Abnett, 2022), it is evident that a failure to reduce emissions will exclude some organisations, SCs, or even countries.

Current sustainability efforts, especially in terms of emissions, are unfortunately focused internally on individual organisations or stages of the SC. This simply leads to burden shifting among stakeholders or countries in the SC. A fundamental shift to reduce a product's or service's total life cycle emissions from the cradle to the grave is required for overall SC sustainability. Sala et al. (2017) confirm that the journey to achieve and maintain a sustainable SC requires very broad systems thinking from the point of raw material extraction (cradle) up until disposal of the product (grave).

Food SCs specifically are under scrutiny due to their importance in maintaining food security and feeding an ever-increasing global population. According to Iakovou, Bochtis, Vlachos and Aidonis (2015), the agrifood sector is undoubtedly one of the most protected and regulated sectors globally. There are, however, a few distinct differences between standard SCs and agrifood SCs, such as the perishable nature of the goods, the short life cycle of products, requirements in terms of national and international legislation due to food safety, phytosanitary requirements, and finally, transportation and storage requirements (Iakovou et al., 2015).

Multiple authors such as Abecassis, Cuq, Escudier, Garric, Kondjoyan, Planchot, Salmon and de Vries (2018), Iriarte, Almeida and Villalobos (2014), Boone, Ganeshan and Jayaraman (2012), Hu (2014), Houé and Guimaraes (2017), Craggs (2012), Despoudi (2020), and McKinnon, Browne, Piecyk and Whiteing, (2015) mention that sustainable SCs are important for the following reasons (in no particular order):

- Gain or maintain access to specific markets in terms of legislation;
- Competitive advantage in the market;
- Improve corporate image or brand reputation;
- Reduce the environmental impact and ensure sustainable management of natural resources;
- Maximise the value of a product to achieve the highest market price;
- Ensure ethical and safe conduct of all stakeholders in an SC;
- Improves traceability in the SC;
- Enables cost savings by increasing efficiency;
- Allows collaboration between stakeholders in the SC;
- Sustaining human livelihoods;
- Sustainable business creates opportunities for future investment;
- Improve investor relations;
- Attract talented individuals to an employer since sustainable businesses are preferred;
- Achieving the Sustainable Development Goals (SDGs) set out by the UN.

Globally, there is an increase in the number of middle-class citizens, which translates to a higher buying power for more expensive products such as fresh fruit imported from South Africa and other countries (Bell & Horvath, 2020). In terms of SA as a country and individual producers and exporters, achieving and maintaining a sustainable fresh fruit SC is critical for the long-term success and prosperity of the sector. A failure to transform could be disastrous for the sector, but the ability to adapt and to become more sustainable could reap many or all of the benefits mentioned above.

2.2.5 The food miles debate

The food miles debate is centred around the concept that food products transported over long distances are environmentally less sustainable than similar locally produced products. This theory states that food produced closer to the point of consumption has a smaller carbon footprint due to a shorter transportation distance. Thus, the debate only focuses on one single variable – transportation distance. The debate originated in the 1990s after what is now known as the *Sustain Alliance* published a report focusing on social, economic and environmental issues resulting from ever-expanding global food SCs and systems (McKinnon *et al.*, 2015). The term and public understanding later evolved to entail only the environmental aspect, specifically concerning carbon emissions. In short, advocates of the food miles debate state that nearer is better, while further is worse.

There is, however, a growing body of knowledge to challenge the public opinion about the food miles debate (Loiseau, Colin, Alaphilippe, Coste & Roux, 2020; Majewski et al., 2020). Researchers such as (McKinnon et al., 2015) emphasise the importance of considering the transport mode (air vs sea, road vs rail, etc.), as well as the efficiency of the route, loading efficiency and vehicle efficiency before making general assumptions about an SC. Academics are also increasingly using LCA, which takes a systems perspective of the entire product's lifespan and analyses stages such as production, storage and transportation. Performing an LCA reveals that transportation is merely one element of many that require consideration (McKinnon *et al.*, 2015). The importance of the transportation stage, and thus, the distance of movement, can be gauged against other elements in the entire life cycle of a product.

However, is there a correlation between the environmental impact, such as carbon emissions and distance travelled? A report titled *Wise Moves* by Garnett (2003) found that there was, to a certain extent, a correlation between the journey distance and the emissions, but several exceptions existed to this. Some of these exceptions include the overall efficiency of the production system, the mode of transport used and the number of other logistical activities performed. Other factors also cast the food miles debate into doubt, as stated by (Garnett, 2003), which include:

1. **The efficiency of manufacturing or production in the country of origin**. In many cases, the production or processing methods are more efficient, and thus, less carbon intensive in a distant country than in a country that imports the products.
2. **Local clustering in production country**. With the majority of manufactured products, it is better to transport a finished product to a location than to move individual components.
3. **Seasonality in the country of import.** Many food types, such as fresh fruit, can be stored in a refrigeration facility or cold store for extended periods. However, it is often less carbon-intensive to ship fruit from a location where the fruit is in season instead of storing it for extended periods.
4. **Acclimatisation in geographical regions.** As with many agricultural products, certain crops require a specific climate (temperature and rainfall) and growing conditions for optimal production. Creating and maintaining these ideal growing conditions in greenhouses is more carbon intensive than importing the same produce from a distant location where the produce is acclimatised without these artificial inputs.
5. **Logistical efficiency.** The overall efficiency of transportation vehicles used to move the cargo in a global SC is much higher than transportation vehicles that perform only short-distance or regional trips. Newer vehicles (vessels, planes, trucks and trains) typically operate on long-distance routes and are equipped with new technology – directly resulting

in higher efficiency. Older vehicles generally operate on shorter distances or routes due to a higher breakdown probability. Further, vehicles on long-distance journeys are typically loaded more efficiently (higher load factor[3]) to make the trip worthwhile compared to shorter journeys. These long-haul vehicles also have a significantly lower percentage of empty running[4] compared to regional delivery vehicles. The combined effect of newer technology, higher loading factors, and less empty running means that long-distance trips have higher logistical efficiency when compared to short-distance logistical activities.

From the above review, it can be concluded that there are several counterarguments to the food miles debate. Simply analysing distribution emissions alone without gauging the results of the other sources of emissions in an SC can be misleading. However, there is a correlation between the distance of transport and the amount of emissions, but this correlation is highly dependent on several factors. However, these factors that affect distributional emissions are not clearly defined to enable the quantification of such an argument. This research project aims to address these factors to facilitate a constructive discussion regarding the food-miles debate. However, irrespective of this research project's results, global food SCs will continue to exist for the foreseeable future (FAO, 2014; Garnett, 2003; Okpala, 2020).

2.3 Problem confirmation: a published article

This section presents a peer-reviewed article published in the journal *'Global Food Security'*. The article[5] assesses existing carbon mapping frameworks used for general freight and fresh fruit distribution through a systematic literature review to achieve RO1(b). This section is vital for the overall research project since a thorough systematic assessment of published and unpublished literature is needed to confirm and validate the problem statement in Section 1.2. In addition, this section provides a baseline for the primary researcher to build the remaining research on existing principles and concepts, thereby ensuring that the "wheel is not re-invented".

'Global Food Security' is an international peer-reviewed journal that publishes high-quality papers that clearly contribute to a better understanding of the social, economic, institutional, technical, and biophysical drivers of future and current global food systems. In an ever-expanding body of knowledge, the journal focuses on providing policymakers, scientists, researchers, and industry with concise and timely research on food safety and nutrition, food availability and access, and the environmental aspects of food systems. Since the journal focuses on aspects that influence global food security, such as distribution emissions, the publication of this section of the dissertation supports both the research project and the existing body of knowledge. The article is available at (https://doi.org/10.1016/j.gfs.2021.100607) but is under a two-year embargo until 2024, whereafter the article becomes open-access. The systematic literature review was repeated on the 18th of January 2023 to identify any new contributions to the literature since the article was published. The review yielded no new relevant additions to the literature.

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[3] Load factor is a metric representing how heavy a vehicle is loaded compared to the payload capacity.

[4] Empty running percentage represents the proportion that a vehicle travels empty during a transport service.

[5] The article was co-authored by du Plessis, M., van Eeden, J., and Goedhals-Gerber, L., (2022). See Appendix B, Section B1 for a formal declaration of author contributions as required for publications included in dissertations by Stellenbosch University.

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2.4 Conclusion

The purpose of this chapter was to set the scene for the dissertation and confirm the need for the remaining envisaged research. This chapter provided an exposition of the South African fruit export industry (**RO1a**), showing that SA is a significant exporter of fresh fruit in the southern hemisphere. The chapter also established the importance of the industry by assessing the economic contribution, food security impact, contribution to employment, and other miscellaneous positive impacts that the industry makes. In addition, the review shows that the South African fresh fruit export sector is well established and continues to grow and expand. The importance of assessing emissions of fresh fruit distribution in the industry is also addressed.

In addition, the chapter presented a published peer-reviewed journal article published in '*Global Food Security'.* The article confirmed the need for a carbon mapping framework (**RO1b**) by summarising the results of an in-depth SLR. In total, 76% of authors stated a need for future research in terms of carbon mapping or carbon estimation. The SLR identified 72 different frameworks, protocols, methodologies or standards. None of the latter enables the consistent quantification of fresh fruits' distributional emissions. Furthermore, the SLR indicated that little research considers fruit distribution or transportation emissions. Only ten authors (14%) analysed in the SLR incorporated distributional emissions in a Life Cycle Assessment. The article also showed that up to 18 assumptions were made to calculate the carbon footprint due to distribution in an avocado shipment. This iterates the significant number of potential differences in independent assessments.

Furthermore, the chapter provides the reader with a better understanding of concepts, principles, methodologies and current protocols used in the emissions realm by discussing relevant research concepts. Essential concepts such as sustainability and the importance thereof in an SC, emissions and the various accounting levels, and the food miles debate were explained. The literature shows that a fundamental shift is required in how emissions, especially distribution emissions in SCs, are accounted for.

The next chapter presents a published peer-reviewed article that identifies and describes all the physical emission-generating distribution activities performed to export fresh fruit from SA. The article provides several distribution chain diagrams that define the structure of fresh fruit distribution. These diagrams form the basis of both the proposed carbon mapping framework and the remainder of emission intensity factor estimation.

3. Generic distribution chains and activities

This chapter addresses the following research objectives:

RO2: To *identify* and *describe* all the physical emission-generating distribution activities performed during the distribution of fresh fruit from South Africa.

RO3: Based on RO2, c*reate* distribution chain diagrams that *define* the structure of fresh fruit distribution. These diagrams should represent all possible distribution scenarios by which fresh fruit can be exported from South Africa.

RO4: *Verify* and *validate* the created distribution chain diagrams developed in RO3.

This chapter consists of six sections that analyse the fresh fruit distribution process. Section 3.1 serves as a *sine qua non* to describe factors that influence logistical decision-making when exporting fruit. These factors affect how distribution occurs on a shipment level, and an understanding thereof is essential. Section 3.2 elaborates on the validation of this chapter's results and lists the various facilities visited as part of the research project.

This is followed by a published peer-reviewed journal article in Section 3.3 that identifies and describes all the emission-generating distribution activities performed during the export of fresh fruit from SA. The article also includes five distribution chain diagrams that define the structure of fresh fruit distribution. The article provides an in-depth assessment of individual distribution activities and a systems view of the entire distribution process. Section 3.4. discusses the importance of the journal article since it defines the various emission-generating activities for which emission intensity factors must be established. In addition, the section also presents a summative assessment matrix for the various emission intensity factors that will be used in the remainder of the project. Section 3.5 elaborates on the *status quo* use of the various transportation modes and logistical facilities identified in the journal article in Section 3.3. Apart from providing insight into the *status quo* of each mode and type of logistical facility in SA, this section also discusses reefer containers – a critical enabler of the current distribution system.

3.1 Logistical decision-making: factors influencing the distribution process

The methods and ways by which fresh fruit is distributed in a SC are influenced by several factors, such as the *volume of fruit produced*, the *market demand* for the product, the *fruit's shelf life,* the *distribution strategy's cost,* a number of *miscellaneous factors,* and *distribution emissions*. These elements determine whether fruit flows through a cold store or other logistical facilities, the time duration of storage at the facility, the type and configuration of vehicles used to transport fruit, and many other elements in the distribution process. These factors are discussed below to inform the process of compiling the journal article in Section 3.3.

3.1.1 Volume of fruit produced

If packing facilities produce too little output for a full container, their produce is shipped via a cold store where consolidation occurs. Alternatively, producers could hold fruit at the packhouse until a larger volume has accumulated. This is, however, uncommon since valuable shelf life is wasted, additional storage costs are incurred, and storage infrastructure is required. Consolidation of fruit, therefore, occurs as soon as possible since this increases the shelf life of the produce further down in the SC. However, if a packing facility's output volume of packed fruit is large enough, the finished packed fruit (i.e. fruit ready for shipment) can be transported directly to the port of export.

3.1.2 The market demand for fresh produce

The market demand for the produce is the second factor determining if the fruit is shipped directly to the port of export or via a logistical facility. If there is a high demand for the produce at that time, it is shipped directly to the port of export. Alternatively, the value of the fresh produce can be increased by storing the fruit in a cold store for a time period and then releasing it into the market. This is only done to achieve a higher market price or to fulfil contractual obligations where a continuous supply of fruit is a prerequisite.

3.1.3 Shelf life of the fruit

For the international transportation leg (main carriage), the transport mode of some fruit types, such as blueberries and stone fruit, is dictated by the potential lifespan of the produce. Even with an optimal cold chain, some blueberry and stone fruit cultivars have too short a remaining shelf life if distributed via deep-sea vessels. This necessitates the use of air transport as mode of transportation for the main carriage to ensure sufficient remaining shelf life in a retail supermarket.

3.1.4 Distribution cost

The *status quo* of fresh fruit distribution is primarily determined by the overall cost of a distribution strategy. Since costs are incurred with each additional activity in the distribution process, the total number of distribution activities is kept to a minimum. Also, air transport is avoided, while deep-sea transportation is preferred since it is significantly cheaper.

3.1.5 Miscellaneous factors

This category incorporates all the operational elements that cause exceptions in the day-to-day functioning of the export industry. Examples include, amongst others, the availability of transport services and reefer containers, delays in the distribution process due to unforeseen circumstances, port delays and decreased inefficiencies, and the detrimental impact of the global COVID19 pandemic on all SCs. These factors are usually regarded as anomalies but have unfortunately become common in the SA fruit export industry. They add cost, require storage and consume energy, inevitably adding carbon emissions.This has inevitably resulted in exporters "firefighting" to export fruit instead of strategically planning the distribution process.

3.1.6 Distribution emissions

This category is the purpose and focus of the research project. The emissions due to distribution currently have no impact on the logistical decision-making process. Fruit exporters and stakeholders are not able to make informed decisions about their distributional emissions since they cannot quantify the carbon impact of their logistical decisions. Subsequently, this dissertation allows the industry to assess the emissions impact of its logistical decisions and incorporate this into the list of factors.

3.2 Validation of distribution chains and activities

Apart from the continuous internal verification through scenario planning, several validation methods were used and are therefore explicitly stated in this chapter to provide a reason for the author's claim to knowledge. Apart from achieving **RO4**, the section is also essential for the validity of the remaining research project since it identifies the activities for which emission intensity factors must be estimated. Semi-structured interviews were conducted with the individuals indicated in Table 3.1. This table gives a description of each interviewee's company of employment and their position, as well as the interviewee's industry experience. The researchers purposefully chose each interviewee for their unique fruit export cold chain perspective because of their different backgrounds covering the extent of the fruit export process. Collectively, the combined experience between the four interviewees amounts to 101 years at the time when conducting the interviews were conducted. It is, therefore, evident that experts in the field validated the distribution diagrams and activities.

Table 3.1: Background information of the individuals interviewed to validate distribution chains and activities

Name	Current company and position	Industry experience
Interviewee A	• A sustainability consultancy firm (Company A) in the agricultural sector specializing in carbon mapping • Chief Operating Officer	• 10 years' sustainability consultant at Company A. • One year's experience at a South African Fruit Exporter, where carbon footprinting of fresh fruit exports was attempted.
Interviewee B	• A consulting firm in the field of logistics focuses on the export and import of fresh produce. • Lead Technical Consultant and owner	• In total, 34 years of experience in the global export of fruit. • Five years as a logistical consultant at Company B. • 16 Years' part-time lecturer at the School of Shipping and School of International Trade. • Eight years' experience as an importer/exporter of fresh fruit and food products at Dole South Africa.
Interviewee C	• Retired.	• Twenty-four years of experience at the soft fruit board (Unifruco) as head of logistics. • Part-time consultant for various fruit export projects. • Involved at Hortgro – the stone and pome fruit representative body.
Interviewee D	• A private consulting firm (Company D) is involved in fruit export logistics.	• 32 years at a large South African fruit exporter as manager of operations and risks.

In addition to semi-structured interviews, several facility visits were conducted throughout the research project. These facility visits were fundamental to understanding how export fruit distribution occurs in the real world. No literature or other source could provide the primary researcher with the same insight and understanding as first-hand experience. Facility visits to the following premises were conducted (usually accompanied by one of the above-mentioned individuals):

- Freight forwarder at Cape Town Airport's Cargo Terminal;
- The break-bulk terminal in the Port of Cape Town;
- Cape Town Container terminal;
- Two large-scale commercial cold storage facilities near Cape Town;
- Several road freight logistics service providers (LSP) facilities and depots;
- Various fruit-packing facilities.

3.3 Published article: “Distribution chain diagrams for fresh fruit supply chains: A baseline for emission assessment.”

This section presents a peer-reviewed article published in the *Journal of Transport and Supply Chain Management* (JTSCM). The journal article[6] identifies and describes all the physical emission-generating distribution activities performed during the international export of fresh fruit from SA. These activities were used to create five distribution chain diagrams defining the structure of fresh fruit distribution. This section is vital for the overall research project since the distribution diagrams form the basis of the carbon mapping framework presented in Chapter 7.

JTSCM is a peer-reviewed scholarly research journal that focuses on the management of how goods and services flow in value chains. These management processes include the design, planning, execution, operation control, and monitoring of all SC activities. The journal provides a platform for new research relating to the fields of logistics, transport management, and other disciplines such as sustainability, that directly affect all value chains. Since the journal’s scope is aligned with the article's purpose, the publication of this section of the dissertation supports both the research project and the industry in managing fresh fruit export. The article is available at (https://doi.org/10.4102/jtscm.v16i0.769) and is open access.

[6] The article was co-authored by du Plessis, M., van Eeden, J., and Goedhals-Gerber, L., (2022). See Appendix B, Section B2 for a formal declaration of author contributions as required for publications included in dissertations by Stellenbosch University.

Journal of Transport and Supply Chain Management
ISSN: (Online) 1995-5235, (Print) 2310-8789

AOSIS

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

Authors:
Martin J. du Plessis[1]
Joubert van Eeden[1]
Leila L. Goedhals-Gerber[2]

Affiliations:
[1]Department of Industrial Engineering, Faculty of Engineering, Stellenbosch University, Stellenbosch, South Africa

[2]Department of Logistics, Faculty of Economics and Management Sciences, Stellenbosch University, Stellenbosch, South Africa

Corresponding author:
Martin du Plessis,
martinduplessis6@gmail.com

Dates:
Received: 25 Mar. 2022
Accepted: 13 June 2022
Published: 30 Aug. 2022

How to cite this article:
Du Plessis, M.J., Van Eeden, J. & Goedhals-Gerber, L.L., 2022, 'Distribution chain diagrams for fresh fruit supply chains: A baseline for emission assessment', *Journal of Transport and Supply Chain Management* 16(0), a769. https://doi.org/10.4102/jtscm.v16i0.769

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

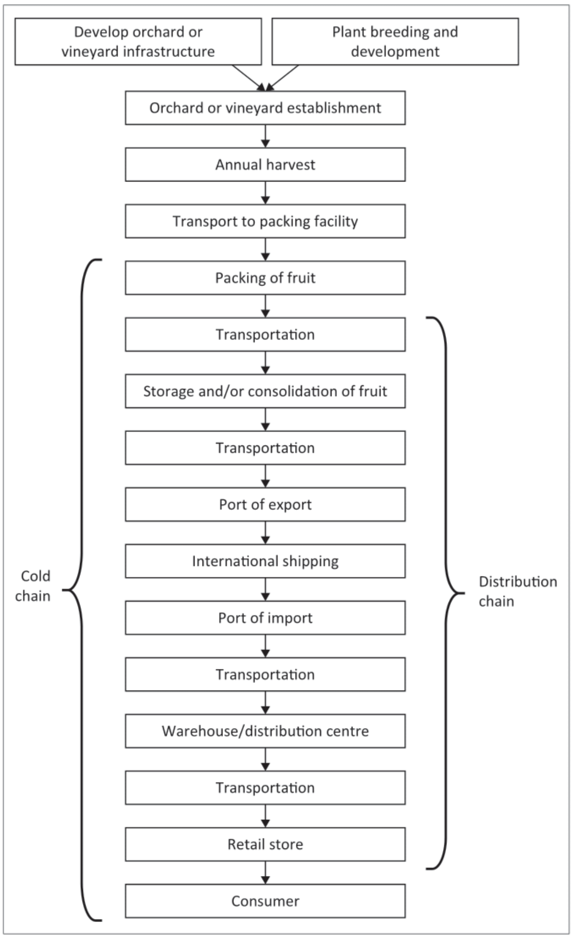
Globally, fresh fruit is in high demand all year round because of evolving consumer preferences. This necessitates a constant supply of fresh fruit to the market. However, because of production seasonality and the limited shelf life of fresh fruit, a year-round supply cannot be sourced from the same 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

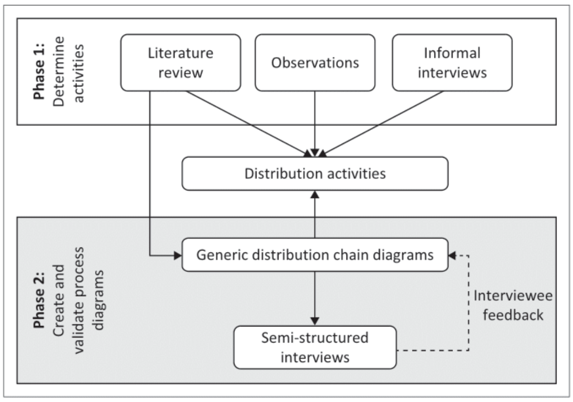


FIGURE 2: A visual explanation of the research methodology applied in this article.

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.

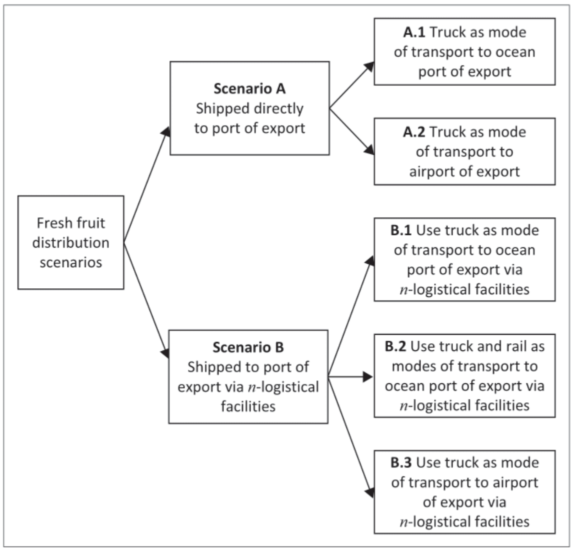


FIGURE 3: Outline of generic distribution chain scenarios.

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.

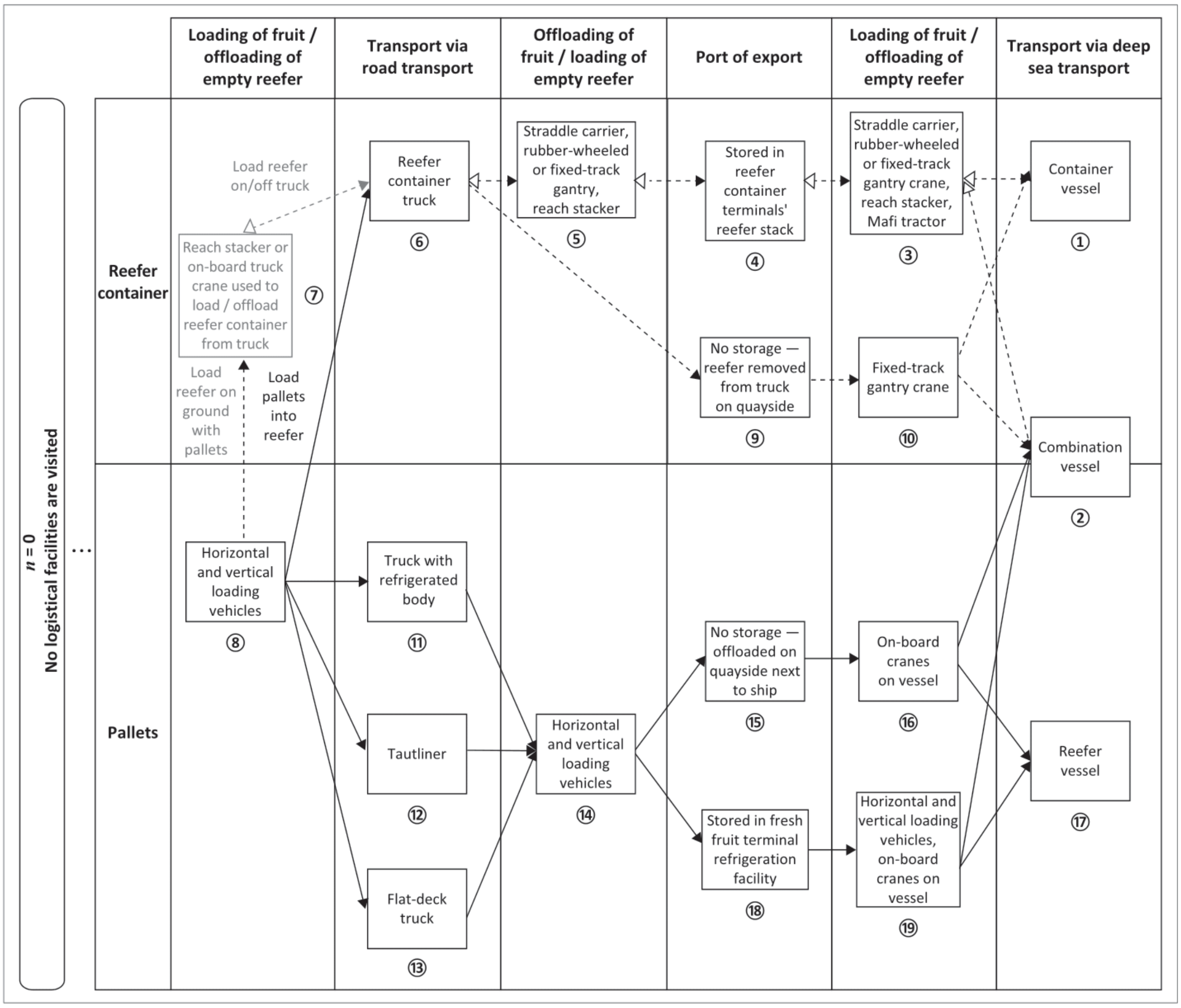


FIGURE 5: Scenario A.1, where fresh fruit is distributed from a packing facility to an ocean port of export via road transport.

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:

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

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

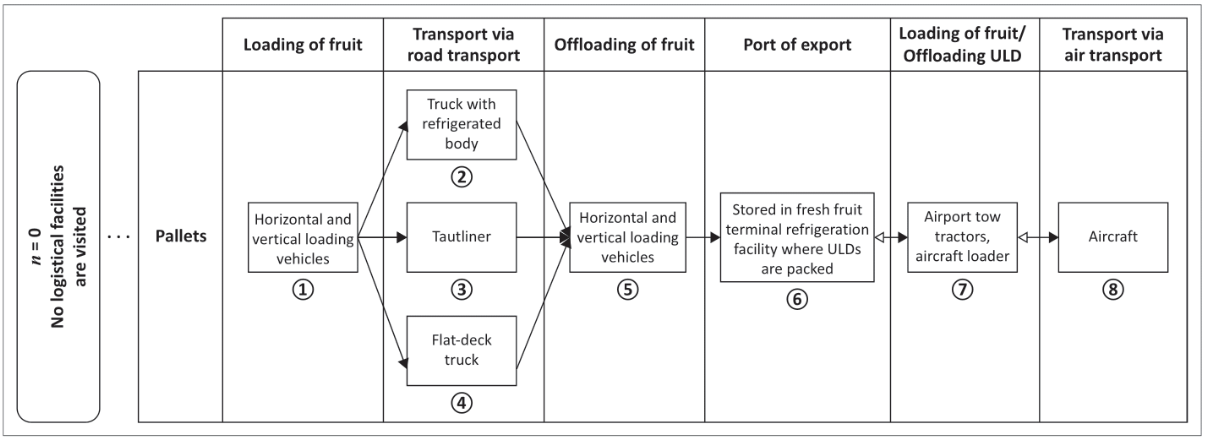


FIGURE 6: Scenario A.2, where fresh fruit is distributed from a packing facility to an airport of export using road transport.

$n_{downstream}$ 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

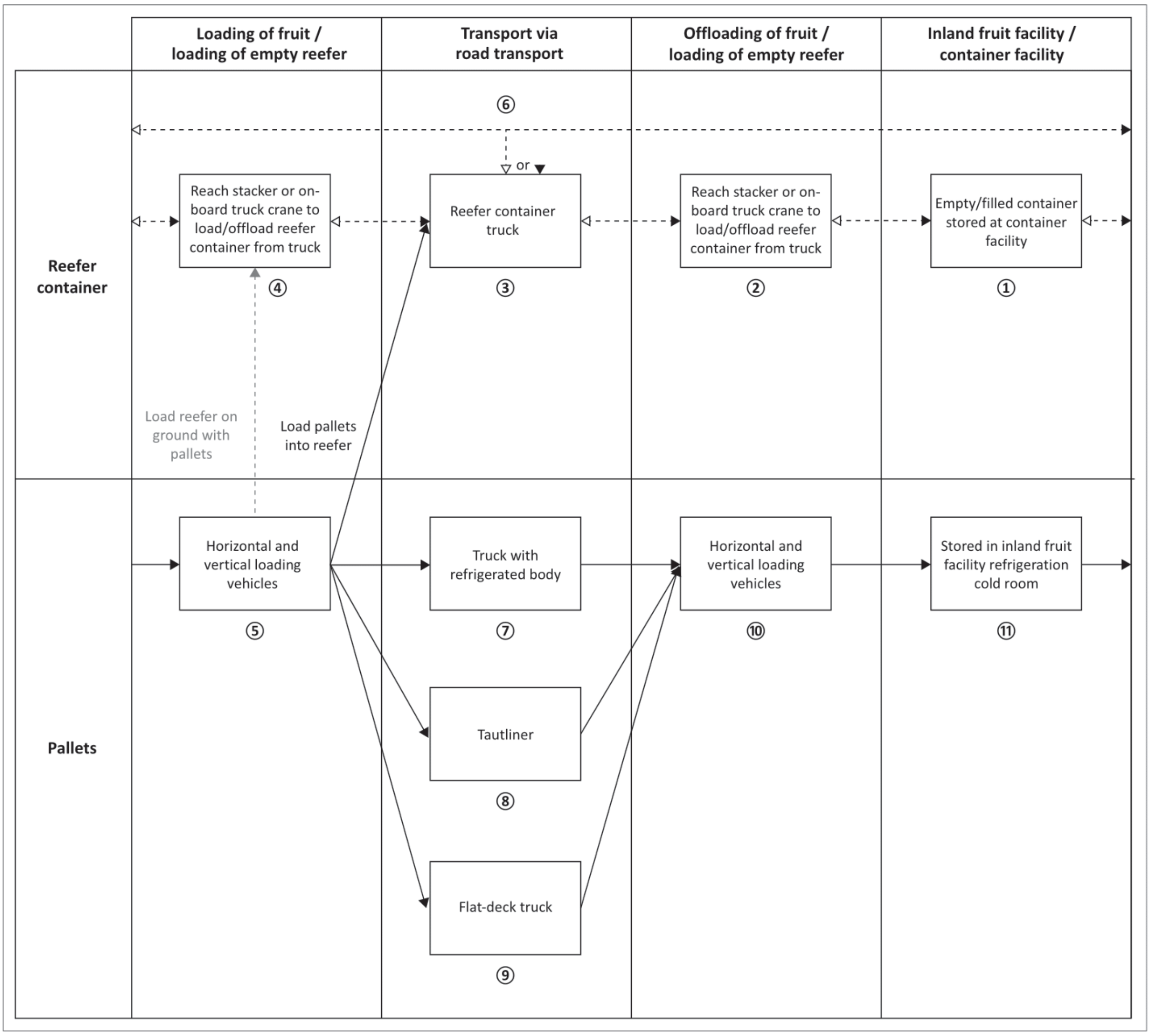


FIGURE 7: *n*-logistical facility repetitions.

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.

Acknowledgements

The authors acknowledge the willingness of industry partners to provide information and access to their facilities.

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.

Funding information

Funding for this study was received from the Royal Academy of Engineering, United Kingdom (ref. no. TSP2021 100310), and also the Stellenbosch University, Faculty of Engineering's Post Graduate Support Programme.

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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Appendices starts on the next page →

Appendix 1: Scenario B diagrams

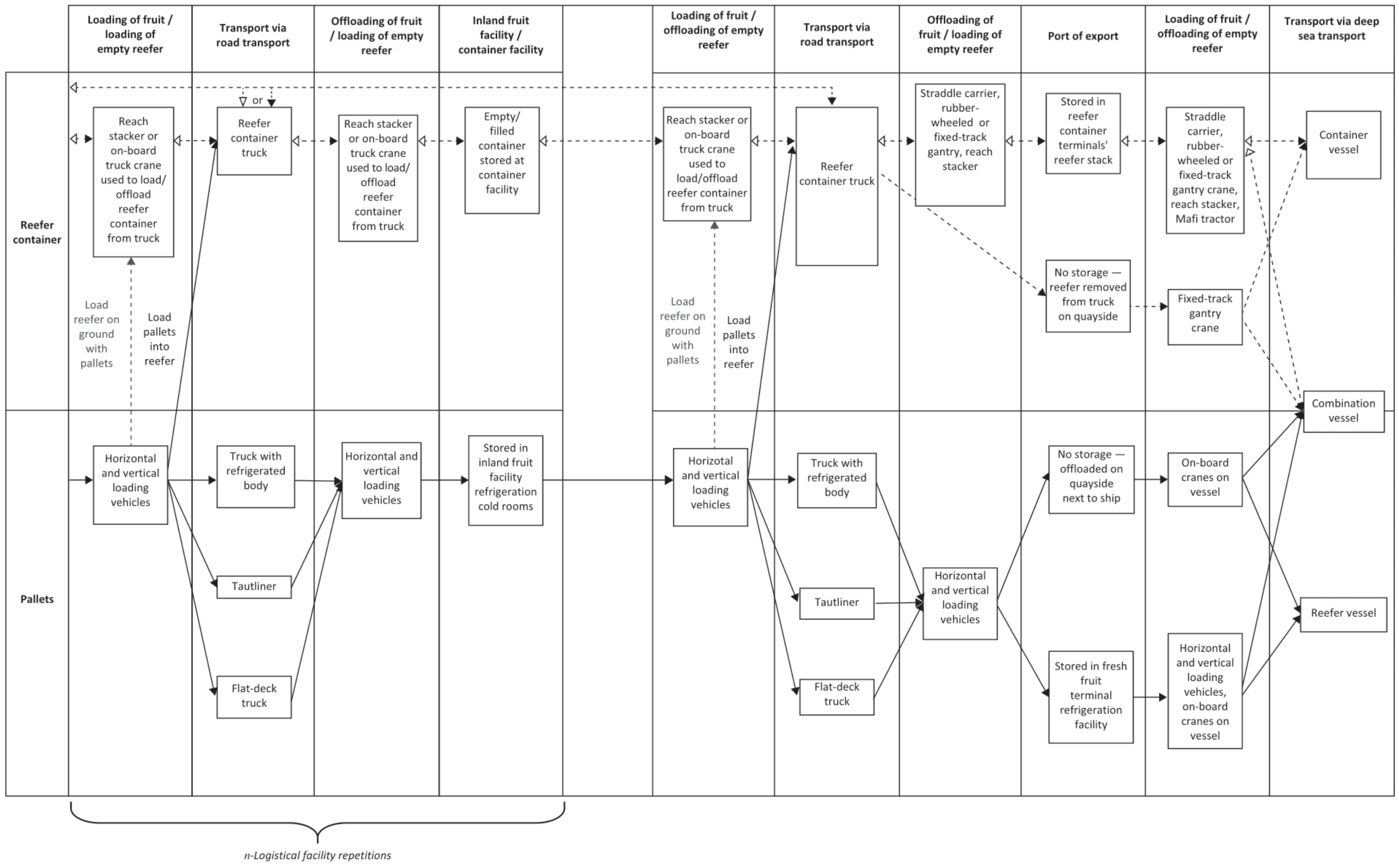


FIGURE 1-A1: Scenario B.1, where fresh fruit is transported by road to an ocean port of export via n-logistical facilities (n = 1, 2, 3...).

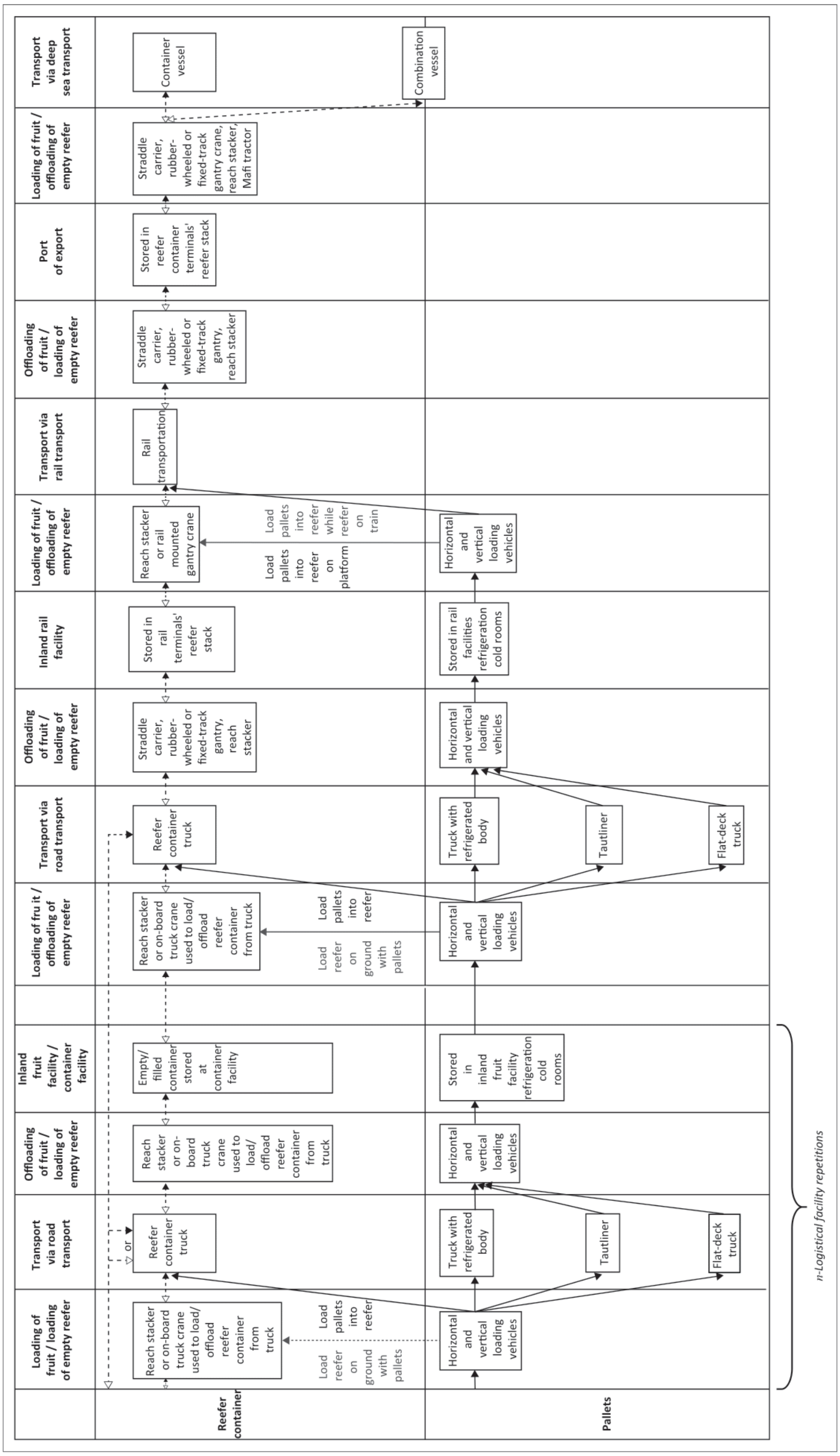


FIGURE 2-A1: Scenario B.2, where fresh fruit is distributed by rail and road to an ocean port of export via n-logistical facilities (n = 0, 1, 2...).

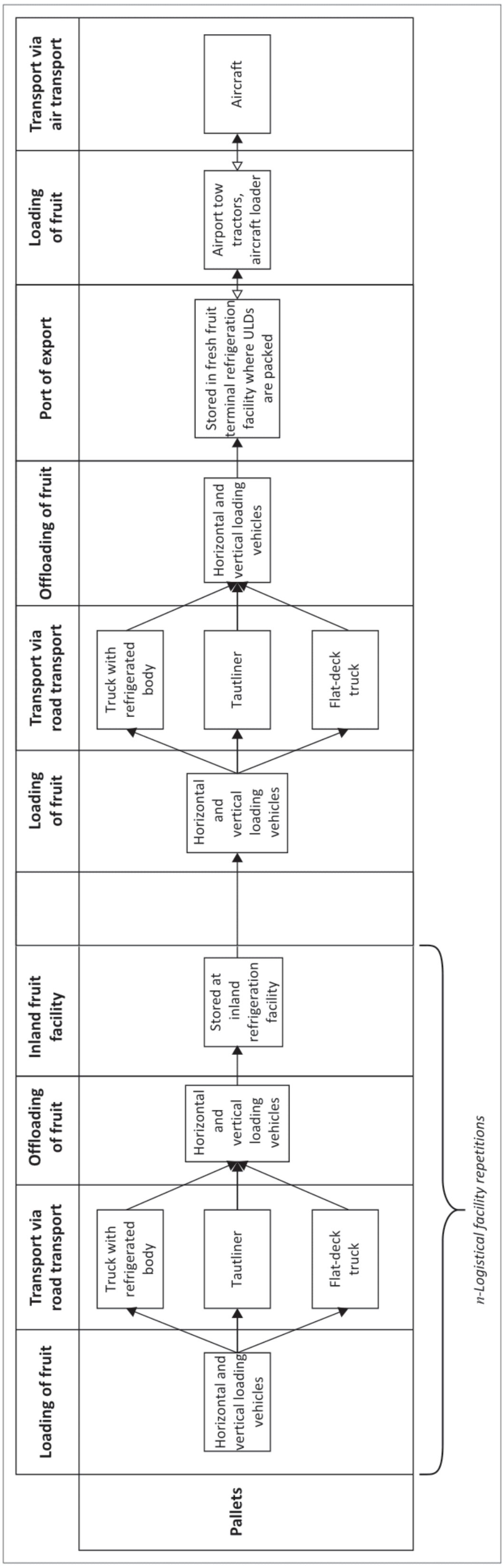


FIGURE 3-A1: Scenario B.3, where fruit is shipped by road to an airport of export via *n*-logistical facilities (*n* = 1, 2, 3...).

3.4 Distribution chain diagrams – an important input for remaining research

The published journal article in Section 3.3 analysed the processes and activities involved in exporting fresh fruit from SA. The article identified the various modes of transportation and facilities where the handling and storage of fresh fruit takes place. This is an essential input for the remainder of the research project (Chapters 5 and 6) since this defines the various emission-generating activities for which emission intensity factors must be established. Using the article in Section 3.3, Table 3.2 is defined to summarise the various emission intensity factors in Chapters 5 and 6. Table 3.2 assesses the availability of emission intensity factors in literature and their suitability for quantifying the emissions of fruit exports from SA. The table also indicates if a factor was derived during the project and the confidence level (low, medium, or high) that the primary researcher has in the recommended emission intensity factors. The confidence levels are defined as follows:

- Low: emission intensity factor based on subjective extrapolation of literature;
- Medium: emission intensity factor based on subjective extrapolation of primary research conducted on representative sample data or credible literature;
- High: emission intensity factor based on primary research conducted on representative sample data, a peer-reviewed journal article, or credible, published literature.

Note that Table 3.2 is purposefully left blank in this chapter and completed in Chapters 5 and 6.

Table 3.2: Summative assessment matrix of emission intensity factors

		Factors available in literature	Suitability of factors in literature	Factors calculated or derived from primary data in this project	Confidence level in recommended emission intensity factor
Transportation					
Transportation mode	Road transport				
	Rail transport				
	Deep-sea transport				
	Air transport				
Handling and storage					
Logistical facilities	**Pallets (storage and handling)**				
	Cold store or inland fruit facility				
	Break-bulk terminal				
	Airport facility				

		Factors available in literature	**Suitability of factors in literature**	**Factors calculated or derived from primary data in this project**	**Confidence level in recommended emission intensity factor**
	Containers (storage)				
	Storage				
	Containers (handling)				
	Inland container facility				
	Inland rail facility				
	Maritime container terminal				

3.5 Status quo of distribution

This section provides an overview and general comments concerning the *status quo* of each mode of transport and the use of logistical facilities in SA. The various subsections discussed are based on the published journal article in Section 3.3 and the categories identified in Section 3.4 for which emission intensity factors must be derived. The *status quo* assessment determines the importance of each distribution chain and the associated activities defined in Section 3.3. This is an important *sine qua non* to establishing or developing emission intensity factors in Chapters 5 and 6. This section also discusses the repositioning of empty reefer containers both from international destinations to South African ports and to the location of loading – an essential enabler for the fruit industry to export fruit.

3.5.1 Road transport

Road transportation is responsible for distributing nearly all fruit destined for export during pre-carriage in SA. According to Brooke (2015), 99% of export fruit is transported by truck to the port of export, translating to roughly 135 000 truck trips in 2015. This value has increased to roughly 180 000 truck trips[7] in the 2021/22 season. The dominance of road transport is due to Transnet Freight Rail's (TFR) failure to provide services of a suitable standard to enable rail transportation of fruit (Jansen, 2022a). Logistics consultant Dave Watts states that "*Rail is virtually not available*" – a clear testimony of the dire state of rail to transport fruit in SA (Jansen, 2022a). Furthermore, an analysis of the South African national Freight Demand Model (FDM™) data revealed that only road transport of fruit was captured. This is confirmed by (Simpson, 2021), who states that rail's contribution to transport fruit is negligible.

Nevertheless, besides being the only mode of transport available, road transport is used extensively in SA since trucks are the most convenient and the only mode with unrestricted access

[7] Assuming that each truck is loaded with a FEU reefer container filled with 20t of fruit. See Section 2.1.1 for more detail.

to production regions. Production regions and packing facilities are located in rural areas where roads are often the only transport infrastructure. This lack of other transport infrastructure, such as rail, forces stakeholders to use trucks for a large part of the pre-carriage phase or even for the entire phase. However, intermodal transport is a potential in the future if there is a revival in the rail industry. Using road as a mode has considerable advantages in that it is customisable and offers flexibility – precisely what is needed for perishable and seasonal cargo.

Road conditions in SA create a significant challenge for LSPs. According to the South African National Road Agency Limited (SANRAL, 2021), 14% of the pavement conditions in SA are regarded as very good, 41% are in good condition, while the remainder are fair (38%), poor (6.6%), or very poor (0.3%). As part of the research project, FDM™ data was modelled in ArcGIS to identify the routes of choice for the pre-carriage of fresh fruit from the production regions to the ports of export. The results revealed that road transport vehicles favoured national roads (N-roadways) instead of secondary roads, which are generally of lower quality. The latter is confirmed by actual industry data of an LSP in the article presented in Section 5.1.2. Nevertheless, road transport will continue to be a fundamental part of the distribution chain for the foreseeable future.

3.5.2 Rail transport

Rail is undoubtedly the most underutilised mode of transport in South Africa. During the 1990s, rail transported high volumes of fruit from packhouses in rural areas to the port of export (Brooke, 2009). However, this changed at the turn of the century. Currently, rail is scantly used since there is a lack of rail infrastructure and associated services. The rail infrastructure is owned and operated by the state-owned enterprise Transnet. Due to long-term financial irregularities (Mvumvu, 2019) and a lack of proper management (Blumenfeld, Wemakor, Azzouz & Roberts, 2019), the majority of passenger and freight rail infrastructure in SA is in a state of disrepair. TFR’s recently declared *force majeure* on several coal contracts (Reid, 2022) proves that the remaining rail services are also under threat. Unfortunately, large sums of money would be required to restore the rail infrastructure to an operational capacity.

Although the transportation distances and volume of fruit justify the use of rail, the factors mentioned above render this mode largely unutilised. There are, however, a few challenges with using or developing rail services explicitly for the fruit industry. Fruit export is largely seasonal, making significant capital investments in infrastructure such as road to rail terminals, rail facilities to handle and store reefer containers, or reefer rail wagons questionable. Further, railway stations or sidings are often located far away from the packing facilities and require transportation by road truck before the rail journey can commence. This means the fruit has to be loaded onto road trucks; thus, it is easier to use trucks for the entire pre-carriage phase. Another pertinent issue with using rail in SA is cargo security, primarily due to insufficient security throughout the duration of the rail journey (Loots, 2022).

Although various difficulties exist, rail as a mode has seen isolated instances of revival. In 2017, rail was responsible for moving approximately 3200 reefer containers of citrus fruit from the northern production region (Bela Bela, Tzaneen, and some from City Deep) to the Port of Durban (SA Fruit Journal, 2018). This was, however, a mere 3.5% of the total citrus export volume at the Port of Durban during the 2017 season. Furthermore, van Zyl (2022) states that seven train shipments (259 FEUs in total) were moved by a multinational LSP from Musina Rail Station to the Port of Durban during the 2020 citrus season as a pilot project to test the feasibility thereof for potential future expansion. The only known fruit transported via rail in the Western Cape is from the Ceres production region via Worcester siding to the Port of Cape Town (Simpson, 2022). According to Simpson (2022), 17 400 tonnes of fruit were transported by rail in 2018, declining to

14 100 tonnes in 2019. No fruit was transported via rail in 2020 due to the impact of the COVID19 pandemic. Operations resumed partially in 2021, resulting in 2 800 tonnes being transported.

Even in the current scenario where Transnet plans to privatise the railway system by 'selling' rail slots to an LSP for a two-year period (Nhlapo, 2022), no quick modal shift from road to rail is expected. Rail's underutilisation is expected to continue in the foreseeable future.

3.5.3 Deep-sea transport

Deep-sea transport is responsible for exporting the vast majority (>99%) of fruit produced in SA. The four main ports of export for fresh fruit from SA in order of volume are the Port of Durban, the Port of Cape Town, the Port of Port Elizabeth and the Port of Ngqura. The Port of Maputo, located in Mozambique, is also increasingly used as a port of export. Transportation of fresh fruit via deep-sea transport is far cheaper than air freight, but shipping via deep-sea transport has a longer journey time. The average journey time from the Port of Cape Town to Europe is approximately 16–18 days, while it could take approximately 25 days from the Port of Durban. This long lead-time means that the mode cannot transport fruit with a short post-harvest lifespan or produce that must be delivered rapidly to the market due to high demand.

Shipping fresh fruit via deep-sea transport can be categorised according to the three ship types (container vessel, reefer vessel, or combination vessel) indicated in Section 3.3. The use of reefer and combination vessels (collectively referred to by industry as conventional vessels) is declining due to the increased use of reefer containers in the past three decades. FDM™ data estimates that 95% of all fruit is shipped via reefer containers using a container vessel, while the remainder is shipped using conventional vessels. This is confirmed by Agrihub data, which shows that 7.3% of the total pallets exported from the Port of Cape Town in 2021 took place via conventional vessels. Of the 221 thousand pallets exported via conventional vessels, citrus fruit represents 96%, while pome fruit and table grapes represent 3.3% and 0.7%, respectively. Despite the small percentage, conventional vessels continue to play an important role, as shown during the COVID19 pandemic when there was an acute shortage of empty reefer containers globally and in SA.

3.5.4 Air transport

Air freighting of fruit contributes a very small proportion (<1%) of the total export volume of fruit from SA. Using airfreight is an expensive mode of transport, but it allows for very fast delivery and short lead times. This is ideal for fruit with a short shelf life. Also, this mode of transport is best suited for high-value fruit, such as blueberries, table grapes, and stone fruit, which is in high demand during a particular time of the year. Table grapes are examples of fresh fruit transported via air transport. SA is the only country that can supply fresh table grapes worldwide from the end of October to the middle of November,. This lack of global supply leads to increased market prices, which justifies transport via air. A demand and price increase is normally the precursor for using air as the transportation mode. Although air transport is used for other types of fresh fruit, these are exceptional cases.

Regarding the volume of produce distributed via air, 13% of SA's stone fruit (8 670 tonnes) was exported by air transport during the 2019/20 season (Jansen, 2020). According to personal communication (SATI, 2022b), air freight was responsible for exporting 1.1% (3 523 tonnes) of the total volume of table grapes in the 2021/22 season. Interesting to note is that Africa, notably Kenya and Uganda are currently the largest markets for airfreighted table grapes from SA. As for blueberries, 43% (5 250 tonnes) of the total exports took place via air (BerriesZA, 2021). However, due to COVID19's impact on global aviation, this number has decreased since there are fewer flights to and from SA. This transport supply shortage led to higher transport prices in the 2021/22 season, resulting in only 15.6% (3 020 tonnes) of blueberries exported using air transportation.

Nevertheless, the decline in air transportation as a mode is subject to change as the number of flights increases, resulting in lower distribution costs of the mode.

3.5.5 Logistical facilities

The storage or holding of fruit is required at certain stages or positions in the SC. As identified in the article in Section 3.3, this is achieved using six types of logistical facilities that handle pallets or reefer containers throughout the distribution process. However, the majority of fruit exported from SA uses only two facilities – cold stores and maritime container terminals. The following link (Cold Stores in South Africa) provides a view of various cold storage facilities in SA. Cold stores and maritime container terminals are pivotal in successfully exporting fresh fruit from SA. Maritime container terminals have caused considerable problems in the *status quo* distribution chain – not only for the fruit export industry but the entire import and export sector in SA.

Transnet National Port Authority (TNPA), a division of Transnet, owns all maritime container terminals in SA, while Transnet Port Terminals (TPT) operates these terminals. South African container ports are ranked as some of the worst in the world according to the 2020 Container Port Performance Index (The World Bank Group, 2021). The container terminals in Cape Town, Port Elizabeth, Durban, and Ngqura are ranked 347th, 348th, 349th, and 351st in the index[8]. With the index assessing a total of 351 ports, SA ports are indeed a cause for concern. Port challenges have led to considerable supply chain disruptions, shipment delays, additional costs, cold chain disruptions, and vessels not calling at SA's ports – all of which are not ideal for a time-sensitive commodity such as fresh fruit. Significant port delays have resulted in some reefer containers waiting between 7 and 21 days before being loaded onto a vessel (Jansen, 2022b). Reefer containers, however, typically wait for one to three days in the reefer stack before being loaded onto the vessel. A combination of port inefficiency, a global shortage of reefer containers due to SC disruptions, and container vessels bypassing SA ports has led to an acute shortage of reefer containers (see Section 3.5.6).

Port problems ultimately cause a bottleneck in the entire distribution chain, especially at cold stores. Fruit accumulates at cold stores since pallets of fruit cannot be loaded into reefer containers and sent further along the distribution chain. This inevitably increases the dwell time of fruit in cold stores and even leads to a delay or fruit not being packed or harvested since there is not adequate capacity in cold stores to refrigerate fruit. Fresh fruit exported from SA spends an average of 6.72 days (see Section 6.2.1) in cold stores. However, this could increase if port challenges are not resolved.

With ports being the current bottleneck in the entire distribution process, significant improvement is required to increase the effective working and efficient functioning of all port terminals. A failure to do so will be detrimental to the entire fruit export industry.

3.5.6 Reefer containers

An important aspect that enables the successful export of fresh fruit from SA and other countries is the availability of a sufficient number of reefer containers. If no empty reefer containers were available at the time of harvest, the global supply chain of fresh fruit would cease since the conventional vessel capacity is insufficient to transport all the fruit. Reefer containers are used for nearly 95% of all fruit exports from SA, while the remainder is transported by conventional vessels

[8] This ranking is according to the statistical approach. Results of the management approach values have a similar ranking.

or air freight. It is, therefore, evident that reefer containers are crucial for the current distribution system.

The COVID19 pandemic is one of the root causes of the current global container shortage (Newton, 2022). The global container shortage inevitably spilled over to SA (Connor, 2021), resulting in severe reefer container shortages in the SA fruit export industry. Important to understand is that the vast majority of reefer containers return empty to SA. According to the article in Section 2.3, 80–90% of the twenty-foot equivalent units (TEUs) landed in the Port of Cape Town's Container Terminal were empty during 2019 and 2020. This large percentage of empty containers is primarily due to an imbalance between imports and exports in SA, and especially a lack of imported refrigerated products. This means there are limited products imported to SA in reefer containers for natural full returns, unless filled with non-refrigerated goods and the cooling unit is switched off. Further, in the current climate, where shipping prices have skyrocketed (Etter & Murray, 2022), repositioning empty containers to countries like SA is unfavourable since more money can be made on trade lines such as the Trans-Pacific between Asia and the US, and Trans-Suez between Asia and the EU. This results in shipping liners not repositioning empty containers timeously to SA, although it is required. Therefore, the SA fruit export industry is at the mercy of shipping liners to supply enough reefer containers when needed by the industry.

Apart from the directional movement in the SC, the only difference between the forward and reverse movement of containers is the weight and absence of temperature control. The reverse movement of empty reefer containers uses the same equipment and processes as the forward movement of reefers filled with pallets of fruit. In essence, all activities are identical but in the opposite direction. Although the containers are not cooled during this empty return trip, the carbon impact of moving empty containers in a global SC should not be neglected.

3.6 Conclusion

The purpose of this chapter was to create distribution chain diagrams that define the structure of fresh fruit exports from SA. As a precursor to the remainder of the chapter, Section 3.1 described six factors influencing how logistical decisions are made when distributing fresh fruit. These factors are the volume of fruit produced, the market demand for the product, the fruit's shelf life, the distribution strategy's cost, miscellaneous factors, and distribution emissions. The research project aims to develop the understanding of the last-mentioned factor. This will enable stakeholders to make logistical decisions based not only on the overall distribution costs, market and product characteristics, and transit time but also on product-associated emissions.

Section 3.2 elaborated on the validation (**RO4**) of this chapter's results. The section also lists the various facilities visited as part of the research project.

The third section of the chapter presented a published peer-reviewed journal article that identifies and describes all the physical emission-generating distribution activities (**RO2**) performed during the international export of fresh fruit from SA. The article also stated five distribution diagrams (**RO3**) that map every potential scenario by which fresh fruit can be distributed. The diagrams consist of several nodes (representing logistical facilities where storage and handling occur) and links (representing the four transportation modes). The article provides an in-depth assessment of individual distribution activities and a systems view of the entire distribution process. The diagrams also show that multiple unique distribution chains can be created due to the large variety of possible vehicles, activities and logistical decisions.

These five diagrams form the foundation of the remaining research objectives since they define the scope (breadth) of emission assessment in the framework (**Part V**) and identify the various activities for which emission intensity factors should be established in **Part IV**. Without these diagrams, the comparability of any emission assessment would not be possible, nor would the primary researcher be able to develop a successful framework.

Section 3.3 presented a summative assessment matrix for the various emission intensity factors that are required in the project. This matrix will be used to summarise the emission intensity factors in Chapters 5 and 6. Section 3.4 elaborated on the *status quo* use of the various transportation modes and logistical facilities in SA. This section showed that the fruit export industry faces considerable logistical challenges constraining the entire sector. Apart from providing insight into the status quo of each mode and type of logistical facility in SA, this section also discussed the vital importance of reefer containers for the fruit export industry.

The next chapter briefly discusses how the emissions of distribution activities can be quantified. Further, the importance of accurate fuel emission factors and the danger of extrapolating emission intensity factors to other countries are discussed as they are a pivotal part of the overall research project.

4. How to quantify the emissions of distribution activities

This chapter addresses the following research objectives:

RO1: To conduct a thorough literature review in order to:

(c) Identify and *establish* fuel emission factors that are specific to South Africa and discuss the potential use of these factors for the remainder of the project;

This chapter forms part of **Part IV** of the dissertation document. The purpose of the chapter is to provide a foundation for Chapters 5 and 6, where the emission intensity factors for fresh fruit distribution are stated. The chapter commences by discussing how the emissions of distribution activities (as defined in the previous chapter) can be determined by explaining the difference between the fuel- and activity-based approaches. This is followed by Section 4.2, which discusses the available emission factors for South African fuel and electricity and the importance of obtaining accurate emission factors. Section 4.3 states the potential risk and inaccuracy of using emission intensity factors intended for other countries or regions.

4.1 The activity- and fuel-based methods

Two methods can be used to calculate the emissions of distribution activities (WBCSD & WRI, 2013; McKinnon, 2018; Smart Freight Centre, 2019) – the fuel-based approach and the activity-based approach (also referred to as the distance-based method). These two approaches are shown in Figure 4.1 and explained in the section below.

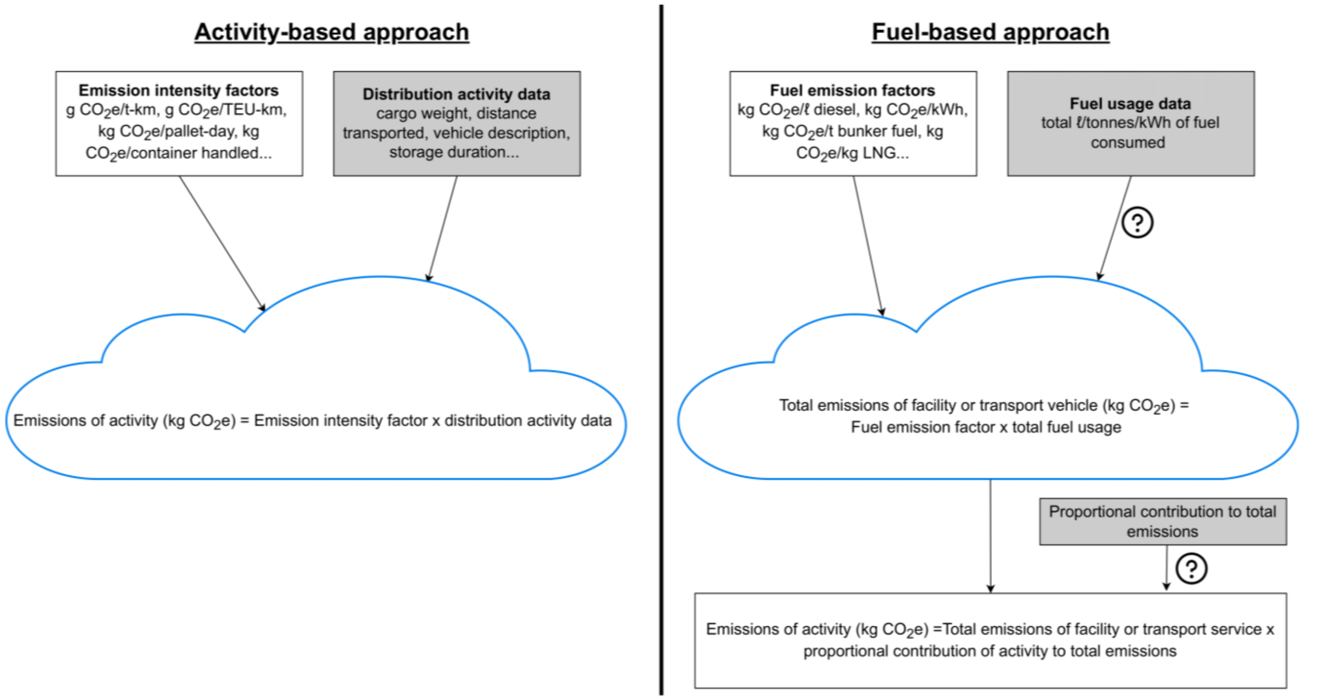
The *fuel-based*[9] *approach* calculates emissions using fuel consumption data (ℓ diesel, kWh, tonnes bunker fuel, etc.) and a fuel emission factor that estimates the quantity of emissions that are emitted when combusting or using one unit of fuel. A fuel emission factor is, therefore, an estimation of the lifecycle CO_2e content of the relevant fuel under scrutiny (Smart Freight Centre, 2019). The *activity-based approach*, on the contrary, uses distribution activity data (tonnes transported, distance driven, etc.) and emission intensity factors to estimate emissions. Emission intensity factors describe the emission rate at which CO_2e is emitted relative to a specific activity (Smart Freight Centre, 2019).

However, there is a significant difference between the data requirements of the two approaches. The greyed blocks in Figure 4.1 indicate the data requirements of each approach. The fuel-based approach has two significant difficulties (indicated with the (?) symbol in Figure 4.1), which render the approach less usable in estimating the carbon footprint of distribution.

The *first* is that the fuel-based approach requires fuel usage data (preferably primary data) to calculate emissions in a specific case. This fuel consumption data is often only known by the company that owns or operates the vehicle or facility and is not shared due to the potential consequences and sensitivity of the data. Examples of fuel consumption data that can be difficult or nearly impossible to obtain are those of ocean-going vessels, trains, aeroplanes, cold stores, and maritime container terminals.

[9] Note that the term "fuel" refers to any form of energy such as electricity or liquid, gaseous, or solid fuels.

The *second* data requirement is the proportional contribution of the shipment to the total emissions. The total emissions of the transport service or facility must be apportioned between all the cargo handled, stored or transported. This creates a significant problem when a transport vehicle or facility is occupied by more than one shipment or waybill, which is the case in most distribution activities, with the exception of road transport. LSPs and facilities should and may not share confidential information about other customers' data, meaning proportions cannot be calculated and validated by external stakeholders. Furthermore, milk runs and the uniqueness of each waybill in terms of weight and volume make it difficult for LSPs to calculate and suggest the proportional contribution. The combination of the two data requirements renders the fuel-based approach nearly unusable.



Source: Author

Figure 4.1: The two emission calculation routes – the activity-based and fuel-based approaches

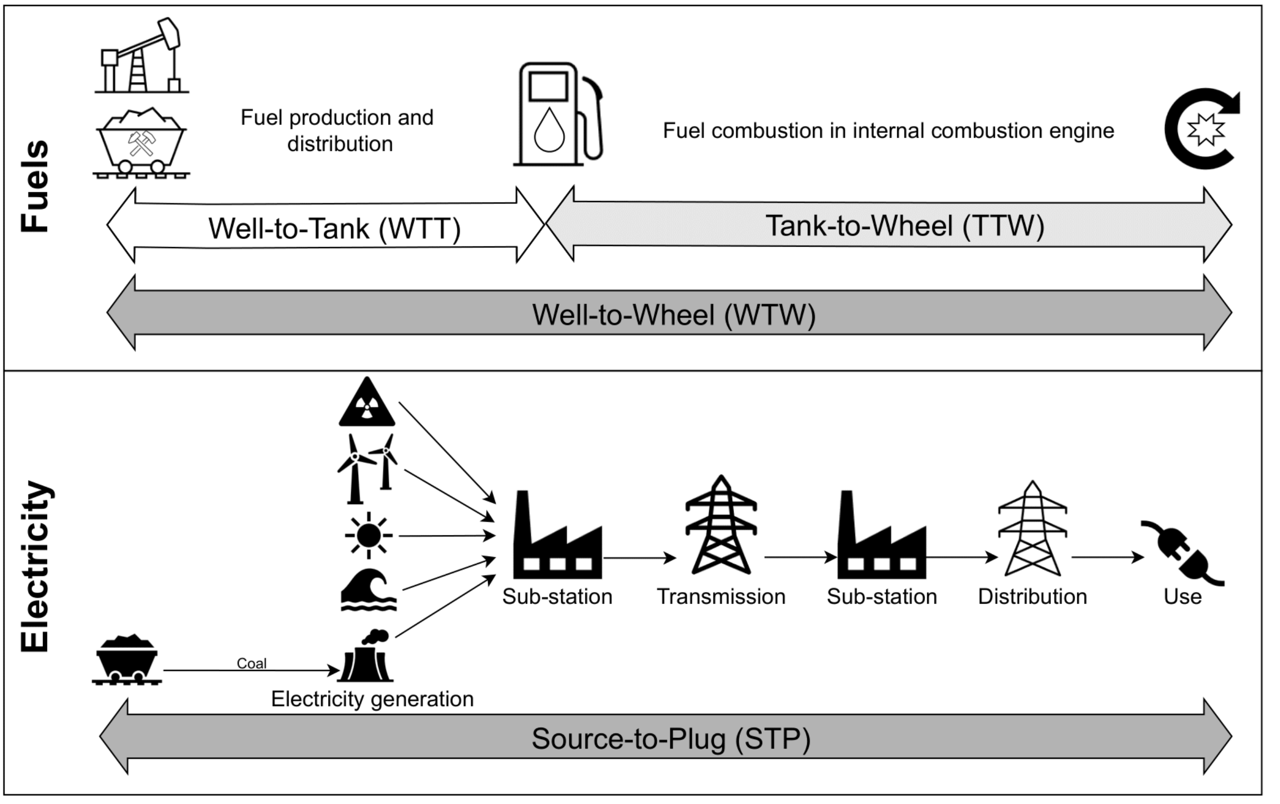
The activity-based approach, however, does not have the same data requirements as the fuel-based method. This method only requires the weight of a shipment, the distance transported, storage duration at logistical facilities, etc., which any stakeholder should have reasonable knowledge of. Subsequently, the activity-based approach is the only method capable of estimating the emissions of individual distribution activities and the entire distribution chain. However, the shortcoming of the activity-based approach is that accurate, appropriate and industry-specific emission intensity factors are not available. According to the primary researcher, these emission intensity factors do not currently exist for all emission-generating activities.

In summary, the two approaches are fundamentally different in terms of usability and accuracy. However, each approach fulfils an essential role and purpose in the logistics carbon realm. The fuel-based method is used in this project and the field of research to develop accurate and credible emission intensity factors, as in Chapters 5 and 6. The activity-based approach then uses the developed emission intensity factors to calculate the emissions of logistical activities, as is the case in Chapter 7's carbon mapping framework.

4.2 South African fuel and electricity emission factors

Accurate fuel and electricity emission factors are essential for estimating GHG emissions. This is not only true for estimating logistical emissions but also for corporate and national emission inventories (see Section 2.2.3). However, average fuel and electricity emission factors differ substantially from one country to another. Refer to Figure 4.2, which depicts the life cycle of fuels and electricity for the remainder of the discussion.

The life cycle of liquid fuels consists of two distinct sections, as shown in Figure 4.2 – a Well-to-Tank (WTT) and a Tank-to-Wheel (TTW) section. The WTT emission factors for fuels differ significantly due to the feedstock (coal, crude oil, LNG, etc.) and the methods used to extract, process, and distribute the fuel. This results in the WTT emission factors of fuels varying substantially from one country to another. The Tank-to-Wheel (TTW) emission per litre of fuel consumed, however, does not differ significantly due to the stoichiometric ratio of the combustion/oxidation of fuels.



Source: Author

Figure 4.2: The cradle-to-grave fuel and electricity life cycle

South African fuels have higher WTT CO_2e emissions per unit of fuel due to the type of feedstock and the processes used to produce liquid fuels (Ahjum, Godinho, Burton, McCall & Marquard, 2020). Unlike other countries that refine liquid fuels from crude oil, SA currently produces up to 20% of its total liquid fuel consumption from coal and natural gas (U.S Energy Information Administration, 2021). Since the 1950s, Sasol has operated the world's only commercial synthetic fuel plant where coal liquefication or the Coal-to-Liquid (CTL) process is performed (SASOL, 2005). The CTL process produces significantly more emissions than the conventional refining process of crude oil (Mantripragada & Rubin, 2011). In addition, the country from which the crude oil or finished products are imported also affects the WTT emissions of the fuel considerably.

Personal correspondence with Ahjum (2019) and a policy paper by (Ahjum *et al.*, 2020) estimates that the South African diesel's WTT emission factor is nearly 160% higher than that of Europe, as shown in Table 4.1. This results in South African diesel being up to 33% more polluting than European diesel. These higher emission factors prove the importance of accurate and specific fuel emission factors for South Africa.

Table 4.1: The fuel emission factor of South African diesel and petrol compared to Europe

	Fuel emission factors for South Africa (kg CO_2e/ℓ fuel) – source (Ahjum, 2019)			Fuel emission factors for Europe (kg CO_2e/ℓ fuel) – source (Smart Freight Centre, 2019)		
	WTT	TTW	WTW	WTT	TTW	WTW
Diesel	1,48	2,61	4,34	0,57	2,67	3,24
Petrol	2,60	2,85	5,22	0,45	2,42	2,88

Personal correspondence with Sasol has indicated that the company has embarked on a process to supply customers with a company-specific WTT emission factor for various types of South African fuel. The published and accredited European diesel emission factor is used in this research project until this becomes available.

Similar to liquid fuels, the Source-to-Plug (STP) emission factor for SA electricity is considerably higher than in other countries due to the energy mix of the national grid. Figure 4.2 portrays the cradle-to-grave life cycle of South African electricity, showing the various generation methods and distribution structures to consumers in SA. In SA, coal-fired power stations generate 87-91% of all the electricity, while nuclear and renewables generate 5% and 4-8%, respectively (Eskom, 2018; Climate Transparency, 2021). This dependency on coal (predominantly lower-grade coal) makes SA grid electricity the most carbon-intensive when benchmarked against peers (Eskom, 2018). According to the second version of *The Eskom Factor* (Eskom, 2018), the emission factor for grid electricity during 2018 was 0.97 kg $CO_2e\ kWh^{-1}$. Note that this is the most recent public emission factor provided by Eskom. This value is based on the total electricity sold by Eskom and includes distributional and transmission losses and is used in the remainder of the research project.

The above section demonstrates why accurate, country-specific emission factors are vital in emission estimation. Reliable and comprehensive CO_2e emission factors for different fuel types do exist for numerous countries and regions; however, none of the factors reflect the South African conditions. Future research is required to estimate emission factors specific to SA.

4.3 The use of other country's emission intensity factors

Section 4.2 showed that the total life cycle emission of fuels and electricity differ per region or country. In addition to this difference, each country's macro and micro logistical environment is unique (Havenga, Witthöft, De Bod & Simpson, 2020), resulting in each country having a distinct logistical efficiency. For example, compare the logistical conditions of the road freight industry in India to that of South Africa. Logistical differences between the two countries' road industries include, but are not limited to: the vehicle types, average vehicle age, the configuration of vehicles and associated payload impact, infrastructure such as roads, ports, logistical facilities and the general condition thereof, average congestion, average empty running, turnaround times for loading and offloading, and the general logistical climate of the country.

The compound effect of a difference in emission factors and logistical efficiency means that emission intensity factors should be developed for each country or geographical region if the activity-based approach is being followed. Caution should be taken when using or extrapolating European or North American emission intensity factors and applying these to other geographical areas or developing countries such as SA. This is particularly true for road and rail transport and logistical facilities. However, international transport services such as transport via deep-sea vessels and air transport are, to a large extent, exempt from this warning since they are not unique to a geographical area.

The only exception to using other countries' emission intensity factors is if a relevant factor is not available for the country under consideration. The development of country and industry-specific emission intensity factors is not only required for SA but also for many other developing countries and regions.

Recall that Table 3.2 in Section 3.4 defined a summative assessment matrix of the various emission intensity factors in the project. This assessment matrix is populated in Chapters 5 and 6 to assess the emission intensity factors in literature and their suitability for quantifying the emissions of fruit export from SA.

4.4 Conclusion

The purpose of this chapter was to explain how the emissions of distribution activities can be quantified and to identify and assess the factors that influence this quantification. Section 4.1 discussed the two methods that can be used to calculate the emissions of distribution activities – the fuel-based approach and the activity-based approach. The section iterated that the data requirements of the fuel-based approach render the method less usable in estimating emissions, resulting in the activity-based approach being the only possible method to assess logistical emissions.

This was followed by Section 4.2, which identified fuel emission factors specific to South Africa and discussed the potential use of these factors for the remainder of the project (**RO1(c)**). The section showed that South African diesel is up to 33% more polluting than European diesel, whilst electricity in the country is the most carbon-intensive amongst international peers. Due to the heavy reliance on coal for energy requirements, accurate emission factors specific to SA are vital for emission quantification in order to enable the use of the activity-based approach. This research project uses the European diesel emission factor since there is currently no accredited South African-specific WTW diesel emission factor. However, the project uses a South African-specific grid electricity emission factor.

Section 4.3 explained why caution should be taken when extrapolating European or North American emission intensity factors and applying this to other geographical areas or to developing countries such as SA.

The next chapter ventures into the emission intensity factors of fresh fruit transportation. This chapter states detailed factors which form an essential part of the carbon mapping framework.

5. Emission intensity factors for transportation modes

This chapter forms part of **Part IV** of the dissertation document. The chapter suggests emission intensity factors for the various modes of transportation by which fresh fruit is exported from South Africa. The emission intensity factors in this chapter were developed specifically for the SA fruit export industry, and therefore reflect the industry's real-world operating and logistical conditions. These emission intensity factors form an essential part of the carbon mapping framework in Chapter 7 and are critical for the overall success of the research project. This chapter addresses the following research objectives:

RO1: To conduct a thorough literature review to:

(d) *Identify* and *assess* existing emission intensity factors relevant to fresh fruit distribution.

RO5: *Establish* and *calculate* emission intensity factors associated with each activity defined in RO2.

RO6: *Verify* and *validate* the emission intensity factors calculated during the project.

Section 5.1 suggests emission intensity factors for the road transportation of fresh fruit. The section also consists of a published journal article that reports on the process of developing a methodology to calculate emission factors from real-world data. It also includes a further published article, where the developed methodology is applied to fruit export-related real-world data, with the outcome being specific road transport emissions intensity factors. This is followed by Section 5.2, which calculated a factor for the rail transportation of fresh fruit via reefer container. Emission intensity factors for the deep-sea transportation of fresh fruit via container vessels and conventional reefer vessels are discussed in Section 5.3. The final transportation mode, transport via air transport, is assessed in Section 5.4.

5.1 Road transportation

According to Section 3.4, more than 99% of export fruit is transported by road during pre-carriage in SA. Accurate emission intensity factors for various types and sizes of road transport vehicles are, therefore, essential. Subsequently, Section 5.1.1 presents a peer-reviewed journal article that developed emission intensity factors for a road freight LSP. Although the focus was not on a vehicle configuration for fruit transport, this paper was seminal in developing the proposed methodology, as implemented in a follow-up article focusing on fruit-related vehicle configurations. This published journal article is presented in Section 5.1.2. Finally, Section 5.1.3 briefly discusses the methods and data used to develop the recommended emission intensity factors. The section presents the first comprehensive source of emission intensity factors for different types and sizes of road freight vehicles used to transport fresh fruit or any type of freight in SA.

5.1.1 Published article: "Development of Emission Intensity Factors for a Road Freight Logistic Service Provider"

This subsection presents a peer-reviewed journal article published in the SAIIE33 Special Edition of the *South African Journal of Industrial Engineering* (SAJIE). The article[10] developed emission intensity factors for an LSP that owns and operates an extensive fleet of tanker vehicles which distributes bulk liquids across SA. Although the journal article is not focused on fresh fruit distribution, the article is included in the dissertation document since the research results, methodology, and collaboration were important for the project and assisted in developing the methodology followed. The article not only provided the LSP with a useful emission intensity factor based on actual real-world data and operations but also paved the way for similar future collaboration between the LSP, the primary researcher, and supervisors. This article was ultimately the precursor to the journal article presented in Section 5.1.2. The journal article in this section was also essential for the primary researcher to develop skills and gain insight into the LSP's data systems and business processes. The journal article was initially submitted to the SAIIE33 conference as a conference paper but was included in the conference-linked special edition of the SAJIE journal due to its unique contribution. The article will be available at (http://dx.doi.org//10.7166/33-3-2788) and is open access.

[10] The article was co-authored by du Plessis, M., van Eeden, J., and Botha, M., (2022). See Appendix B, Section B3 for a formal declaration of author contributions as required for publications included in dissertations by Stellenbosch University.

South African Journal of Industrial Engineering Nov 2022 Vol 33(3), pp 15-28

DEVELOPMENT OF EMISSION INTENSITY FACTORS FOR A SOUTH AFRICAN ROAD-FREIGHT LOGISTICS SERVICE PROVIDER

M.J. du Plessis[1*] , J. van Eeden[1] & M. Botha[1]

ARTICLE INFO

Article details
Presented at the 33rd annual conference of the Southern African Institute for Industrial Engineering, held from 3 to 5 October 2022 in Zimbali, South Africa

Available online 11 Nov 2022

Contact details
* Corresponding author
martinduplessis6@gmail.com

Author affiliations
1 Department of Industrial Engineering, Stellenbosch University, South Africa

ORCID® identifiers
M.J. du Plessis
0000-0001-9668-3253

J. van Eeden
0000-0001-9684-2357

M. Botha
0000-0003-0009-8792

DOI
http://dx.doi.org//10.7166/33-3-2788

ABSTRACT

The Global Logistics Emissions Council (GLEC) framework developed logistics emission factors to be used uniformly in North America and Europe. It included an approximation for African countries; however, actual South African emissions were not accurately reflected. Therefore, in this study, carbon emissions factors were calculated using calculated tonne-kilometres and the energy-based methodology. The authors obtained several datasets from a logistics service provider (LSP) consisting of vehicle routes, refuelling data, and freight load data. The project developed factors for each individual trip, for similar repetitive trips, and for the entire data set. These different sets of factors were developed to allow the use of different emission calculation and reporting standards. The LSP could use these emission intensity factors to estimate carbon emissions using the activity-based approach, report emissions according to legislation, and predict how much carbon emissions would be emitted to move a customer's shipment.

OPSOMMING

Die *Global Logistics Emissions Council (GLEC)* raamwerk het logistieke emissiefaktore ontwikkel vir eenvormige gebruik in Noord-Amerika en Europa. Alhoewel dit 'n benaderde skatting vir Afrika-lande insluit, word die werklike Suid-Afrikaanse emissies egter nie akkuraat weerspieël nie. In hierdie studie word koolstofvrystellingsfaktore bereken deur die gebruik van berekende ton-kilometer sowel as energie-gebaseerde metodologie. Die outeurs het verskeie datastelle van 'n logistieke diensverskaffer verkry wat bestaan uit die roetes gebruik deur hul voertuie, brandstofdata sowel as vrag data. Die projek het faktore ontwikkel vir individuele vragverskuiwings, vir soortgelyke herhalende vragte, en vir die datastel in sy geheel. Hierdie verskillende stelle faktore is ontwikkel om die gebruik van verskillende emissieberekeninge en verslagdoeningstandaarde moontlik te maak. Die logistieke diensverskaffer kan nou hierdie emissie-intensiteitsfaktore gebruik om koolstofvrystellings te skat deur die aktiwiteitsgebaseerde benadering te gebruik. Hierdie emissie-intensiteitsfaktore kan ook gebruik word om emissies te rapporteer soos vereis word deur wetgewing, en om te voorspel hoeveel koolstof vrygestel sal word om 'n kliënt se vrag te verskuif.

1. INTRODUCTION

Terms such as 'greenhouse gases' (GHGs), 'emissions', and 'carbon footprint' have become common buzzwords in modern society [1], [2]. Owing to increased pressure, governments, organisations, and individuals often use these terms to create an illusion of environmental sustainability [2], [3]. In most cases, unfortunately, this is only done to advance economic or political interests [4]. Despite a lack of understanding of the sources or size of emissions, ambitious emission reduction goals or targets are still set. Ideally, before organisations set emission reduction targets, a good starting point would be to quantify how carbon-intensive everyday business activities are. An analysis would enable organisations to understand how they produce emissions and allow future comparisons to measure progress.

This is particularly relevant in the road-freight industry, since LSPs often do not know the quantity of emissions when transporting a shipment. In addition, clients increasingly ask transporters how much is emitted as a result of the transport of their cargo. However, the field of allocating freight transport emissions is still in its infancy [5]. This is evident from research done by Du Plessis *et al*. [6] and the Smart Freight Centre [7] that shows the lack of sector-specific guidance to aid stakeholders in determining distributional emissions.

Many companies in the road-freight sector face the same challenge: how much is emitted on average when moving a tonne of freight one kilometre? This factor is known as the 'emission intensity factor' (EIF). Although EIFs are available in the literature [7], [8], [9], the accuracy and relevance of these suggested factors to the South African road-freight sector is questionable. Accurately calculating the emissions of transport activities is essential for any road-freight company to understand how its actions and decisions create emissions. This would allow LSPs to compare alternative transportation scenarios potentially to decrease emissions.

Thus this paper establishes an EIF for a large road-freight company, Company X, that operates in over 20 countries and employs over 10 000 people. The developed EIF is specifically for the tanker division, which transports bulk liquids in South Africa. This enables Company X to determine how much emissions is emitted by a typical shipment, and allows internal benchmarking to gauge its progress in reducing emissions.

2. LITERATURE REVIEW

This section briefly reviews the literature by discussing the importance of emission reduction and the associated pressure on organisations. Section 2.2 provides an overview and profile of South Africa's road-freight emissions, while Section 2.3 explains how to quantify LSPs' emissions and the problems associated with doing this accurately. The final section discusses the available EIFs found in the literature.

2.1. The importance of reducing emissions

The global community has pledged to reduce GHG emissions on several occasions. The most notable are the 1992 United Nations Framework Convention on Climate Change (UNFCCC), the 1997 Kyoto Protocol, and, more recently, the Paris Agreement of 2015. According to the Intergovernmental Panel on Climate Change (IPCC) [10], global GHG emissions must peak by 2025 and then reduce by 43% in 2030 if a 1.5 °C temperature increase is going to be achieved. In response to these global agreements, South Africa agreed to reduce emissions by 42% by 2025 [11]. In addition, the South African Government signed into law the Carbon Tax Act (Act No. 15 of 2019), which imposes a tax of ZAR 120 per tonne of CO_2e emitted. This amount was increased to ZAR 144 per tonne of CO_2e for the year 2022, whereafter the value will increase by the consumer price inflation (CPI) each year [12]. The Air Quality Act (Act No. 39 of 2004) also requires organisations above an annual emission threshold of 0.1 Mt CO_2e to report their emissions to the South African Greenhouse Gas Emissions Reporting System (SAGERS). This forces organisations to calculate and report their total emissions (Scope 1 and Scope 2 emissions) according to the GHG Protocol Corporate Accounting and Reporting Standard [13]. In addition, customers put pressure on companies to reduce their emissions, or else they will take their business elsewhere [14]. It is clear that organisations have both a legal requirement and a corporate responsibility to transition to a decarbonised economy that uses renewable energy, low-carbon technology, and less fossil fuel. Adapting to an environmentally sustainable business model is a definite prerequisite to remain relevant and competitive.

2.2. Road-freight emissions

According to Ajhum, Merven, Stone and Caetano [15] and the South African Department of Transport [16], the entire transport sector in South Africa emits around 60 $MtCO_2e$ per annum. This represents nearly 14% of South Africa's total emissions [17]. Road freight accounts for 90.0% to 91.2% of the transport sector's emissions [16], [17]. The proportion of road-freight emissions is expected to increase even further, since Transnet Freight Rail (TFR) can no longer provide an adequate rail service – as is evident from the recently declared *force majeure* on several coal contracts [18]. Road transport is and will become increasingly important for any freight movement in South Africa.

Authors such as Ahjum *et al.* [15] predict that electric, hydrogen, biofuel, and natural gas vehicles will become a reality in a future South Africa. However, authors such as Mckinnon [5] state that the transport sector is one of the most challenging industries to decarbonise, since it relies heavily on fossil fuels. Until alternative fuels and vehicles become a reality and a shift occurs, heavy-duty diesel trucks will continue to transport the vast majority of freight in South Africa and globally. Authors such as Kamdar [19] estimate that there are up to 350 000 freight trucks on South Africa's roads alone. Thus a better understanding of how road transport vehicles produce emissions when transporting cargo is essential.

Various factors – such as the vehicle's speed, aerodynamics, engine and powertrain technology, driver behaviour, waiting and idle time, operational efficiency and route planning, load factor, empty running or potential backhaul, service interval, tyre pressure, and use of low-resistance tyres – affect the emissions of a transport activity. However, before a micro bottom-up analysis is done to determine the impact of these individual factors, the current system's emissions should be known. This requires a top-down assessment to identify the status quo, which is the purpose of this paper.

2.3. Quantifying the emissions of road transport

There are two possible methods to calculate the emissions of all freight transport activities: the **energy-based approach** and the **activity-based approach** [7], [8]. Since most emissions from road-freight transport are energy-related, the first method uses the amount of fuel used (ℓ) and an emission factor (kg CO_2e/ℓ) to convert the energy usage to emissions (kg CO_2e). This is known as the **energy-based approach**, since the actual amount of energy consumed during each trip is used to calculate the emissions. The **activity-based method** estimates the emissions when the actual energy consumption (ℓ of fuel used per trip) is unavailable. This method uses an EIF (kg CO_2e/t-km), the shipment weight (t), and the distance (km) to estimate the emissions (kg CO_2e) of a shipment. A vehicle's fuel usage is replaced, therefore, with an average factor that estimates how much fuel is used to move one tonne of freight a kilometre.

The energy-based approach is always more accurate than the activity-based approach. The actual fuel consumption of a trip accounts for vehicle efficiency, vehicle age, trailer configuration, load factor, cargo type, empty running, driver habits, route travelled, traffic conditions or congestion, waiting or idle time, and weather conditions. The activity-based method, however, assumes that the chosen EIF variables are similar to the shipment being calculated, which is not always true. It is evident that there is a need for various appropriate and accurate EIFs to be used in the activity-based method.

Despite the shortcomings and apparent flaws of the activity-based method, it is still a valuable method for estimating emissions, once an appropriate EIF is available. The method could increase in popularity because of its ease of use and its ability to cover data shortcomings such as fuel usage or detailed payload, which only the LSP knows.

2.4. EIF for road transport

Even though road transport is important, no research has assessed the carbon intensity of the mode in South Africa. In addition, there is little peer-reviewed international research about road freight's EIF in the public domain. However, the Global Logistics Emissions Council (GLEC) framework [7] suggests a comprehensive set of EIFs for different sizes of road transport vehicle. These EIFs are conservative, and apparently overestimate the emissions in most cases. The suggested factors account for the type of load transported, the load factor, and the vehicle's percentage of empty running. Table 1 indicates the EIF for a large articulated truck (gross vehicle mass [GVM] less than 60 t), which is comparable to that of Company X, analysed in this research. Although the factors are for Europe and South America, the Smart Freight Centre (SFC) [7] states that the European and South American EIFs can be used for Africa if they are increased by 22%, as shown in Table 1. The GLEC's proposed upliftment by 22% is based on the extrapolation of an International Council on Clean Transportation dataset. However, the present authors question the accuracy of this 'blanket' upliftment between different regions. Despite its limitations, the suggested EIF is a good starting point for Company X to estimate the scale or size of emissions for this type of truck configuration – although it should be noted that this is not specific to a tanker truck.

Table 1: Emission intensity factors for an articulated truck (GVM < 60t)

	Basis for calculations		Emission intensity factor for well-to-wheel (WTW) (g CO_2e/t-km)	
Type of load	Load factor	Empty running	Europe and South America	Africa
Mixed/Average	60%	17%	63	77
Heavy	100%	38%	55	67
Container	72%	30%	63	77

Adapted from [7]

3. RESEARCH METHODOLOGY

The methodology used in this study is divided into six steps, as displayed in Figure 1. Each of the steps is discussed in more detail below.

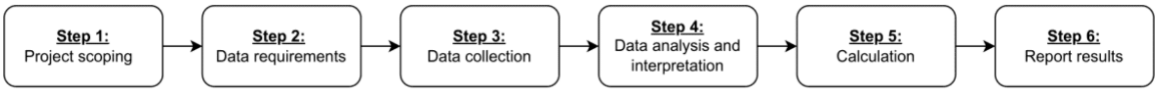


Figure 1: The research methodology used in the paper

3.1. Project scoping

This study uses the principles, boundaries, and methods for transport service analysis stated in the European Standard EN 16258:2012 [20], which is used to calculate the EIF of individual trips. In addition, the United States Environmental Protection Agency (US EPA) SmartWay methodology [9] is used to calculate the overall average EIF of the entire truck fleet. Both methodologies ([20], [9]) are used and accepted in the GLEC framework, and so are used in this paper.

Reference must be made to the allocation of the emissions of milk-run deliveries, since a different method is used. Milk runs are different because the shortest theoretical distance between the origin and the destination is used to allocate the emissions. This differs from [9] and [20], which would use the travel distances between successive delivery locations. This means that the emission allocation of milk runs is independent of the actual distance driven by the vehicle. Refer to the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) [21] (pp 63-64) for a detailed example.

This paper analyses the cradle-to-grave (also known as the 'well-to-wheel') emissions from the physical distribution or transportation of bulk liquid by an on-road truck. The emissions and the EIF are stated as a carbon dioxide equivalent (CO_2e). All other emissions from to the construction, maintenance, and disposal of infrastructure, vehicles, or consumables are outside the project's scope.

The project focused on Volvo FH440 truck tractors pulling tri-axle food-grade tankers with a maximum capacity payload of 36 tonnes. Figure 2 is a diagram of the truck-and-trailer combination analysed in this paper. Eight representative trucks from Company X's fleet were selected, and all trip movements for a three-month period were analysed.

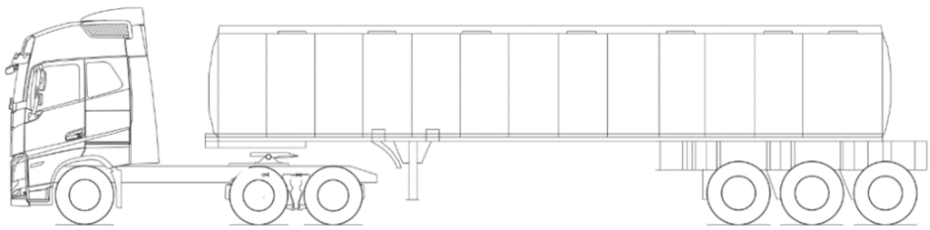


Figure 2: Diagram of the type of vehicle analysed in the paper (used with the permission of TruckScience)

3.2. Data requirements

The following data values were required for each trip, and were collected or derived from Company X's data:

- Departure date and time;
- Arrival date and time;
- Pickup location;
- Delivery location;
- Empty running distance/percentage;
- Load factor;
- Total trip distance;
- Amount of diesel fuel used during the trip.

Another important data value that is needed is the fuel emission factor (kg CO_2e/ℓ) of diesel fuel. Company X requested their fuel provider, a multinational South African fuel company, to provide the project with a country-specific factor for diesel fuel. The fuel company acknowledged the importance of such a factor, but stated that there were no immediate foreseeable plans to establish such a factor. Since a country-specific fuel emission factor could not be obtained for this project, 3.11 kg CO_2e/ℓ was used. This value is the average of the European and North American factors as proposed in the GLEC framework [7].

3.3. Data collection

Despite the size and technological advancement of Company X's business processes, collecting the required data presented a number of challenges. Several data systems, each from a different department in Company X, were integrated to create a complete list. These were the transport management system (TMS), the vehicle telematics system, the fuel management system, the asset register, the client base file, and the delivery files. These different systems were integrated into a single Excel file that could derive or calculate all the required fields, as stated in Section 3.2.

3.4. Data analysis and interpretation

The details of the data analysis and interpretation are discussed in Section 4, given its importance.

3.5. Calculation

In order to determine the EIF of a transport activity, the equations given in this section were used. Note that it is a prerequisite that the data be in the correct format.

Emission intensity factor

To calculate the EIF of a single shipment, Equation (1) was used:

$$EIF_{trip} = \frac{Emissions_{trip}}{(t-km)_{trip}} \qquad (1)$$

where EIF_{trip} is the emission intensity factor (kg CO_2e/t-km), $Emissions_{trip}$ is the total CO_2e emissions (kg) emitted during the trip based on actual fuel consumed, and $(t\text{-}km)_{trip}$ is the tonne-kilometre value of the trip. The $(t\text{-}km)_{trip}$ value in milk runs is the sum of all origin–destination pairs' tonne-km values, as stated in Equation (3).

Total emissions

In order to calculate the emissions for each trip, Equation (2) was used:

$$Emissions_{trip} = Fuel_{used} \cdot Emission\ Factor \tag{2}$$

where $Emissions_{trip}$ is the total amount of CO_2e emissions (kg) emitted during the transport activity, $Fuel_{used}$ is the total amount of diesel fuel in litres (ℓ) used during the trip, and Emission Factor is the fuel emission factor for diesel fuel (3.11 kg CO_2e/ℓ).

Tonne-kilometre

The tonne-kilometre value for each trip can be calculated as shown in Equation (3):

$$(t - km)_{trip} = Weight_{cargo} \cdot Distance_{loaded} \tag{3}$$

where $(t - km)_{trip}$ is the tonne-kilometre value, $Weight_{cargo}$ is the weight (t) of cargo moved, and $Distance_{loaded}$ is the road distance travelled (km) between the collection and delivery points of the shipment. Note that, in milk runs, $Weight_{cargo}$ refers to the weight of cargo delivered to the specific delivery location, while $Distance_{loaded}$ refers to the shortest theoretical road distance between the origin and the delivery destination.

Load factor

The load factor is a ratio that describes how heavily a transport vehicle is loaded. For each trip, this can be calculated using Equation (4):

$$Load\ Factor\ (\%) = \frac{Weight_{cargo}}{Load_{capacity}} \tag{4}$$

where Load Factor (%) is the load factor of the trip, $Weight_{cargo}$ is the weight (t) of the cargo moved, and $Load_{capacity}$ is the maximum payload capacity (36 t) of the transport vehicle. In milk runs, $Weight_{cargo}$ is the weight (t) of cargo initially loaded onto the vehicle.

Empty running

The empty running of a transport vehicle is a ratio that indicates what proportion of travelled distance a vehicle is not carrying cargo. This is also referred to as 'lost' kilometres. For each trip, this can be calculated using Equation (5):

$$Empty\ Running\ (\%) = \frac{Distance_{empty}}{Distance_{total}} \tag{5}$$

where Empty Running (%) is the empty running for the trip, $Distance_{empty}$ is the total distance travelled empty (km) during the trip, and $Distance_{total}$ is the total distance travelled. Note that the $Distance_{loaded}$ in milk runs is conceptually the same as in regular trips.

3.6. Report results

The results of this research are discussed in Section 5 of this paper.

4. ANALYSIS

Analysing the collected data is undeniably one of the project's most challenging and important steps. Understanding how a vehicle travels, and relating this to the collected data from Step 3, is more complex than it might seem. The easiest method to analyse and understand the data is to illustrate a vehicle's movement visually, as shown in Figure 3. A visual representation of a vehicle's movement provides more insight into the route travelled, the delivery and collection locations, and points of interest such as depots, fuel stations, and wash bays. Figure 3 shows the movement of a single truck for a month, during which several trips across South Africa were made. From Figure 3, it is evident that the particular asset travelled mostly in and around Cape Town and between Cape Town and Pretoria. It also completed two trips to Durban, one to East London, and one to Limpopo. All of the other vehicles' trips were analysed similarly.

The visual representation of asset movements helped to identify the standard format of a 'trip'. This identification would have been overlooked if a visual analysis had not been performed. All trips follow the process shown in Figure 4, independent of the type of product in the tanker, customer, or delivery location. Starting at a depot, a fully fuelled truck with a clean tanker travels to the point of collection. Here the tanker is filled with cargo and then it travels to the delivery location. After offloading the cargo at the delivery location, the truck and empty trailer return to a depot to be washed and refuelled before the next trip starts. Washing the tanker after each load is essential, since the cargo is food products, and strict sanitary protocols are followed to avoid the contamination of food products.

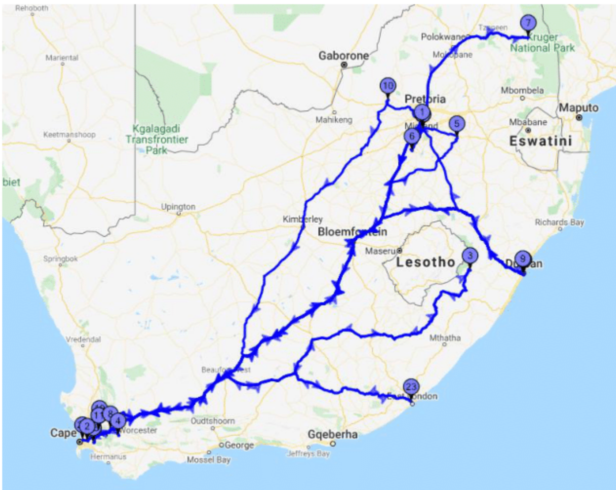


Figure 3: Typical monthly movement of a Company X vehicle

The only exception to the operational process described in Figure 4 was if the type of product allowed for repeat loads without washing the tanker. None of the analysed trips, however, fell into this exception category. The movement to and from a depot is typically empty, while the movements between other points of interest are loaded. For Company X, a 'new' trip begins when a vehicle visits a depot, its fuel tank is filled, and the tanker compartments are washed.

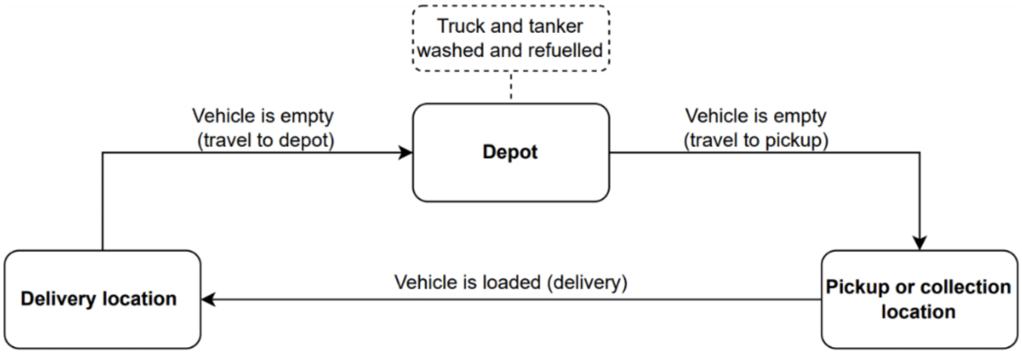


Figure 4: The operational process of a Company X trip

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This identification of the operational process allowed the researchers to split each trip and its associated data into different segments, as shown in Figure 5. This trip segmentation is a prerequisite to performing the calculations in Section 3.5. From Figure 5, it can be seen that two different distances were used: the total trip distance from the TMS or the vehicle telematics system, and a Google Maps distance between the collection and delivery locations. The total trip distance was determined by aggregating the distance values between two timestamps (departure and arrival date and time) in the TMS and the vehicle telematics system. The maximum distance between the TMS and the vehicle telematics system was selected as the total trip distance. The Google Maps distance was calculated, assuming that trucks follow the shortest feasible road distance between the collection and delivery locations. Both distances validated each other, since the Google Maps distance should have been shorter than the total distance obtained from either the TMS or the vehicle telematics system.

A visual analysis also validated the timestamps, since the movement of a vehicle needed to correlate with these timestamps. In addition, geolocations indicated whether a vehicle was stationary or moving. This helped to identify and explain instances where a vehicle was parked at a depot or was waiting to be loaded or offloaded. Using geolocations and timestamps ensured that each trip was correctly divided in to loaded or empty sections, according to Figure 5. The equations stated in Section 3.5 were then applied to each trip to calculate an EIF for that trip.

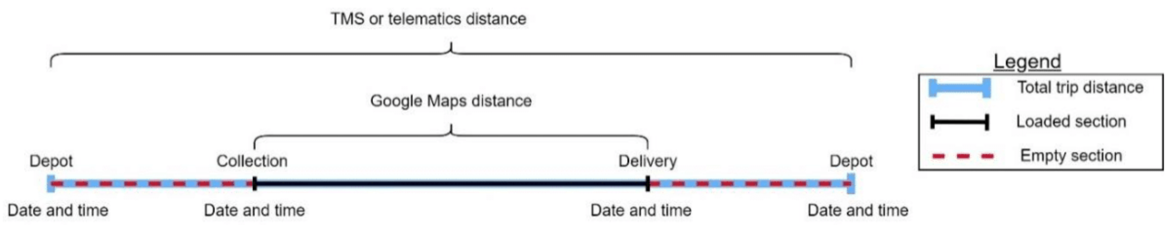


Figure 5: Segmentation of trips and the associated data source for the distance

Since the EIF is calculated based on the loaded kilometres (tonne-km), segmenting trips into loaded and empty segments is vital. In addition, calculating the percentage of the empty running or 'lost' kilometres of a trip requires that trips be segmented accordingly. Using the described analysis process, 134 trips, of which six were milk runs, were analysed. A summary of the dataset is shown in Table 2, from which it is evident that a significant amount of cargo (3879 t) was transported by the eight vehicles in 134 trips. It is important to note that more than half of the total travel distance was empty. This could be ascribed to the dedicated equipment type used for bulk liquid transport that cannot be used for other purposes.

Table 2: An overview of the analysed data

Total weight moved (t)	3 879
Total distance (km)	336 199
Total empty distance (km)	178 412
Route most often travelled	Paarl to Springs
Total fuel used (ℓ)	163 624
Average number of trips per truck in a month	17
Average trip duration (days)	2.59 days

5. RESULTS

The results of the paper are discussed in three sections. The first section discusses the entire dataset, while Section 5.2 gives the results based on specific routes (N1, N2, N3, and N3-N5-N1). The third section, Section 5.3, assesses the results of specific origin-destination city pairs.

5.1. Entire dataset

Table 3 states the average EIF for the entire dataset, calculated according to the US EPA's SmartWay methodology [9]. The total tonne-kilometre value in Table 3 is the sum of each trip's tonne-kilometre value. From this tonne-kilometre value, it is evident that a significant amount of freight was shifted in the three-month analysis period. It is also notable that the 134 trips consumed over 163 kℓ of diesel, resulting in about 507 t of CO_2e emissions. The basis for results in Table 3 indicates the empty running and loading profile for the entire dataset. In total, 53.1% of all vehicle kilometres travelled were empty or 'lost' kilometres. In addition, if a vehicle was carrying a load, the truck was only loaded to 68.7% of its possible 36 t payload capacity. On average, if Company X moves a tonne of cargo a kilometre, 0.130 kg CO_2e is emitted.

This value is 106% greater than the GLEC framework factors for Europe and South America, and 69% greater than the GLEC's proposed factor for Africa, which has a conservative load factor of 60% and an empty running value of 17%.

Table 3: Emission intensity factor for the entire dataset of 134 trips

Total tonne-kilometre value (t-km)	Total fuel used (ℓ)	Basis for results		Emission intensity factor (kg CO_2e/t-km)
		Percentage empty running	Percentage load factor	
3 901 946	163 624	53.1%	68.7%	0.130

Analysing the data in Section 4 revealed that Company X's vehicles were often repositioned empty between trips to a different depot. The emissions from inter-depot repositioning cannot be allocated to trips carrying cargo, since this would penalise some customers while others would be advantaged. Thus an empty running EIF (kg CO_2e/km) was also derived for Company X's fleet, as shown in Table 4. According to Table 4, an empty truck emits 1.19 kg CO_2e per kilometre travelled. Note that the unit of the empty running EIF is only distance-based (km travelled).

Table 4: Emission intensity factor for the empty travel of vehicles

Total distance (km)	Total weight (ton)	Total fuel	Basis for results		Empty running emission intensity factor (kg CO_2e/t-km)
			Percentage empty running	Percentage load factor	
19906.90	0	7627.96	100%	0%	1.19

After the average EIF for both loaded and empty travel had been determined, all trips were assessed to identify how the empty running and the load factor of the vehicle affected the EIF. The EIF was plotted against each trip's empty running and load factor, as indicated in Figures 6 and 7. Note that the yellow square values in Figures 6 and 7 indicate outliers according to the 1.5 interquartile rule. These outlier values were omitted from Table 3's results or any other results in the paper, since they would have skewed the results disproportionally. These trips could be described as special cases with low load factors to avoid instances of completely empty repositioning.

Analysing the results in Figure 6 revealed a positive correlation between the EIF and the percentage of empty running, as shown by the trendline in Figure 6. This means that, as the proportion of distance travelled empty increases, the EIF also increases. The opposite is true for a vehicle's load factor and EIF, as indicated by the trendline in Figure 7. As the load factor increases, the EIF decreases, indicating a negative correlation. This means that the emissions from a trip do not increase in proportion to the vehicle load.

Apart from displaying the calculated EIF, Figures 6 and 7 also show the results compared with the proposed GLEC factors. The proposed GLEC EIF of 0.080 kg CO_2e/t-km (horizontal green line) shows that a significant number of data values lie above the suggested factor. The same applies to the adjusted EIF (red horizontal line), which indicates the 22% that was added to account for the GLEC's proposed African operational conditions.

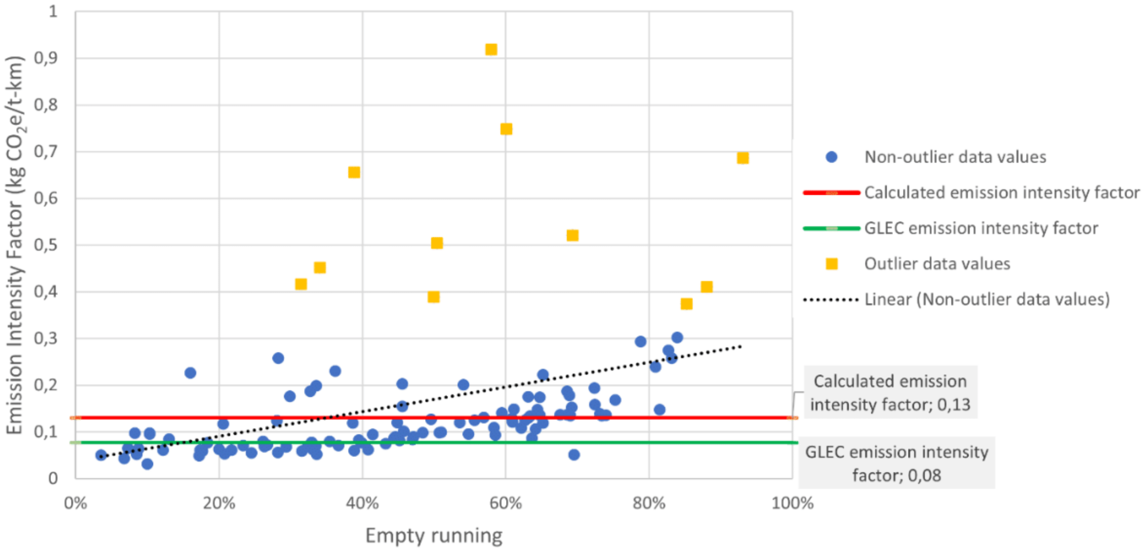


Figure 6: The relationship between empty running and the EIF

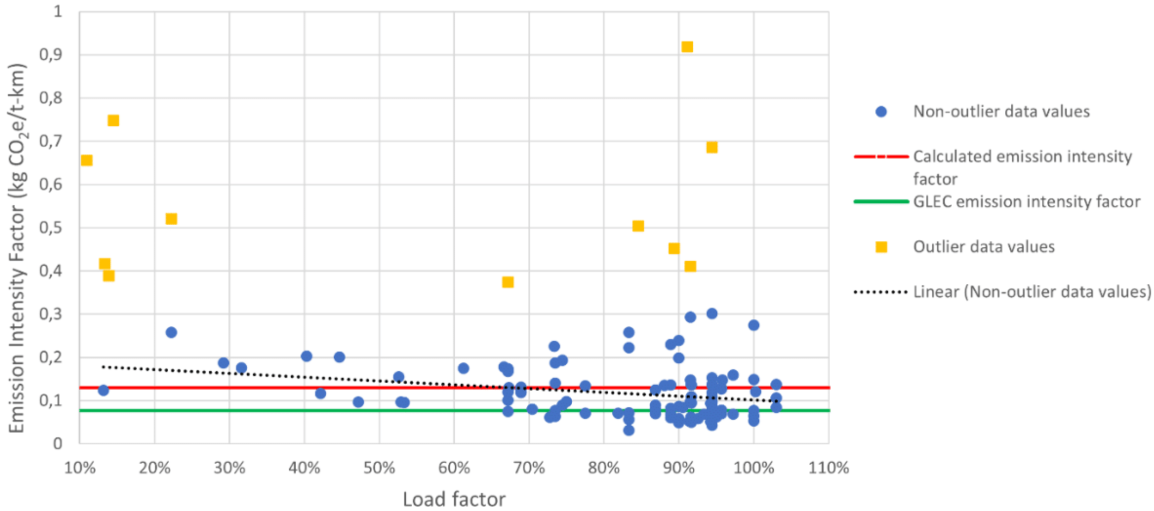
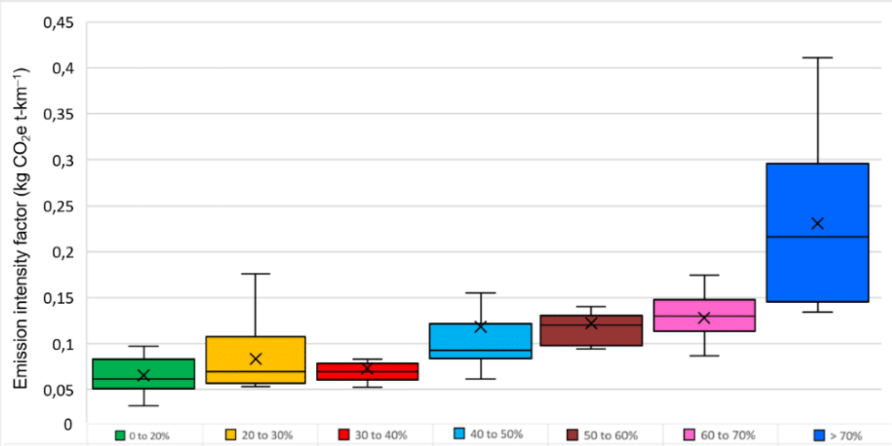


Figure 7: The relationship between the load factor and the EIF

From Figures 6 and 7, it is evident that the number of trips assessed needs to be increased significantly to provide more reliable results. The EIFs in these two figures are far apart, and further analysis of additional trips should be used to determine whether these points are representative.

It is also clear from Figures 6 and 7 that the empty running of a vehicle has a more significant impact than the load factor of the vehicle. Subsequently, Figure 8 was developed to investigate the impact of different empty running intervals. Figure 8 shows a box-and-whisker plot for each interval of empty running and a data table indicating the average, minimum, and maximum EIFs in the range. Two important observations are made from Figure 8: as the empty running interval increases, so does the EIF; and the smaller interquartile range of the box-and-whisker diagram, the more consistent the results are.



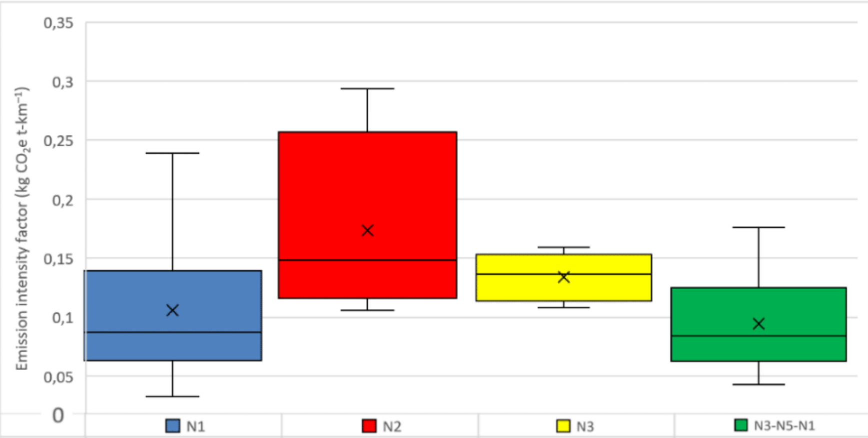
	0 to 20%	20 to 30%	30 to 40%	40 to 50%	50 to 60%	60 to 70%	> 70%
Average	0,07	0,08	0,07	0,12	0,12	0,13	0,23
Minimum	0,03	0,05	0,05	0,06	0,09	0,05	0,13
Maximum	0,10	0,18	0,12	0,39	0,20	0,17	0,41

Figure 8: The emission intensity factor for various intervals of empty running

5.2. Route-based

The second type of analysis is based on the intuition that the EIF is linked to the route travelled. Every route is different in respect of the elevation gain, the average traffic conditions or congestion, and the waiting or idle time at weighbridges and in urban areas. Thus the dataset of 134 trips was assessed to identify which trips travelled specifically on national roadways. Only national roadways needed assessment, since Section 4's analysis showed that Company X's vehicles prefer national roadways (N-routes) instead of secondary roadways (R-routes). The results of the route-based analysis are shown in Figure 9. Also, note the data table in the figure that states each route's average, minimum, and maximum EIF. Company X's vehicles predominantly travel four routes: the N1, the N2, the N3, and a combination of the N3-N5-N1 from Durban to Cape Town. The results in Figure 9 assessed bi-directional origin-destination trips on the routes, meaning that trips in both directions were assessed.

The box-and-whisker diagram in Figure 9 shows that each route has a sizeable interquartile range, except for the N3, which has a smaller variation. Despite the variation, it is clear that there is a difference in the average EIF between the different routes. All routes, however, require that more trips be accessed to increase confidence in the results.

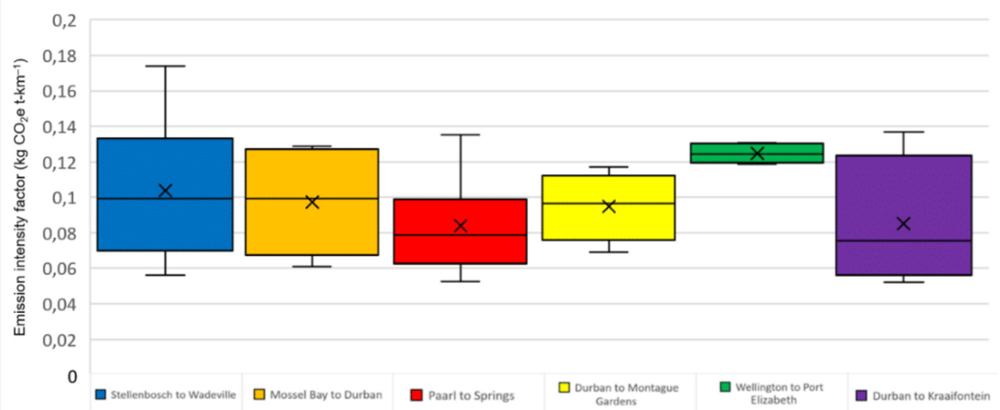


	N1	N2	N3	N3-N5-N1
Average	0,11	0,17	0,13	0,09
Minimum	0,24	0,11	0,11	0,04
Maximum	0,03	0,29	0,16	0,18

Figure 9: Emission intensity factor according to the routes travelled

5.3. Origin-destination pairs

The origin-destination pairs analyse the trips of Company X's clients between specific cities. This differs from the route-based results, since the origin and destination locations are more refined, which intuitively would give more consistent results. From Figure 10, it is clear that there is still a significant variation in the EIF, even though the same origin-destination pairs were assessed. The exception is trips from Wellington to Port Elizabeth, which have more consistent results. All other origin-destination pairs require more assessment, since the range of results is quite large.



	Stellenbosch to Wadeville	Mossel Bay to Durban	Paarl to Springs	Durban to Montague Gardens	Wellington to Port Elizabeth	Durban to Kraaifontein
Average	0,10	0,10	0,08	0,09	0,12	0,09
Minimum	0,06	0,06	0,05	0,07	0,12	0,05
Maximum	0,17	0,13	0,14	0,12	0,13	0,14

Figure 10: Emission intensity factor for various origin-destination locations

6. CONCLUSION

This paper established an EIF for a road-freight transporter, Company X, that transports bulk liquids in South Africa. The project assessed eight trucks' logistical activity and movement for three months, during which 134 trips were completed. The results revealed that, on average, if Company X moves a tonne of cargo a kilometre, 0.130 kg CO_2e is emitted. This factor enables Company X to determine how much is emitted by a typical shipment, and allows for internal benchmarking to gauge progress in reducing emissions. Although not for tankers specifically, the EIF of 0.130 kg CO_2e/t-km is 106% greater than the GLEC framework's factor for Europe and South America, and 69% greater than the GLEC's proposed factor for Africa, which has a similar load factor but a lower percentage of empty running. It is evident that the generic EIF in the GLEC framework significantly underestimates the emissions, and that more detailed EIFs should be stated in the GLEC framework or other literature sources.

The tanker industry is unique in the road-freight sector, since tankers must be cleaned after each trip. This is particularly relevant for Company X, since they transport food products, for which strict sanitary protocols apply. The cleaning requirement led to an empty running or 'lost' kilometres of 53.1%, meaning that more than half of the total distance travelled was unladen. If Company X wishes to reduce its emissions, the percentage of empty running must be reduced dramatically. However, this requires a financial investment either to create more depots at strategic locations or to outsource the cleaning of tankers to companies near the delivery or collection locations, which might not be financially feasible.

From the analysis, it was also evident that, in Company X's case, empty running has a larger impact on the EIF than the load factor. As a result, the impact of empty running on the EIF was assessed for various routes and origin-destination pairs. Although Sections 5.1 and 5.2 show the potential of a route and origin-destination assessment, a more extensive dataset is required to provide more consistent and trustworthy results. The authors advise Company X to use the EIF stated in Figure 8. If the empty running value is unknown, the average conservative EIF of 0.130 kg CO_2e/t-km must be used.

This paper shows that the road-freight sector is very carbon-intensive. If South Africa wants to achieve its ambitious emission reduction goals, a radical transformation is required. Furthermore, decarbonising the road-freight sector would require substantial investments in driver training, newer vehicle technology, lower carbon fuels, aerodynamic fixtures, lightweight trailers, and similar aspects. Road-freight companies should also optimise their route planning to limit a vehicle's empty travel. A combination of investment and route optimisation is essential to increase the efficiency of transport activity, which would reduce emissions. With rising fuel prices, road-freight companies should come to understand the importance of streamlining business operations, potentially leading to a reduction in emissions. The potential of a modal shift to a less carbon-intensive mode such as rail transport should also not be ruled out. Although rail is not suitable for the type of commodity analysed in this paper, other bulk commodities such as coal and ore are ideal candidates for rail transport.

Significant future work is required in the road-freight industry - not only in terms of a standard emission estimation methodology, but also concerning the data collection and analysis process. Data collection is a big challenge if a company's departments function in 'silos', leading to challenges in identifying related trip data. Further, the analysis process is tedious; so it is hoped that organisations could collect data in the future during the business process or by identifying collective datasets related to trips. This would avoid a 'post-mortem' of multiple extensive datasets to understand the movement of vehicles and the associated data.

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5.1.2 Published article: "Calculating Fuel Usage and Emissions for Refrigerated Road Transport using Real-World Data"

This subsection presents a journal article in the journal *Transportation Research Part D: Transport and the Environment*. The journal article[11] analysed 147 long-distance trips during which nearly 200 000 km were travelled, 3 693 tonnes of cargo was moved, and 84 588 ℓ of diesel fuel were consumed. In addition to transportation, 23 250 hours of refrigeration data were assessed to establish the average fuel consumption of refrigeration during road transportation. This article is the first known assessment of actual real-world LSP data analysing how refrigerated heavy goods vehicles consume fuel and produce emissions on a transport service level. The article ultimately enables researchers and LSPs to accurately determine a transport service's expected fuel use and emissions. This contradicts current literature that extrapolates theoretical data to estimate real-world fuel consumption and emissions of road freight vehicles and transport services. The ground-breaking methodology developed for the article also paves the way for easier data collection and assessment of similar projects in the future. The LSP has already indicated that they are interested in expanding the research across their fleet to assess other types of vehicles since environmental sustainability is becoming increasingly important for their business.

The journal *Transportation Research Part D: Transport and the Environment* was selected since it aims to publish articles that assess the environmental impact of transportation. In addition, the journal focuses on the policy implications and managerial responses associated with transportation systems, which align with the research project's overall aim. The article is available at (https://doi.org/10.1016/j.trd.2023.103623), but is under a two-year embargo until 2025, whereafter the article becomes open-access.

[11] The article was co-authored by du Plessis, M., van Eeden, J., Goedhals-Gerber, L. and Else, J., (2022). See Appendix B, Section B4 for a formal declaration of author contributions as required for publications included in dissertations by Stellenbosch University.

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5.1.3 Recommended factors

According to the researcher and Interviewee B, C and D (see Section 3.2), all road transportation vehicles that convey fresh fruit can be grouped into one of two categories – trucks that transport "small" volumes of fruit over "short distances" and trucks that transport "bulk" volumes of fruit over "long distances". The exact definitions of "small", "short distances", "bulk", and "long distances" are debatable, but the intended conceptual difference is clear. Trucks that move fruit regionally are generally rigid and transport a few pallets of fruit from a packhouse to a nearby cold store or an airport of export. These trucks are generally smaller and not refrigerated – however, refrigeration is possible in some cases. Trucks that move fruit over longer distances are typically larger articulated vehicles and transport several pallets (20+) or a reefer container. The exception to this long-distance movement is trucks carrying reefer containers. These trucks can either travel long or short distances to and from a maritime port. Larger trucks are generally refrigerated, but some unrefrigerated combinations are possible. Apart from this reefer container truck exception, the following is evident – smaller trucks travel short distances while larger trucks travel longer distances.

Despite the difference in vehicle size, transport distance, use of refrigeration, and payload capacity, the **load factor**[12] is usually high (80–90%) on all fully loaded shipments of both categories of road transport vehicles. This recommended load factor was determined from industry data collected as part of the journal article in Section 5.1.2. The only exception to the latter load factor is blueberry shipments, which have an average load factor of 40–60% (based on LSP data). All fresh fruit, except for blueberries, is generally a heavy commodity, and with the increasing use of high-cube pallets, the load factor is unlikely to decrease. Based on the LSP data in the journal article in Section 5.1.2, it can be assumed with a high confidence level that the load factor of trucks transporting full loads of any fresh fruit (except blueberries) will be approximately 85%. As for blueberry shipments, an average load factor of 55% is representative of export shipments.

As for the **empty running** of the two categories of road transport vehicles, there is a big difference. Smaller trucks transporting fruit over short distances generally have a higher empty running (approximately 45%). Finding a return load for these smaller dedicated vehicles that only travel a short distance to and from remote production regions is not possible due to the imbalance of freight flows. In comparison, trucks travelling long distances via economic hubs such as Gauteng (Havenga, 2020) have a far lower empty running (approximately 5 to 10%, according to the article in Section 5.1.2 and industry data analysed). Due to the proximity of maritime ports to other industries that require freight movement to inland regions and the significant travel distance to these inland regions, long-haul trucks will almost always have a proportionally low empty running. Furthermore, due to the small profit margin in the road freight industry, transporters will always try to source a return load for the repositioning journey of long-haul vehicles. However, trucks transporting reefer containers or trucks travelling to remote production regions are exceptions to this low empty running percentage.

Nevertheless, it is reasonable to state that smaller trucks travelling short distances are prone to a higher empty running of approximately 45%, while long-distance trucks generally have an empty running of nearly 10%. Trucks transporting containers or reefer semi-trucks repositioning to remote production regions such as the Orange River region in the Northern Cape can, however, have an empty running value as high as 50% in some cases.

[12] The author acknowledges that the load weight depends on the type of commodity, fruit size, packaging, pallet size, and the number of pallets in the shipment.

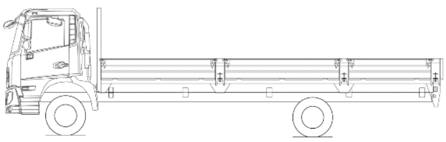
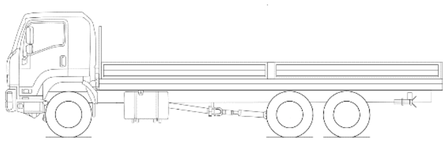
Table 5.1 was developed for the different types of road transport vehicles used in SA to transport fruit destined for export based on the above discussion, the detailed data analysis performed for each of the journal articles in Sections 5.1.1 and 5.1.2, industry input from two LSPs and fruit export stakeholders, and TruckScience data. Table 5.1 indicates an emission intensity factor for dry and refrigerated transportation for each type of vehicle. The suggested emission intensity factor reflects the fruit export industry's realistic operating conditions, such as the type of vehicle, configuration, load (pallets or a reefer container), load factor, empty running, and refrigeration.

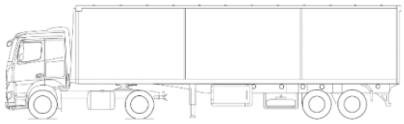
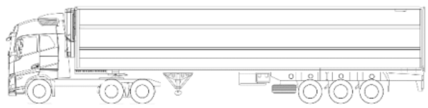
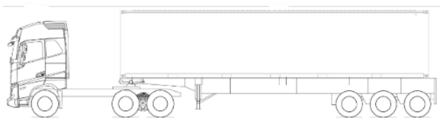
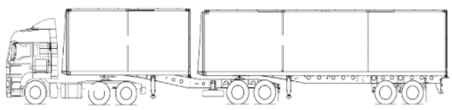
Two methods were used to determine or calculate emission intensity factors for the road transportation of fresh fruit. The emission intensity factors for all articulated vehicles in Table 5.1 were developed using the methodology and formulae reported in the two journal articles in Sections 5.1.1 and 5.1.2, and the real-world data of actual fresh fruit shipments collected from LSPs. However, due to data limitations, the emission intensity factors for the two rigid road trucks in Table 5.1 were calculated using the *EcoTransIT World Emission Calculator*. This route was deemed appropriate since the relative contribution of these vehicles' emissions toward the total carbon footprint of a shipment is small. In addition, this method is similar to the Smart Freight Centre (2019) process used in the GLEC framework to suggest intensity factors for European and South American road transportation.

Note that the refrigerated emission intensity factor for standard interlink tautliners in Table 5.1 is purposefully left blank. Table 5.1 also indicates the gross vehicle mass (GVM) or gross combination mass (GCM) and the payload to aid users in identifying a vehicle class more easily when choosing an emission intensity factor.

The emission intensity factors in Table 5.1 are the first South African emission intensity factors developed for the road freight industry. Furthermore, to the best of the authors' knowledge, these emission intensity factors for articulated vehicles are the first international factors developed from actual industry data.

Table 5.1: Recommended emission intensity factors for road transportation

Vehicle description	**Description of factor**			**Emission intensity factor ($g\ CO_2e/t\text{-}km$)**	
	Load type	**Empty Running**	**Load factor**	**Dry**	**Refrigerated**
 4x2 Rigid (GVM:±14 t, max payload: ±8 t)	Pallets	45%	55%	150	171
			85%	107	128
 6x4 Rigid (GVM:±24 t, max payload:±15 t)	Pallets	45%	55%	121	143
			85%	86	100

Vehicle description	Description of factor			Emission intensity factor (g CO_2e/t-km)	
	Load type	Empty Running	Load factor	Dry	Refrigerated
 4x2 truck tractor and tandem semi-trailer (GCM: ±34 t, max payload: ±15 t)	Pallets	10%	55%	174	184
			85%	116	122
 6x4 truck tractor and tridem semi-trailer (GVM: ±49.5 t, max payload: ±32 t)	Pallets	10%	55%	87	91
			85%	59	62
		50%	55%	148	157
			85%	99	105
 6x4 truck tractor and tridem semi-trailer loaded with 40-foot reefer container (GCM: ±49 t, max payload excl. container: ±28 t)	Container	10%	55%	98	103
			85%	66	70
		50%	55%	168	173
			85%	112	115
 Standard interlink tautliner - 6x4 truck tractor with tandem-tandem trailer (GCM: ±56 t, max payload: ±36 t)	Pallets	10%	55%	99	-
			85%	67	-

Source: developed by the author. Diagrams used with permission from TruckScience.

5.2 Rail transportation

The process of establishing an emission intensity factor for rail transport in SA is discussed across two sections. Section 5.2.1 elaborates on the difficulty of sourcing primary data from Transnet Freight Rail (TFR) and subsequently attempts to determine a national average emission intensity factor for rail using publicly available data and a top-down approach. In Section 5.2.2, primary data from a pilot project and the EcoTransIT calculator is used to calculate an emission intensity factor for transporting reefer containers. Finally, Section 5.2.3 states the recommended factors that should be used in the carbon mapping framework.

5.2.1 A factor for Transnet Freight Rail

Establishing a meaningful emission intensity factor for rail container transport using TFR data is not currently possible. According to a source with in-depth knowledge of the various data systems and types of data collected by TFR, two systems are used – *Systems Management* and *Sprint.*

Systems Management is a management-orientated system used for financial and operation control purposes, while the database called *Sprint* potentially contains the necessary trip level data to calculate an emission intensity factor. Repeated requests to TFR were unsuccessful in gaining access to *Sprint* data. However, even if access could be obtained to *Sprint* data, the source believes that the required fuel or electricity consumption data on a trip level is not available in *Sprint* since Transnet has limited visibility due to data collection limitations at this level of detail.

The source concludes by stating: "*I think it is impossible to get detail from Transnet of how much diesel was used in any sort of detail split, and especially impossible for one single train movement*".

Due to this correspondence, the primary researcher opted to use a top-down approach to calculate an emission intensity factor for TFR to gauge the carbon intensity of rail transport in SA. This is achieved by using publicly available information in Transnet's Integrated Reports and data from the FDM™. The integrated reports (Transnet, 2019; Transnet, 2020) state either the total diesel or electricity used by TFR or the total emissions values for Transnet, as shown in Table 5.2. The two integrated reports also provide detail that enables the primary researcher to determine the proportional contribution of TFR to the total emissions of Transnet. This can be used to derive the total CO_2e emissions of TFR for each financial year. The total CO_2e emissions are then divided by the corresponding tonne-kilometres value sourced from the FDM™. Table 5.2 shows that the emission intensity factor for rail transport in SA ranges between 19.56 to 22.09 g CO_2e/t-km.

Table 5.2: Estimated emission intensity factor for TFR

	Financial year		
	2018	**2019**	**2020**
TFR diesel consumption (Mℓ)	-	-	167,99
TFR electricity usage (GWh)	-	-	2214,78
Total Transnet emissions (Mt CO_2e)	4,00	3,78	-
Percentage contribution by TFR	80%	74%	-
Total TFR CO_2e emission (Mt CO_2e)	3,20	2,80	2,69[13]
Total tonne-km moved (Gt-km)	144,86	143,00	126,89
Emission intensity factor (g CO_2e/t-km)	22,1	19,6	21,2

Source: Calculated using FDM™ data and (Transnet, 2019; Transnet, 2020).

The calculated factors in Table 5.2 are realistic when compared to North American and European diesel rail, which have an emission intensity of 16 and 28 g CO2e/t-km, respectively (Smart Freight Centre, 2019). In addition to being comparable to other countries' emission intensity factors, the factors and process summarised in Table 5.2 were validated by Simpson (2022). It should, however, be noted that a few dedicated rail corridors, such as the Sishen-Saldanha line (iron ore) and the coal export lines to Richards Bay, significantly reduce the average emission intensity of the

[13] Calculated using a fuel emission factor of 3.24 kg CO_2e/ℓ diesel and a grid electricity emission factor of 0.97 kg CO_2e/kWh. See Section 4.2 for a detailed discussion of these factor choices.

calculated factor since these lines are highly efficient and export a significant volume of dry bulk mining goods. According to the author, the calculated factors in Table 5.2 cannot be used for this research project since they do not accurately reflect rail container transport in SA.

Another perceived source of a potential emission intensity factor for rail transport is the *Transnet Freight Rail Carbon Calculator* application. On 13 August 2015, Transnet spokesperson Mboniso Sigonyela issued a statement on behalf of Transnet, which indicated that a carbon calculator app would be launched for its rail services (van Wyngaardt, 2015). The app would allow users to calculate the emissions per shipment by selecting an origin-destination pair, a commodity type (dry-bulk or containers), shipment weight, and the traction type (electric or diesel). The application was developed by the Johannesburg Centre for Software Engineering (JCSE), based at the University of the Witwatersrand. Unfortunately, private communication with Transnet personnel involved in the project revealed that the calculator was never launched in the public domain, and no records exist of the calculator's use. Subsequent communication, however, revealed that the developers used European emission intensity factors in the application, meaning the application would be of little to no value for the research project.

5.2.2 A factor derived from pilot project data

A multinational LSP, which owns and operates an extensive fleet of logistical assets, conducted a feasibility study for container rail transportation in SA in 2019 and 2020. In the pilot study shown in Figure 5.1, reefer containers filled with citrus were loaded at the Musina Intermodal Terminal and transported to the Port of Durban. This section uses this pilot project’s logistical data (load weights, configuration, time duration, etc.) as input to determine an emission intensity factor.

Figure 5.1: The pilot rail project where reefer containers were transported (Source: LSP)

Unfortunately, the author could not obtain primary fuel data from the LSP for the locomotive and onboard genset used to power the integral reefer containers during transport. Subsequently, the pilot study’s logistical data is used in conjunction with the *EcoTransIT World Emission Calculator* to calculate an emission intensity factor. Note that the factor developed in this section is explicitly for diesel traction since electric traction is not available on all railway lines. In addition, the carbon intensity of SA grid electricity is significantly higher than in other countries (see Section 4.2), resulting in the *EcoTransIT Emission Calculator* not being usable for electric traction in SA.

According to the LSP, a container train consists of various sections shown in Figure 5.2. Each train comprises a diesel locomotive, a caboose for staff accommodation, 37 railway carriages loaded with FEU integral reefer containers, a 10 000 ℓ diesel fuel cell carriage, And a 500 kVA Caterpillar genset carriage. Each reefer container was loaded with 20 high-cube citrus pallets (1.2 tonnes per pallet), resulting in a combined weight of 24 tonnes of cargo per reefer container. The total weight of the train combination (excluding the locomotive) shown in Figure 5.2 is 1 757 tonnes.

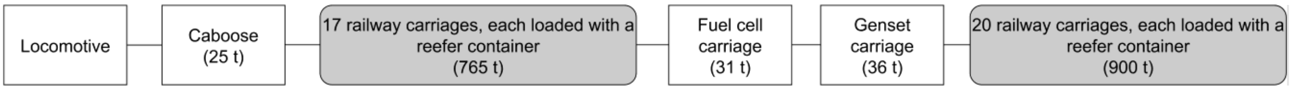


Figure 5.2: Train configuration of the pilot project and the associated weight of each train section.

In terms of the method of operation, empty reefer containers are collected from the Port of Durban, whereafter the train travels to Musina Intermodal Terminal. This means the train has an empty running of 50% since half of the travelled distance is without cargo. Regarding the load factor, the EcoTransIT World (2020) methodology states that the load factor should be based on the maximum load capacity of the container. Assuming that a FEU high-cube reefer container has a payload capacity of 29.5 tonnes results in an approximate load factor of 80%. Finally, according to the LSP, the average time duration from loading to arrival in the Port of Durban was three days and four hours (76 hours).

The logistical data of the pilot project was then used as input in the *EcoTransIT World Emission Calculator* to establish a "dry or ambient" emission intensity factor for transporting containers by diesel rail. This results in a "dry" emission intensity factor of 19.4 g CO_2e/t-km, which excludes the effect of refrigeration. Based on the trip duration of 76 hours and an average load factor of 50% On the 500kVA genset (55.3 ℓ/hr fuel consumption) results in an emission intensity factor for refrigeration of 12.1 g CO_2e/t-km.

This results in an overall emission intensity factor for refrigerated rail container transport of 31.5 g CO_2e/t-km.

5.2.3 Recommended factor

Based on the results and discussion in Sections 5.2.1 and 5.2.2, the author recommends the emission intensity factor shown in Table 5.3 for refrigerated rail transportation of reefer containers. The suggested factor is based on the best current data that reflects the real-world operating conditions of transporting fresh fruit via reefer containers.

Table 5.3: Recommended emission intensity factor for rail transport

Traction type	Load factor	Empty running	Emission intensity (g CO_2e/t-km)
Diesel	80%	50%	31,5

5.3 Deep-sea ocean transportation

Accurate emission intensity factors for deep-sea transport are important since the activity proportionally contributes the most towards the total carbon footprint of fresh fruit distribution. Also, Section 3.5 stated that almost all fruit exported from SA (>99%) uses the mode as main carriage. Section 5.3.1 suggests emission intensity factors for transportation via container vessels, while Section 5.3.2 discusses a factor for conventional reefer vessels calculated from industry data.

5.3.1 Container vessels

Efforts were made to collect data from a large international shipping line that serves various SA ports. Unfortunately, the shipping line's South African office politely declined to participate in the research. Subsequently, the researcher contacted Prof. Alan McKinnon to enquire if access to the Clean Cargo Working Group (CCWG) data could be obtained. Approximately 85% of the global container vessel capacity reports vessel fuel consumption and logistical data to the CCWG. However, this changed in January 2022, after 18 years, when the CCWG was integrated into the Smart Freight Centre (SFC). Due to this transfer and the sensitive nature of the data, no data sharing with external sources will occur in the near-foreseeable future according to private correspondence with Dan Smith, Program Director of the SFC. The decision by SFC not to share data is deemed essential for the long-term relationship between all parties and the future of the SFC. However, the SFC did not rule out the possibility of sharing data in a few years to develop emission intensity factors specifically for SA and other ports en route to the country.

Until data sharing becomes a reality, the author recommends and uses the emission intensity factors in the *2021 Global Ocean Container Greenhouse Gas Emission Intensities* document (Smart Freight Centre, 2021). The suggested factors are based on 3 737 container vessels owned by 18 carriers, collectively responsible for nearly 78% of global ocean container freight in 2021. Emission intensity factors for both dry and reefer container transportation are suggested for various global trade lanes. The emission intensity factor assumes that vessels operated at 70% capacity utilisation.

Two emission intensity factors for each trade lane or route are suggested in Table 5.4 for container vessels. The first emission intensity factor should be used when shipping a reefer container filled with fruit in one direction. This assumes the reefer container does not return empty to SA. The second factor is the emission intensity factor for shipping a refrigerated container in one direction and returning the empty container to SA. The factors were defined this way to reduce the overall complexity of the carbon mapping framework (see Section 7.1 for more). Note that the unit of container vessel emission intensity factors is g CO_2e/TEU-km and not g CO_2e/t-km as with other transport modes. A conversion from TEU-km to t-km is not possible or recommended, primarily due to the lack of visibility of the contents of the containers.

As with other modes, the transport vehicle's size considerably impacts the emission intensity factor. According to private correspondence with the SFC, the average TEU capacity of vessels not travelling to and from Africa is 5 790 TEUs. However, the capacity of vessels servicing African ports is 3 402 TEUs – nearly 41.2% smaller than other trade routes. This inevitably results in deep-sea container transport in African countries being more carbon-intensive than in other regions.

Table 5.4: Recommended emission intensity factor for container vessels

Trade lane or route	Emission intensity factor ($g\ CO_2e/TEU\text{-}km$)	
	Refrigerated container in one direction (filled with fruit)	Refrigerated (filled with fruit) in one direction and empty return
Africa to-from Asia	155,4	243,1
Africa to-from Europe	174,0	276,2
Africa to-from North America (East Coast/Gulf/West Coast)	193,5	327,7
Intra-Africa	233,0	368,2
Other (only used when origin-destination pair is not listed)	179,2	285,9

Adapted from (Smart Freight Centre, 2021)

5.3.2 Conventional reefer vessels

The assessment and subsequent results are based on data collected from an international shipping line (Company R) that owns and operates a fleet of more than 30 reefer vessels. The data allows the primary researcher to establish how reefer vessels are operated and determine the carbon intensity of transporting fresh fruit by reefer vessels. The remainder of this section provides an overview of the collected data, the employed methodology, results and a discussion thereof, and a recommended emission intensity factor for shipping fresh fruit via reefer vessels. According to the author, this is the first known publicly available emission intensity factor for reefer vessels.

5.3.2.1 Overview of data

After extensive discussions to explain the context and purpose of the envisaged research, Company R agreed to participate in the research on condition of remaining anonymous. A data-sharing agreement was set up, and data was shared with the author. The dataset consisted of 25 fresh fruit shipments, all departing from the Port of Cape Town. Sixteen of the trips were performed in 2021, representing 50% of all the export shipments of fresh fruit from the Port of Cape Town by reefer vessel that year (according to Agrihub dataset). The remaining nine trips were for the year 2020. In total, the 25 analysed trips transported 130 thousand tonnes of fresh fruit, travelled a total distance of 236 thousand nautical miles (437 thousand km) and consumed 34 540 tonnes of fuel. The analysed trips represent approximately 3.6% of the total tonnes of fresh fruit exported from South Africa during the 2020/2021 season.

An example of one of the 25 trips' data that was shared is shown in Table 5.5. Each trip consists of several port and sea segments, of which the location is indicated by the United Nations Code for Trade and Transport Locations (UN/LOCODE). For each segment, the gross cargo weight (metric tonnes), distance in nautical miles (NM), time duration (hrs), and fuel usage (metric tonnes) of each engine for different fuel types were provided. Regarding the different engines in Table 5.5, M/E refers to the main engine used for the vessels' propulsion, while A/E is the auxiliary engine used for purposes other than propulsion, such as electricity generation for all on-board equipment and the refrigeration system. The boiler, on the contrary, produces steam and hot water for heating and processing loads. According to Company R, this relates to all vessel engines. With regard to fuel type, all three engines used marine grade oil (MGO), very low sulphur fuel oil (VLSFO) with a maximum sulphur content of 0.5%, or ultra-low sulphur fuel oil (ULSFO) with a maximum sulphur content of 0.1%. Note that the choice of fuel is affected by price, availability, and maritime fuel and emissions regulations, and subsequently, all three fuels were used interchangeably across all engines.

Table 5.5: Example of a reefer vessel trip data

Trip segment	Port/Sea	Cargo [mt]	Distance [NM]	Duration (hrs)	M/E VLSFO [mt]	M/E ULSFO [mt]	M/E MGO [mt]	A/E VLSFO [mt]	A/E ULSFO [mt]	A/E MGO [mt]	Boiler VLSFO [mt]	Boiler ULSFO [mt]	Boiler MGO [mt]
ZRMAT - ZACPT	Sea	0	1868	118	72,1	0	0,4	10,6	0	0	0	0	0
ZACPT	Port	0	0	271	0	0	0,6	37	0	0	4,5	0	0
ZACPT - USGLC	Sea	3438	6820	496	320,9	0	10,3	98,9	0	5,4	0	0	0
USGLC	Port	0	0	69	0	0	3,1	0	0	10,7	0	0	0,7

Thirteen different reefer vessels were analysed in the 25 trips. The average overall length of the 13 vessels is approximately 146 m, while the average beam of vessels is nearly 21.4 m wide. The average international gross tonnage (GT) of the analysed vessels is 9 448 t, the net tonnage (NT) is 4 877 t, while the winter deadweight tonnage (DWT) is 10 475 t. Finally, the average age of the analysed fleet is 28.8 years, with the newest vessel having been built in 2000.

The various ports and routes travelled during the 25 trips are visually depicted in Figure 5.3. Alternatively, click on this link to view Figure 5.3 in more detail on Google Maps. All trips start in the Port of Matadi, Democratic Republic of Congo, where cargo is discharged from the vessel. No data prior to this port was given. The unladen vessel travels to the Port of Cape Town in SA, where loading commences in the break-bulk terminal. Each vessel is loaded with between 3 400 and 5 100 tonnes of fruit, depending on the vessel's capacity. After loading the reefer vessel with standard pallets (pallet height of approximately 2.1 m and an average weight of nearly 1 t according to Agrihub data), the vessel departs to either the Port of Gloucester or the Port of Philadelphia in the United States of America (USA). Alternatively, the vessel performed a milk run en route to the USA, where 190 and 230 tonnes of fruit were discharged in Senegal or Ghana. After this, the vessel departs to the USA, where the remaining cargo is discharged.

Figure 5.3: Visualisation of the analysed reefer vessel trips displaying the various ports and routes

5.3.2.2 Methodological aspects

The assessment was performed according to EN 16258, which states how a transport service's energy consumption and WTW (in this case, the Well-to-Wake) emissions should be calculated for the operational phase of the vehicle.

In line with EN 16258 and the GLEC framework, the most appropriate and recent fuel emission factors from a published document were used in the assessment. Conservative fuel emission factors for medium-speed marine engines were sourced from Comer and Osipova (2021), associated with the International Council on Clean Transport. For VLSFO and ULSFO, a 100-year Well-to-Wake factor of 4.392 g CO_2e/g fuel was used, while for MGO, a factor of 4.237 g CO_2e/g fuel was used.

The most challenging aspect of the reefer vessel analysis was determining the load factor at the start of each trip. Unfortunately, this is a common problem for all types of transport vehicles (Santén & Rogerson, 2018); however, the author believes that this is especially true for maritime vessels. The average load factor of the 25 trips was required for comparison, future research and benchmarking purposes. In addition, the load factor is needed to ensure that an emission intensity factor is not incorrectly chosen when calculating the emissions of vessels transporting heavier or lighter cargo.

Determining a vessel's weight and payload capacity is complex and ambiguous since this changes according to the density of water sailed in. In addition, the maximum permissible draft of ports and canals (Panama or Suez Canal) also dictates vessels' weight and payload. Furthermore, the average sea conditions and seasonality also affect a vessel's weight and carrying capacity. Fortunately, detailed tonnage (GT and NT) and weight (DWT) information of the 13 vessels could be retrieved from Company R. The detailed payload information incorporates all the above-mentioned aspects.

Using the GT or NT of a vessel to determine the load factor is erroneous since both are dimensionless metrics that refer to the moulded volume or enclosed cargo space of a ship (U.S Department of Transportation, 2008). The DWT (also referred to as deadweight tonnes or deadweight carrying capacity), however, states a vessel's maximum weight carrying capacity. The DWT value includes the weight of all stores, crew, cargo, ballast water, fresh water, and fuel (School of Shipping, 2002). Subsequently, the winter DWT was used as a vessel's maximum weight carrying capacity. This is aligned with both the GLEC framework and the EcoTransIT World methodology. The author is of the opinion that the lower, conservative winter DWT value is most appropriate for Atlantic sea conditions.

However, using the winter DWT as a vessel's maximum weight carrying capacity requires that the “payload weight” be adapted to incorporate the weight of fuel, crew, stores, ballast water, and fresh water. Unfortunately, detailed data for the crew weight, stores, ballast water, fresh water, and total fuel weight at the start of the journey could not be obtained. Nevertheless, the following assumptions were made, and a load factor at the start of the trip was calculated:

- The load factor represents how heavily a vessel is loaded compared to the winter DWT when departing from the Port of Cape Town, SA.
- “payload weight” refers to the weight of all fuels consumed during the trip and the weight of cargo loaded;
- The weight of ballast water, fresh water, crew, and stores are negligible;

Note that the assumptions made to calculate a load factor do not affect the emission intensity factor of the assessment. The remaining part of the analysis was far less ambiguous, as shown in the below sections.

5.3.2.3 Assessment results and discussion

An analysis of the type and weight of fuel used by each engine is shown in Figure 5.4. This figure shows that the M/E of vessels consumes approximately 72.7% of the total fuel by weight. Further, 89.2% of all fuel consumed is VLSFO, the majority of which is used by the M/E. Despite the lower sulphur content and subsequent lower particulate matter (PM) emissions, ULSFO is rarely used (trips 5, 17, and 22). Finally, it is noteworthy that each trip consumes nearly 612.2 tonnes of fuel on average. Also, note that the boilers consume only a small portion of the total amount of fuel used during each trip.

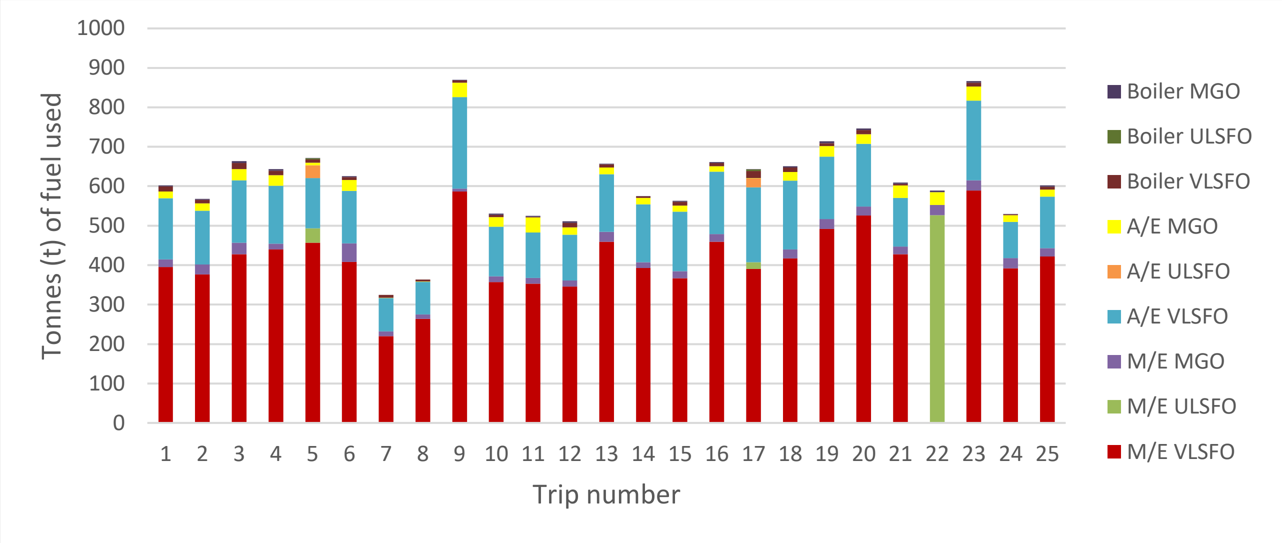


Figure 5.4: A breakdown of the total weight and type of fuel used by each engine in the 25 reefer vessel trips

The effect of empty running (%) on the emission intensity factor (g CO_2e/t-km) is indicated in Figure 5.5, showing that the 25 trips have an average empty running of nearly 22%. This is due to all trips travelling empty from the Port of Matadi to the Port of Cape Town. Subsequently, the two milk run trips to the US via Ghana and Senegal were divided into parts to assess a different empty running percentage. From the four created milk run trips in Figure 5.5, a lower empty running value results in a smaller emission intensity factor. However, this positive correlation is untrue for the original 25 trips since the same empty running percentage has various emission intensities. The author believes this is due to a combination of each vessel's characteristics and the effect of a varying load factor.

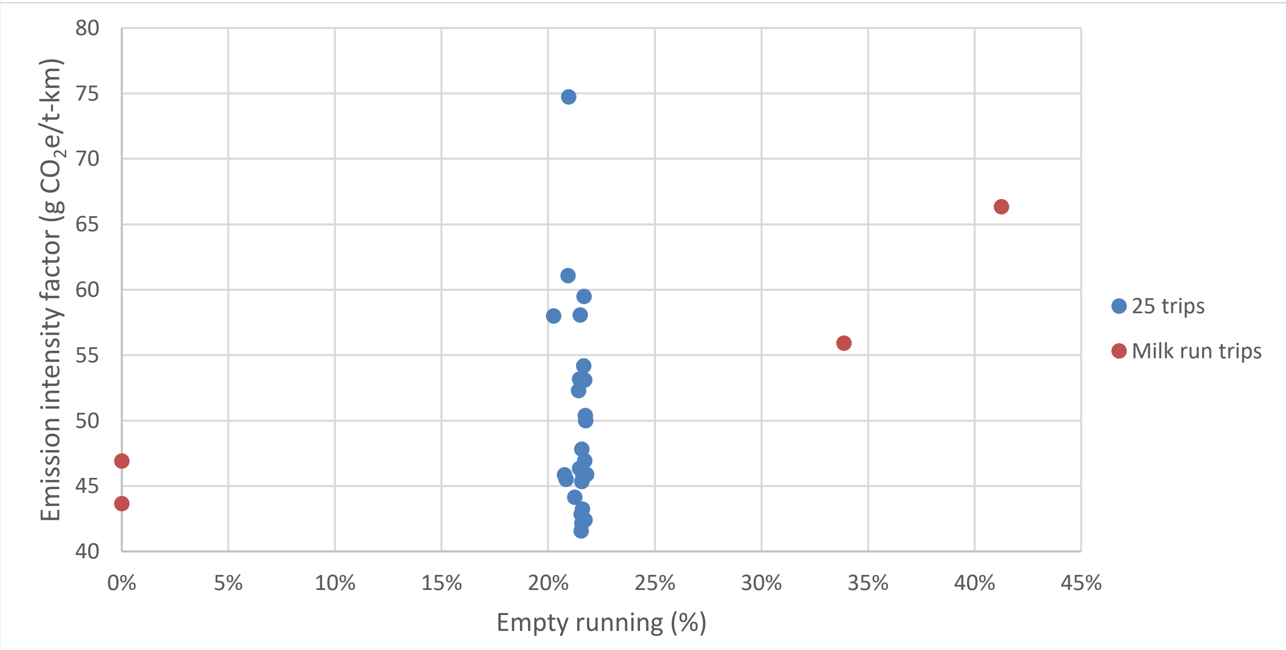


Figure 5.5: The relationship between empty running and emission intensity factor of reefer vessels

Figure 5.6 plots the load factor versus the emission intensity factor of the 25 original trips and four created milk runs. The figure shows a negative linear correlation between the load and emission intensity factors, confirming the logic that the lighter a vehicle is loaded, the less cargo there is to divide emissions amongst. Figure 5.6 is, however, misleading since the calculated correlation is -0.165, meaning there is no correlation in the analysed dataset. Despite this, the primary researcher believes the correlation between a vessel's load factor and emission intensity factors is greater. However, a larger sample size of vessels transporting different types and weights of cargo will be required to confirm this hypothesis.

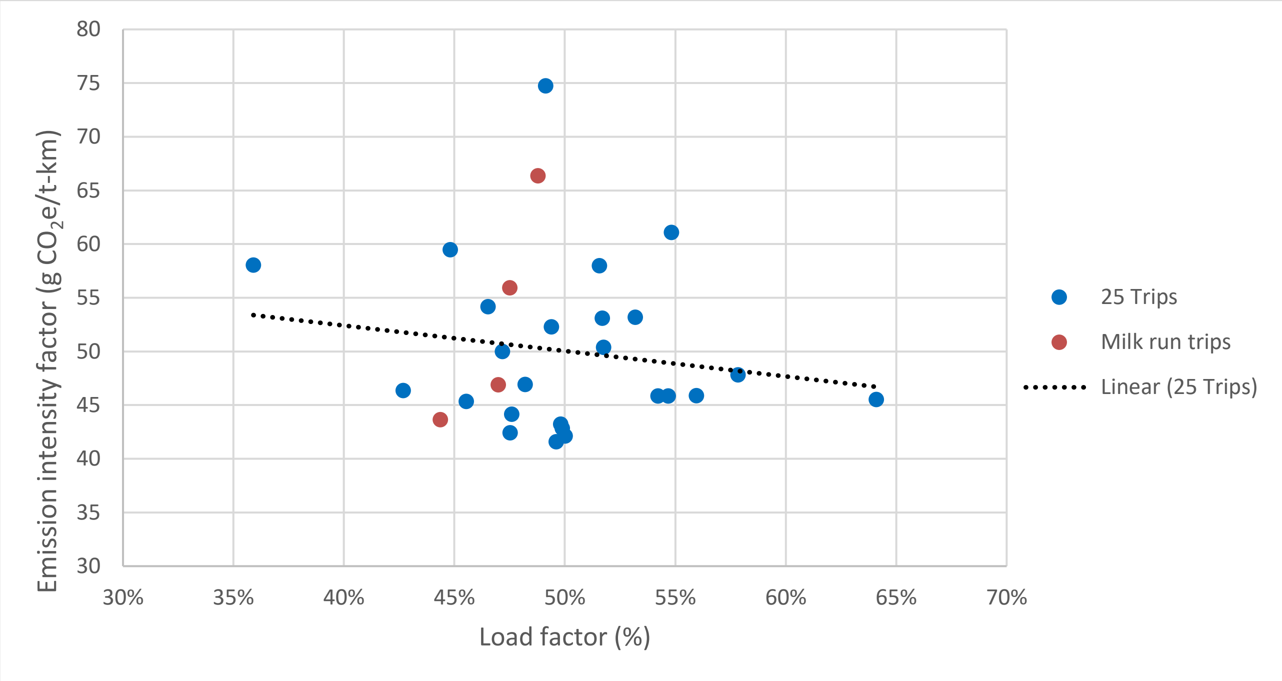


Figure 5.6: The effect of load factor on the emission intensity factor of reefer vessels

Attempts were also made to assess refrigeration and transportation separately to determine the proportional contribution of each to the overall emission intensity factor (g CO_2e/t-km) of a reefer vessel. This assessment, however, assumes that non-propulsion engines (A/E and boiler) are used exclusively for refrigeration, while the M/E is used for the vessel's propulsion (transportation). However, the sensitivity of this assumption cannot be determined since Company R does not have data on a more detailed level that can confirm or deny that the refrigeration system consumes the majority of generated electricity. Assuming that non-propulsion engines are used exclusively for refrigeration, 28% of the emissions result directly from refrigeration to maintain the cold chain requirements, as shown in Figure 5.7. The remaining 72% of the emissions are due to the propulsion system required to move the vessel (transportation).

Regarding the shipment weight, there is no clear evidence from the 23 trips in Figure 5.7 that a larger shipment size (tonnes of fruit) increases or decreases the proportional contribution of transportation or refrigeration to the emission intensity factor. Note that the milk run trips (trips 7 and 8) were omitted from Figure 5.7 since they are not comparable. Further, the primary researcher believes that trip 22’s A/E and boiler data were incomplete.

Since refrigeration’s total energy consumption and subsequent emissions are a function of time, the impact of trip duration was also investigated. The average duration for a trip departing from the Port of Matadi, loading in the Port of Cape Town, and arriving in the US, is 908 hrs (37.8 days), with a standard deviation of 83 hrs or 3.5 days. Note that this includes the duration of all activities in a port and the sailing time. Considering that a trip takes 38 days to complete, a standard deviation of 3.5 days on 23 trips is relatively small. Based on this premise, dividing the emission intensity factor for a reefer vessel into a “dry or ambient transportation” and a “refrigeration” component adds additional complexity that is not required. If there is, however, a significant difference in the time duration of future trips, the splitting of refrigeration and transportation will be a requirement to increase the accuracy of emissions intensity factors.

Apart from the load factor and empty running, a vessel's average cruising speed can significantly impact the emission intensity factor. Slow-steaming (a deliberate reduction in the average cruising speed of a vessel) lowers a vessel's fuel consumption, ultimately reducing the emission intensity. However, the impact of a longer refrigeration period due to slow steaming can potentially cancel out the gain. The average cruising speed where diminishing emissions reduction occurs can be calculated from the data, but a larger small sample size would be required for any confidence in the calculated results. Subsequently, the researcher refrains from recommending a change in the vessel speed to decrease the overall emissions.

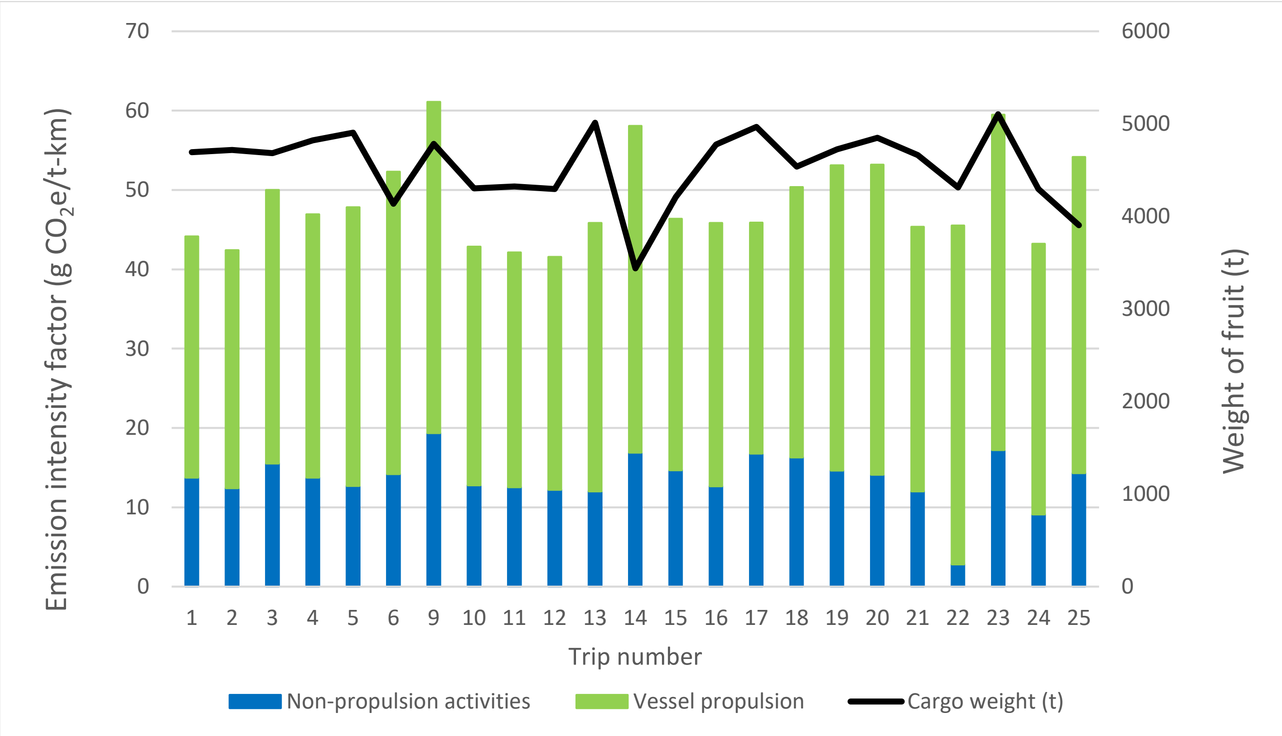


Figure 5.7: The proportional contribution of propulsion and non-propulsion activities (refrigeration) to the emission intensity factor of reefer vessels

A comparison of the calculated emission intensity of transporting cargo under ambient conditions to the GLEC frameworks is shown in Figure 5.8. According to the Smart Freight Centre (2019), the emission intensity factor for a general cargo vessel with a DWT smaller than 10 000 t is 21 g CO_2e/t-km. Despite having a similar DWT (DWT of 10 475 t), the ambient emission intensity factor for the analysed trips is 35 g CO_2e/t-km – 66% higher than the GLEC value. However, the difference in empty running and load factor percentages should be noted, proving the importance of considering these elements. It should also be noted that ambient transport results are conservative since the potential contribution of the A/E and boiler could increase this value – even if there is no refrigeration.

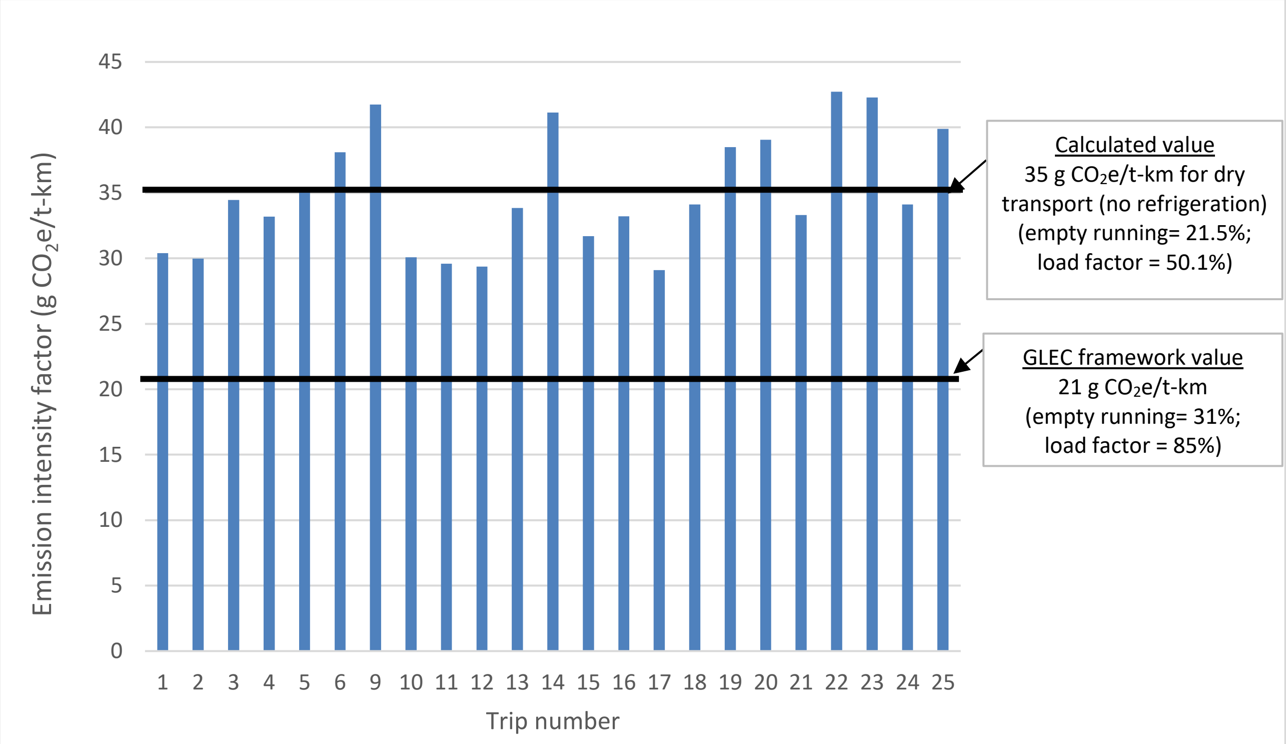


Figure 5.8 A comparison of the emission intensity of ambient transportation via reefer vessel to the GLEC framework values

5.3.2.4 Recommended factor

Based on the assessment results and discussion in Section 5.3.2.3, the emission intensity factor in Table 5.6 should be used when distributing fresh fruit via reefer vessel. The suggested factor should be used for all routes and vessel sizes.

Table 5.6: Recommended emission intensity factors for deep-sea transportation by reefer vessel

Vessel size	Load description	Description of factor		Emission intensity factor (g CO_2e/t-km)
		Load factor	Empty running	
DWT of 10 475 t	Pallets of fresh fruit	50%	21,5%	48,6

5.4 Air transportation

Air transportation is not only the most expensive mode of carriage but also the most carbon-intensive mode. Fortunately, a significantly small portion (<1%) of the total volume of fruit exported from SA is transported via air transport. To estimate an emission intensity factor, the primary researcher sourced primary data from a commercial pilot with 20 years of experience at a national commercial carrier and an additional 22 years of flight experience as a test pilot for new commercial aircraft. A second commercial pilot with 18 years of flying experience for the same national carrier was asked to validate the provided flight data. The data represent the average fuel consumption and loaded weight of two models of combi-aircraft[14] (Airbus 340-300 and Airbus 330-300) performing direct flights between OR Tambo International Airport in SA and Heathrow International Airport in the UK. The collected data in Table 5.7 enabled the primary researcher to calculate an emission intensity factor for transcontinental flights from SA.

Table 5.7 shows that a one-way flight between SA and the UK consumes between approximately 63 t and 75 t of fuel, producing nearly 245 t and 292 t of emission. These fuel consumption and emission values were validated using the *Eurocontrol Small emitters tool*. The specific aircraft and flight data result in an emission intensity factor of 639 to 713 g CO_2e/t-km, which is in the range of the GLEC framework's suggested values.

Table 5.7: Calculated[15] emission intensity factor for air transportation

	Airbus 340-300	**Airbus 330-300**
Combined weight of cargo and passengers (kg)	49 900	37 400
Empty plane weight (kg)	129 000	121 870
Max landing weight (kg)	192 000	187 000
Load factor (%)	93,18%	85,17%
Fuel used (kg)	75 200	63 300
Total flight emissions (kg CO_2e)	291 776	245 604
Approximate flight distance (km)	9 145	9 210
Emission intensity factor (g CO_2e/t-km)	**639**,**4**	**713**,**0**

Source: calculated from collected data.

Unfortunately, determining an emission intensity factor for air transportation is more challenging than the assessment presented in Table 5.7 due to the effect of high-altitude combustion of aviation fuel. According to the IPCC and SFC, GHG emissions produced at high altitudes (typical cruising altitude of 8 to 12 km) react differently from those produced at lower levels. This emission of gases at a higher altitude results in the same gases having a larger Global Warming Potential (GWP).

Due to the combined effect of high-altitude combustion, the small sample size collected from the two pilots, and the small proportion of fruit exported using the mode, the primary researcher uses and recommends the higher “conservative” emission intensity factors stated in the GLEC framework, as shown in Table 5.8. Three possible planes can be used – a combination or combi aircraft, a dedicated freight aircraft, and a third class if the aircraft type is unknown. The third type of aircraft should only be selected if there is uncertainty regarding the aircraft type. The factors in Table 5.8 are based on the EN 16258:2012 methodology and assume a load factor of 70% for

[14] Aircraft that carry both passengers and cargo. Also referred to as belly freighters or hybrid aircraft.

[15] Calculated using a fuel emission factor of 3.88 kg CO_2e/kg aviation gas as stated in the GLEC framework (Smart Freight Centre, 2019). Also, note that the load factor is based on the maximum landing weight of the aircraft.

freight and 80% for passengers. The results in Table 5.7 validate that the recommended emission intensity factors in Table 5.8 are indeed realistic and potentially applicable to South African conditions.

Table 5.8: Recommended emission intensity factor for air transport

Type of aircraft	Emission intensity factor (g CO_2e/t-km)
Combi	990
Freighter	560
Unknown	800

Source: GLEC framework (Smart Freight Centre, 2019).

5.5 Conclusion

The purpose of this chapter was to identify, assess, calculate or establish emission intensity factors (**RO1d** and **RO5**) for the various modes of transport by which fresh fruit is exported from SA. The emission intensity factors in this chapter were developed specifically for the SA fruit export industry and, therefore, reflect the industry's real-world operating and logistical conditions. These emission intensity factors are novel since they are the first of their kind in SA and the world that are focused on a specific refrigerated commodity.

Section 5.1 suggested emission intensity factors for the various types of road transport vehicles that are commonly used in SA. This is the first and only publicly known research into emission intensity factors for SA road freight vehicles. The section also stated two published journal articles (**RO6**). These journal articles are novel and present ground-breaking research results in the road-freight industry.

This is followed by Section 5.2, which calculated an emission intensity factor for the rail transportation of fresh fruit via reefer containers. Emission intensity factors for the deep-sea transportation of fresh fruit via container vessels and conventional reefer vessels was discussed in Section 5.3. The section presented the first known assessment of conventional reefer vessels to establish an emission intensity factor. The last and final section of the chapter established a factor for the transport of fresh fruit via air transport.

As part of the conclusion to the chapter, Table 5.9 summarises the availability and suitability of the various modes' emission intensity factors found in literature. The table also indicates if a factor was derived or calculated explicitly for the project and the confidence level of the various recommended emission intensity factors.

Table 5.9: Summative assessment of transportation modes' emission intensity factors

<table>
<tr><th colspan="2"></th><th>Factors available in literature</th><th>Suitability of factors in literature</th><th>Factors calculated or derived from primary data in this project</th><th>Confidence level in recommended emission intensity factor</th></tr>
<tr><td colspan="6"><u>Transportation</u></td></tr>
<tr><td rowspan="5">Transportation mode</td><td>Road transport</td><td>Yes</td><td>Does not reflect SA road freight conditions</td><td>Yes</td><td>High</td></tr>
<tr><td>Rail transport</td><td>Yes</td><td>Factors (especially electric traction) are unsuitable since train configuration is not comparable to SA conditions. Refrigeration emissions are grossly underestimated.</td><td>Yes</td><td>Medium</td></tr>
<tr><td rowspan="2">Deep-sea transport</td><td>Container vessel – yes</td><td>Factors are appropriate.</td><td>No</td><td>High</td></tr>
<tr><td>Reefer vessel – no</td><td>No factors in literature.</td><td>Yes</td><td>High</td></tr>
<tr><td>Air transport</td><td>Yes</td><td>Factors potentially overestimate emissions.</td><td>Yes</td><td>Medium</td></tr>
</table>

The emission intensity factors for the four modes of transport in this chapter form an essential part of the carbon mapping framework in Chapter 7 and are critical for the overall success of the research project. It should, however, be noted that various opportunities exist for further research to narrow down the emission intensity factors for the different modes of transport analysed. The next chapter ventures into the emission intensity factors of fresh fruit handling and storage at the various types of logistical facilities.

6. Emission intensity factors for logistical facilities

This chapter forms part of **Part IV** of the dissertation document. The chapter suggests emission intensity factors for the various logistical facilities or sites that handle and store pallets of fruit and reefer containers. This chapter addresses the following research objectives:

RO1: To conduct a thorough literature review in order to:

(d) *Identify* and *assess* existing emission intensity factors relevant to fresh fruit distribution.

RO5: *Establish* and *calculate* emission intensity factors associated with each activity defined in RO2.

RO6: *Verify* and *validate* the emission intensity factors calculated during the project.

As an antecedent to the emission intensity factors of the logistical facilities, Section 6.1 states the importance of a fundamental shift in how the emissions of refrigerated products are calculated. This section is also important since it provides a rationale and understanding of the factors stated in the rest of the chapter.

Section 6.2 discusses the logistical facilities that handle and store pallets of fruit as a functional unit. The section consists of a published peer-reviewed journal article that establishes an emission intensity factor (kg CO_2e pallet-day^{-1}) for storing pallets of fruit in cold stores. This article is the first known emission assessment of fresh fruit storage on a commercial scale. The section also suggests emission intensity factors for a maritime break-bulk terminal and an airport facility where fruit is briefly handled and stored as part of the distribution process of pallets.

Section 6.3 suggests emission intensity factors for all the facilities or sites that handle and store reefer containers as functional units.

6.1 A shift in methodology to assess logistical facility emissions

Factors for logistical facilities or sites should ideally consist of two parts: an emission intensity factor for the physical handling at a facility, and a second emission intensity factor for the storage duration in or at the facility.

This separation is necessary since refrigerated products' emissions are a function of the storage duration. If fresh fruit required no refrigeration, as is the case with cargo that can be transported at ambient temperatures, the separation of handling and storage would not have been necessary since the storage would consume no energy and, therefore, emit no emissions. A separate factor is also required since reefer containers can move through a facility without being stored. Handling empty containers in the distribution chain's reverse or upstream direction also requires a factor.

Furthermore, two separate emission intensity factors for logistical facilities are necessary to provide fair and accurate results since not all fruit is stored for the same duration. Hence, a metric allowing stakeholders to account for the storage duration independently of handling is appropriate and fundamentally necessary. Providing a separate factor for handling and storage will also avoid under- or overestimating the actual emissions since the assessment is based on the actual storage durations of a shipment instead of industry averages.

Current emission intensity factors for logistical facilities, such as the GLEC framework (Smart Freight Centre, 2019) and other logistical buildings (Dobers, Perotti & Fossa, 2022), fail to incorporate the time duration of storage, leading to a skewed or warped emissions value. This evident flaw in methodology is attributed to the infant stage of emission accounting at refrigerated logistical facilities and the perception that logistical facilities' emissions are negligible compared to the overall distribution chain emissions (McKinnon, 2018). The remainder of the chapter and the research project enables the epoch required to estimate refrigerated products' handling and storage emissions accurately and fairly.

6.2 Pallets

Three types of facilities can potentially handle and store pallets of fruit during the distribution process – an inland fruit facility or cold store, a break-bulk terminal in a maritime port, and an airport facility in the cargo terminal of an airport of export. Due to its location, each type of facility forms a node in a different distribution chain (see Section 3.3) and subsequently stores fruit for a different number of days. This difference in each facility's average storage duration (dwell days) significantly impacts the emission intensity factor. The remainder of the section discusses the factors for each of the three facilities.

6.2.1 Cold stores – a published article: "The Carbon Footprint of Fruit Storage: A Case Study of the Energy and Emission Intensity of Cold Stores"

This subsection presents a peer-reviewed article published in the journal '*Sustainability*'. The article[16] assessed the emissions of eight refrigerated facilities that collectively moved a total of 646 572 pallets of fresh fruit during 2020. Five of the largest facilities analysed represent 18.83% of the total fruit exported from SA during 2020. The assessment, therefore, has a relatively large sample size and is deemed representative of the cold storage sector. The article ultimately establishes that storing and handling fresh fruit is carbon intensive since each pallet stored translates to 7.52 kg CO_2e day^{-1}. This and other results in the article are fundamental for the carbon mapping framework (**Part V**) since the emissions of fruit storage and handling emissions cannot be established without this section. The developed research methodology in the article also sets a standard for future assessment of cold stores emissions since no such methodology currently exists that can provide guidance.

Sustainability is an open-access international, multidisciplinary, peer-reviewed scholarly journal focusing on technical studies relating to sustainability and sustainable development. The journal strives to publish research that supports the UN 2030 Sustainable Development Goals (SDGs). Since the journal's scope and aim align with the research project, the publication of this section of the dissertation supports the research project, researchers, and industry in assessing the emissions of fresh fruit storage in cold stores. The article is available at (https://doi.org/10.3390/su14137530) and is open access.

[16] The article was co-authored by du Plessis, M., van Eeden, J., and Goedhals-Gerber, L., (2022). See Appendix B, Section B5 for a formal declaration of author contributions as required for publications included in dissertations by Stellenbosch University.

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Article

The Carbon Footprint of Fruit Storage: A Case Study of the Energy and Emission Intensity of Cold Stores

Martin Johannes du Plessis [1,*], Joubert van Eeden [1] and Leila Louise Goedhals-Gerber [2]

1 Department of Industrial Engineering, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa; jveeden@sun.ac.za
2 Department of Logistics, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa; leila@sun.ac.za
* Correspondence: martinduplessis6@gmail.com

Abstract: Despite their importance in all transportation chains, logistical sites—and in particular refrigerated facilities—are the weakest link in current emissions literature. This is largely due to a lack of quantitative research that focuses on these facilities. This article is the first of its kind to assess the emissions of eight refrigerated facilities that handle and store fresh fruit. In 2020, the analyzed facilities moved a total of 646,572 pallets of fresh fruit and emitted 32,225 t of CO_2e. Five of the largest facilities were responsible for handling 18.83% of the total fresh fruit exported from South Africa during 2020. The results revealed that storing and handling a pallet of fruit in a large-scale commercial cold store requires 7.62 kWh of electricity per day. Storing and handling fresh fruit is carbon intensive since each pallet stored translates to 7.52 kg CO_2e d^{-1}. However, other factors such as the seasonality and volume of fruit handled, facility characteristics and the availability of solar electricity systems, among others, all have a significant impact on the emissions value of the facility and on the emission intensity per pallet moved through the facility.

Keywords: carbon footprint; cold chain; cold storage; decarbonization; GHG emissions; fresh fruits; refrigerated storage; South African fruit exports; sustainable supply chain

check for updates

Citation: du Plessis, M.J.; van Eeden, J.; Goedhals-Gerber, L.L. The Carbon Footprint of Fruit Storage: A Case Study of the Energy and Emission Intensity of Cold Stores. *Sustainability* **2022**, *14*, 7530. https://doi.org/10.3390/su14137530

Academic Editor: Vladimír Kočí

Received: 26 May 2022
Accepted: 11 June 2022
Published: 21 June 2022

1. Introduction

International trade was at an all-time high of USD28.5 trillion for 2021—an increase of 13% compared to pre-pandemic levels [1]. The global economy has evidently recovered to a large extent after the COVID-19 pandemic. Alongside this recovery is an automatic increase in freight logistics since the exchange of goods still represented 78.2% of the total global trade (USD22.3 trillion) during 2021 [1]. Freight logistics has been and will always be a vital part of the world economy because all supply chains depend on the movement of goods [2]. If GDP growth remains coupled with international freight flow, the International Transport Forums (ITF) project that by 2050, freight transport alone will have grown by a factor of 2.6 to 345 trillion t-km compared to 2015 [3].

In 2019, the transport sector as a whole was responsible for 8.2 Gt of CO_2 or 27% of all greenhouse gas (GHG) emissions [4]. After the industrial and building sectors, the transportation industry is the sector responsible for most global emissions. This is confirmed by Wang and Ge [5] from the World Resource Institute (WRI), who estimate that the transport sector as a whole emitted 24% of all emissions during 2016. Focusing on freight logistics specifically, road freight, ocean freight, rail freight, air freight, and logistics sites collectively emit approximately 5 to 5.5% of the total global GHG emissions [6,7]. Other authors, such as Rüdiger et al. [8], estimate that up to 7% of Germany's total GHG inventory for 2015 is due to freight logistics. Note the difference between freight transport (physical movement of cargo by various modes) and logistics, which includes both freight transport and activities at logistical sites such as warehouses, terminals, and ports. Higgins et al. [9] emphasize the importance and fundamental role of logistical sites in international, national and local transportation systems for the successful movement of goods. As international trade continues to grow, so does the demand for logistical facilities to handle, store or tranship the increasing volume of goods [10]. In addition, the expected growth in the transport sector [3] and events such as the COVID-19 pandemic, which disrupted the global supply chain to such an extent that global transit times increased by approximately 25% [11], means that even more logistical sites will be used and required in future.

In terms of the emissions of logistical sites, the World Economic Forum (WEF) estimates that logistical buildings contribute 13% of the total freight sector's emissions—equivalent to the air freight sector and the rail freight sector's emissions combined [6]. The extent of emissions from logistical facilities is confirmed by numerous sources in the literature. Authors such as Ries et al. [12] estimate that up to 20% of all freight logistics emissions in the USA could be as a result of warehouses alone. Rüdiger et al. [13] state that emissions from warehousing and transshipment facilities could be a quarter of the total emissions of the freight logistics sector. Rüdiger et al. [8] also estimate that nearly 15% of emissions from freight are a direct result of activities at logistical sites.

Although the importance of analyzing the emissions of logistical sites is evident, only limited quantitative research has been done in the field. The most notable is the emission intensity factors (emission intensity factors state the amount of emissions emitted per logistical unit when performing a specific activity and are measured as kg CO_2e per logistical metric such as t-km, TEU-km, t-moved, pallet-d, etc.) developed by Dobers, Perotti and Fossa [14] for the Fraunhofer Institute for Material Flow and Logistics (IML), which estimate the carbon intensity of moving goods through different types of logistical sites. See Section 1.2 for an exposition of available emission intensity factors for logistical sites. These emission intensity factors [14] are also used and recommended by the Global Logistics Emissions Council (GLEC) Framework [2]. The scarcity of any form of emissions data for facilities or sites at which goods are handled, stored, or transshipped is confirmed by McKinnon [15]. Several other authors [2,12,14,16–18] stress the importance and the valuable contribution of future research that is required for logistical facilities in this regard.

Various factors such as the design, technology, equipment, internal operations, and type of commodity influence a logistical facility's energy usage. Authors such as Lewczuk, Kłodawski, and Gepner [19] analyzed these factors to estimate a facility's energy usage and emissions. This type of analysis requires a bottom-up approach whereby the impact of the individual factors is assessed to determine the facility's total emissions. However, the article's focus is not to investigate how factors influence the emissions but rather to increase the visibility of the scale of emissions at these facilities. For this, a top-down approach is preferable since it assures that emissions are not over- or underestimated. A top-down approach makes fewer assumptions and inevitably ensures that the actual energy consumption and associated emissions are apportioned to the goods that moved through the facility. This article is the first known top-down analysis to determine the carbon footprint of fresh fruit storage and handling in cold stores.

1.1. Research Aims

This article aims to assess and quantify the following items by using data from several refrigerated logistical facilities that handle and store fresh fruit as a commodity:

1. Determine the total emissions of each analyzed facility (t CO_2e);
2. Calculate the average electricity consumption rate (kWh pallet-d^{-1}) of moving and storing a pallet in a facility for a day;
3. Determine an average emission intensity factor (kg CO_2e pallet-d^{-1}) for each facility to estimate the carbon intensity of fresh-fruit handling and storage at the facility.

1.2. Literature Review

1.2.1. Definition of Cold Stores

This article analyses warehouses and transshipment sites that handle two special classes of refrigerated goods, classified as fresh (4 °C to 7 °C) and sensitive (0 °C to

2 °C) [20]. The facilities analyzed in this article are purpose-built for the handling and storage of fresh fruit, but vegetables and dairy-related products are other examples of goods that fall in this "chilled" temperature range. However, the storage of fresh fruit is different from that of dairy and vegetables since some fresh fruit also requires a controlled atmosphere where the gaseous concentrations of oxygen, ozone, ethylene, water vapor, nitrogen, and carbon dioxide in the circulated air are regulated [21].

In the remainder of this article, warehouses and transshipment sites that specialize in the handling and storage of fresh fruit are referred to as cold stores. Du Plessis, Van Eeden and Goedhals-Gerber [22] refer to these cold stores as inland fruit facilities.

1.2.2. Calculating Emissions

The quantification of emissions is seemingly a straightforward process based on the actual or estimated amount of energy consumed by a facility. This energy consumption is then multiplied by an emission factor (emission factors are used to convert the amount of fuel and energy used to emissions and are measured as kg CO_2e per quantity such as ℓ, kWh, kg) to translate the energy consumed to emissions. In addition to energy, the effect of fugitive emissions is incorporated by assessing the refill values of refrigerants. The total emissions value (energy and refrigerants) is then apportioned among all the goods that have moved through a facility to estimate the emissions of one logistical unit. Refer to Section 3 for the equations required to quantify and apportion emissions.

The most suitable methodology to quantify emissions of a logistical facility is suggested by Dobers et al. [20]. This methodology aims to provide users with a generic step-by-step guide to assess and audit the carbon emissions of any type of logistical building for the purpose of calculating the emissions of a logistical chain. However, Dobers et al. [20] state that adjustments may be made to account for site-specific characteristics, such as the type and nature of the goods moved, to provide more meaningful results. The latter is, however, easier said than done, as explained in Section 2.1.

The methodology developed by Dobers et al. [20] is built on the emissions accounting principles of the internationally recognized GHG Protocol [23]. In addition, the methodology is endorsed by the GLEC Framework [2] and used as their methodology of choice for logistical sites. The analysis is aligned with a lifecycle approach to assess the total fuel lifecycle emissions, i.e., the well-to-wheel (WTW) emissions of all fuels. The assessment analyzes all relevant GHGs and then expresses the results in terms of carbon dioxide equivalent (CO_2e). Simply stated, CO_2e indicates the global-warming potential that a given substance has when compared to carbon dioxide.

1.2.3. The Allocation Problem and Dwell Days

The goods that move through a facility differ greatly due to differences in their weight and size, their varying refrigeration requirements and subsequent energy consumption, the time duration of storage, and handling requirements. This complicates how fuel, refrigerants, emissions or even costs are divided among goods. All the above-mentioned give rise to what is known as the allocation problem: how to ensure that emissions are apportioned in a fair and equitable manner among all goods.

In particular, the most important factor influencing the allocation in a refrigerated facility is the duration of storage. Subsequently, to apportion the emissions of a refrigerated facility fairly and accurately, the duration of storage, referred to as *dwell days*, must be accounted for. It is important to understand the effect dwell days have on the allocation of emissions. If the dwell days of a cold store were to be an average value of x days, it is assumed that all goods spend x days on average in the facility. When fuel, refrigerants or emissions are apportioned among the goods that have moved through the facility, the total values are divided by the product of dwell days and the number of goods moved through the facility (see Equations (3)–(5)). This means that all results in an assessment are a function of both the dwell days of goods in the facility and the throughput of the facility. The authors are of the opinion that this is the fairest and most accurate method of incorporating time as a variable in the assessment. This is contrary to current literature by authors such as Dobers et al. [20], Dobers and Perotti et al. [14], Iriarte et al. [24] and Smart Freight Centre [2], which does not account for dwell days at all.

1.2.4. Existing Emission Intensity Factors

The most comprehensive set of GHG emission intensity factors in literature was developed by Dobers and Perotti et al. [14] and entailed the assessment of 168 logistical sites in Europe. The analysis and results were conducted and reported on an annual basis and, therefore, disregard seasonality. All logistical sites were classified into three categories: facilities that transship ambient, chilled or mixed goods; facilities that store and transship ambient, chilled or mixed goods; and facilities that store ambient, chilled or mixed goods. It is interesting to note that the sample size of chilled facilities was a mere 18 sites in total and no reference was made to the type of refrigerated product, i.e., fresh, sensitive, pharmaceutical, or frozen. Furthermore, Dobers and Perotti et al. [14] mention that an average weight of 450 kg was assumed per pallet for ten facilities; however, they do not suggest a factor to convert between weight and pallets. The results of the assessment are shown in Table 1.

Table 1. Emission intensity factors for logistical sites from literature.

Type of Logistical Site	Ambient (kg CO_2e t^{-1})	Mixed (kg CO_2e t^{-1})	Chilled (kg CO_2e t^{-1})
Transshipment	3.4	3.8	11.1
Storage and transshipment	1.7	12.3	7.3
Warehouse (storage)	1.9	8.9	8.2

Adapted with permission from Dobers and Perotti et al. [14].

1.2.5. A South African Perspective

The growth in the global fresh-fruit export industry is unprecedented. Authors such as Du Plessis et al. [18] state that the industry will grow by 6% per annum on average. South Africa is no exception to this growth trajectory. The fresh-fruit export industry has grown by 11% from 2020 to 2021; this after a 10% growth during the previous year [25]. In addition, South Africa is the world's second-largest citrus exporter and the leading exporter of fresh fruit by volume in the southern hemisphere [26]. This rapid expansion, coupled with the scale of the industry, undoubtedly creates challenges.

Another perspective unique to South Africa is the source and availability of fuels such as electricity, LNG, and diesel. No distribution pipelines for LNG or diesel to the cold stores exist in South Africa. Eskom Holdings SOC Ltd. is the only power utility in South Africa and depends on coal for electricity generation. According to Eskom [27], 90.4% of all the electricity in 2020 was generated by coal-fired plants by burning 108.6 million t of coal. This makes South Africa's electricity the most carbon-intensive or "dirty" electricity in the world compared to peers [28]. Despite the environmental impact, coal will remain the primary source of energy in years to come due to the affordability compared to alternative energy sources, the economic contribution of the coal industry to the economy, and the role of employment [28].

Finally, South Africa is different from other countries due to the extreme vulnerability of the national electricity grid. Eskom's generation capacity is often not sufficient to meet the electricity demand, which is then lowered by removing regions from the national grid on a rotational basis. This concept is referred to as "loadshedding" and is, unfortunately, a common phenomenon in South Africa. During loadshedding, businesses and some households use diesel generators to supply electricity. This requires a significant financial investment and also leads to increased operational costs since electricity generated by diesel generators is more expensive than grid electricity.

1.3. The Role and Function of Cold Stores

Apart from connecting different elements in a transport chain to balance the efficient flow of goods, cold stores also perform several other functions:

- Storage of goods for short durations (less than 24 h) or extended periods (several days or months);
- Acting as a buffer in the fresh-fruit supply chain to ensure a constant supply to markets;
- Providing a link between various transportation modes such as road, air, rail and deep-sea transport;
- Temperature control and/or re-cooling of fruit to the optimal storage temperature;
- Cold sterilization of fruit to kill any pests, microbes or fungi in or on the fruit;
- Allowing producers or production regions to consolidate fruit loads to use transport modes more efficiently;
- Providing a link between a change in the functional unit of transport, e.g., from pallets to refrigerated (reefer) containers;
- Providing an inspection site for fruit to ensure compliance with phytosanitary requirements in the country of import.

Note that no repacking of fruit (except after inspection of samples), order picking, sorting, relabeling, or customization is performed at cold stores. The pallets of fruit, therefore, do not undergo any type of transformation when moving through a cold store and can be seen as a unit for the purpose of handling and emissions calculation.

2. Research Methodology

This research article uses the Fraunhofer Institute's Guide for greenhouse gas emissions accounting at logistical sites [20] as the base methodology. Section 2 deals with the key methodological aspects of the study. These include the general principles of assessment, which are discussed in Section 2.1. Section 2.2 explains how the base methodology was adjusted and which assumptions were made in the study. In Section 2.3 the boundaries of assessment are defined, while Section 2.4 elaborates on the data collection phase. Finally, Section 2.5 discusses how the collected data were assessed and prepared for calculation. The calculation phase is discussed in Section 3 while the analysis, interpretation and reporting of results are presented in Sections 4 and 5. Figure 1 provides a visual representation of the methodology used in the study.

2.1. General Principles of Assessment

In terms of the sources of emissions, two types of energy are used in cold stores, namely electricity and diesel. No LNG is used at any of the facilities. Electricity is used by the refrigeration plant, general lighting, offices, etc., while the diesel is used for back-up generators and/or handling equipment at the facility. In addition, to comply with the standards and methodology set out by Dobers et al. [20] and the WBCSD and WRI [23], a third source of emissions is also included: the leakage of refrigerants. Since all the facilities are temperature-controlled, refrigerant leakage must be included in the assessment.

In terms of the various organizational scopes defined in the GHG Protocol: Corporate Accounting and Reporting Standard [23], the following cold-store emissions are analyzed in the assessment:

- Scope 1 emissions: The emissions due to the burning of fuels, i.e., tank-to-wheel (TTW) in assets owned or controlled by the reporting company. Also included in this scope are the emissions due to refrigerant leakage from equipment at the reporting company's plant.
- Scope 2 emissions: The indirect emissions due to purchased electricity by the reporting company.
- Scope 3, category 3 emissions: The indirect upstream emissions due to the extraction, production, and transportation of fuel and energy-related products that are not included in Scope 1 or Scope 2 emissions. This includes the upstream emissions of

purchased fuels, i.e., well-to-tank (WTT) and the upstream emissions of purchased electricity, taking transmission and distribution losses into account. For a detailed discussion of calculating a reporting company's category 3 emissions, refer to the WBCSD and WRI's Technical Guidance for Calculating Scope 3 Emissions [29].

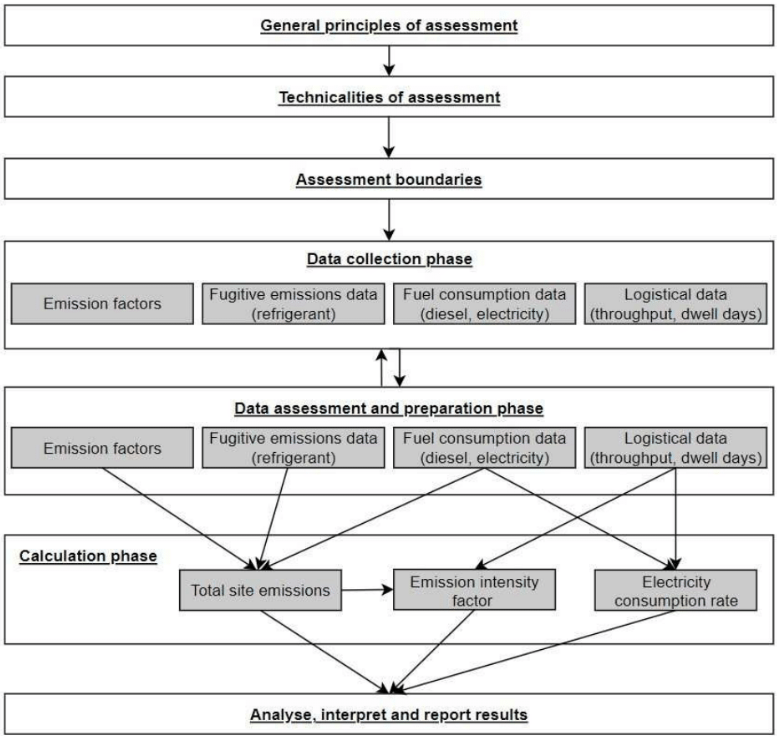

Figure 1. Exposition of the research methodology that was employed.

The results of this article will state the total operational lifecycle emissions of a cold store.

2.2. Technicalities of Assessment

This section discusses the adjustments made to the Dobers et al. [20] methodology, as well as the assumptions made to perform the study.

2.2.1. Adjustments to Methodology

Dobers et al. [20] state that the guidance provided is generic and may be adjusted to account for both site- and product-specific characteristics. In light of the latter, the authors deemed it appropriate to (1) adjust the methodology in terms of the functional unit of analysis, (2) incorporate a time-based element in the analysis, and (3) account for emissions on a monthly and yearly basis. These three aspects are discussed below.

1. In this assessment, the unit of analysis is pallets instead of the conventional tonne that is generally used in the emissions realm. According to Dobers et al. [20], the use of pallets as units of analysis is acceptable as long as these units are used throughout the assessment and allow for comparison of emissions over years. This means the resultant unit for emission intensity factors is kg CO_2e pallet^{-1} instead of kg CO_2e t^{-1}. The reason for this adjustment is justified: all cold stores, fruit exporters, producers and stakeholders refer to pallets as the metric or functional unit after fruit has been packed and palletized and distribution commences. In addition, the pallet weight

is often not captured by cold stores since this adds an added level of complexity to business operations and does not contribute any significant value. Using the consignment-based indicator (pallets) instead of the weight-based indicator (tonnes) still provides a consistent metric that is already in use. If the conversion between pallets and weight is required, the conversion factor of 1030 kg pallet^{-1} can be used.

2. The time duration of storage or dwell days directly affects the utilization percentage of the facility (i.e., how well the available capacity of the cold store is used). This, in turn, affects the emissions allocated to each pallet that moves through the facility. It is deemed essential to incorporate the time duration of storage in the assessment to provide an accurate and true representation of both the electricity consumption rate and emission intensity of storing a pallet. The time aspect is incorporated by either collecting the average dwell days of pallets from cold stores or by obtaining the average utilization percentage of the cold store. If neither of the two variables is available, a time-based element cannot be incorporated into the assessment. Refer to Section 3, Equation (2) for the conversion between dwell days and average utilization.
3. Dobers et al. [20] suggest that emissions should be accounted for on an annual basis to remove seasonal effects. The authors are, however, of the opinion that the seasonal effect of different harvest seasons for different fruits must be assessed. Different fruit types, each with different refrigeration requirements and throughput volumes, are moved through a cold store during different months of the year. In addition, the effect of ambient temperature during different months of the year is also incorporated by performing the analysis on a monthly basis. However, to comply with Dobers et al. [20], the assessment and results of some facilities are done for both a monthly and an annual period.

2.2.2. Assumptions Required for Assessment

To analyze any cold store at a site or facility level, the following ten assumptions are made:

1. The weight difference between fruit types and packaging configurations is negligible. This means all pallets of fruit have the same weight.
2. All pallets have the same number of dwell days in a facility, independent of the type of fruit and the destination market.
3. The energy consumed due to cold sterilization is apportioned to all pallets that move through the facility. The effect of fruit destined for different markets is therefore negligible.
4. Pallets in the facility are all handled or processed in a comparable fashion, from offloading to storage to the eventual loading for shipment to the destination market.
5. The energy effect of some fruits arriving at optimal storage temperature and others arriving above target temperature is allocated evenly among all pallets that move through the cold store.
6. All fruit types and packaging configurations have the same cooling characteristics.
7. The type of packaging has little to no effect on the energy efficiency and use of the cold store.
8. The effect of fruit loss in any of the analyzed cold stores is ignored.
9. Only the operational emissions or use-phase emissions of equipment and infrastructure are assessed.
10. Leakage of refrigerants occurs in the same period that refilling with refrigerants occurs. Furthermore, the quantity of refrigerants refilled during a year is apportioned evenly between all months of the year.

Intuitively, some of the ten assumptions may seem more realistic or appropriate than others. However, until more detailed data collection occurs at cold stores, these assumptions are required to perform the assessment for any cold store.

2.3. Boundaries of Analysis

The operational control approach prescribed by Dobers et al. [20] was used in this study. This means the following activities are included: inbound and outbound handling of pallets at the cold store; handling required for the storage and the retrieval for outbound transport; refrigeration of the fruit during storage or transshipment; internal yard logistics required during everyday operation; lighting of the facility; IT equipment used in the facility; and all office equipment and space used for administrative purposes.

At the analyzed cold stores, battery-powered and diesel forklifts are used as handling equipment to handle all pallets. Also included in the scope, as previously mentioned, were the fugitive emissions due to refrigerant leakage from the refrigeration plant or equipment. Subsequently, all GHG emissions that are emitted within the geographical location (the yard and the actual building) of the cold store and from equipment or infrastructure owned or controlled by the cold store were covered in this assessment.

Aligned with Dobers et al. [20], the following activities are deemed to be out of scope and were omitted from the assessment: the inbound and outbound transport to and from the facility by road transportation, employee commuting, business travel, and the manufacturing and dismantling of any asset (building or equipment).

2.4. Data Collection

The data required for this article have been classified into two groups, namely consumption data collected from the various cold stores and emission factors retrieved from the literature.

2.4.1. Cold-Store Consumption Data

The type of data collected is intrinsically linked to the goal of the assessment. As the desired emission intensity values become more refined, more comprehensive data capturing and collection are required. However, this is often not available due to the data not being captured for each activity category (order picking, storage, repacking, or other value-adding activities). The benefit of such an added level of complexity is, however, debatable. Nevertheless, since all pallets of fruit are deemed to be similar and processed in the same fashion, none of the above-mentioned activity categories applied to the analyzed cold stores. This means that an average emission intensity factor for the entire cold store can be calculated based on overall data values for the entire site. This high-level energy consumption data is almost always readily available—as was the case in this study—but is often difficult to obtain due to its sensitive nature.

In order to calculate an average emission intensity factor at site level, all the data listed in Table 2 was collected for several years, as available (ranging from one to six years). It is essential that all the listed data values are collected. If a single data value is absent, it compromises the assessment as prescribed by Dobers et al. [20], which, in turn, affects the integrity of the results.

Table 2. Consumption data collected from the various cold stores.

Electricity	Diesel	Refrigerant Data	Logistical Data
Total amount of grid electricity (kWh) used	Total amount of diesel (ℓ) used at the facility by generators and/or equipment	Types of refrigerants used at the facility	Pallet capacity of facility
Total amount of electricity generated (kWh) by solar panels		Refrigerant capacity of all systems (kg)	Total throughput at the facility (number of pallets)
		Total refill values of refrigerants (kg)	Average dwell days or utilization percentage of the facility

The data in Table 2 was collected from facilities via email after an initial data-collection meeting and data-sharing agreement had been put in place. This was preceded by a site visit to the cold stores and various meetings to discuss the data requirements. The data was supplied to the researchers either in Excel, PDF, or text format.

Due to the seasonal nature of fresh fruit, it was requested that the data values listed in Table 2 be provided per month. If the data were not available per month, the cold store supplied the values for every year.

2.4.2. Emission Factors (EF)

Following the identification of sources of emissions, suitable emission factors (EF) were selected to convert the amount of fuel used or refrigerants emitted to emissions volumes. For this, several reputable sources, as advised by Dobers et al. [20], Smart Freight Centre [2] and the WBCSD and WRI [23], were retrieved and used.

In terms of an EF for electricity, Eskom's 2021 Integrated Report was used to provide the most recent EF. According to Eskom [27], a total of 205,635 GWh of electricity was sold during 2020 and 201,624,115 t of CO_2e were emitted in the same year. This resulted in an EF of 0.98 kg CO_2e kWh^{-1} for electricity supplied to a South African consumer through the national electricity grid. This calculated value excludes losses due to transmission and distribution (technical losses), losses due to theft (non-technical losses), own internal usage by Eskom, and wheeling (electricity generated by small, independent power producers). As the calculated EF is slightly higher than the suggested 2017/18 value of 0.97 kg CO_2e kWh^{-1} [28], the most recent and conservative value of 0.98 kg CO_2e kWh^{-1} is used in this article.

No EF for South African diesel fuel could be found in the literature or obtained from local fuel suppliers. Subsequently, the EF for diesel fuel (WTW of 3.24 kg CO_2e ℓ^{-1}) was retrieved from the European Standard EN 16258 [30] and used in the assessment. This is according to the Smart Freight Centre's [2] recommendation that, in the likely event that no country-specific value exists, the EF for European fuels should be used. Note that the value of 3.24 kg CO_2e ℓ^{-1} is for all grades of diesel fuel since there is no differentiation for diesel between different fuel grades such as 500 or 50 parts per million (ppm).

To quantify the emissions of refrigerants, the global-warming potential of all refrigerants is assessed on a 100-year time horizon. The factors were retrieved from the Intergovernmental Panel for Climate Change's 4th Assessment Report [31], since this report provides the most comprehensive list of EF. These are also the values used by the Smart Freight Centre [2] in the GLEC framework. (Although the 6th Assessment Report is available, it may not be quoted, cited, or distributed as of yet. The 5th Assessment Report does not provide a comprehensive list of all refrigerants; therefore, to avoid confusion, the 4th Assessment Report was used throughout this study.)

2.5. Data Assessment and Preparation Phase

After the data from the various cold stores were received, it was assessed for completeness and correctness. The data values were then captured and stored in a single Excel document. If any of the data values mentioned in Table 2 were missing or regarded as outliers, the representative at the cold store was contacted to provide the value or confirm that the specific data values were correct.

Due to different cold stores having different business practices, the data were not captured by all the cold stores in a consistent manner. The data preparation phase was therefore essential to eliminate inconsistencies and ensure that consistent data would be available for calculation purposes.

3. Calculations

To calculate (1) the total emissions of a cold store, (2) the rate of electricity consumption, and (3) the emission intensity of a pallet, the formulae listed below were used. Some formulae are based on Dobers et al. [20] but have been adjusted, as explained in Section 2.2. Calculations were performed on a monthly and a yearly basis, depending on the completeness of the data collected. The formulae used to calculate the results stated in Section 4 are listed in the order of use in the remainder of this section.

3.1. Total Site Emissions

To quantify the total site emissions (research aim 1) of a cold store for a given period, Equation (1) was used:

$$Emission_{Total} = \sum_{i=1}^{n} (Quantity_i \cdot EF_i) \tag{1}$$

where:

$Emission_{Total}$ = the total GHG emissions of the cold store for a period (kg CO_2e)
n = the total number of fuels (diesel, electricity or refrigerant) consumed
$Quantity_i$ = the amount (ℓ, kWh or kg) of i used
i = the type of fuel (diesel, electricity) or refrigerant used
EF_i = the emission factor for i (diesel, electricity or refrigerant) in (kg CO_2e per unit).

3.2. Dwell Days or Utilisation

A time-based allocation was preferred to fairly distribute emissions among pallets with short- and long-storage dwell times. To incorporate a time-based element in the analysis, either the dwell days or utilization data for the facility was collected. Since the dwell days are a variable in the remainder of the calculations, the utilization percentage was converted to dwell days using Equation (2). Note that $Days_{Period}$ in Equation (2) is the total number of days in a period for which the data has been supplied. $Days_{Period}$ for monthly assessments can therefore be either 28, 29, 30, or 31 days, whereas $Days_{Period}$ for annual assessments is always 365 days.

$$D_{dwell} = \frac{Capacity_{Facility} \cdot Days_{Period} \cdot Utiliz_{Ave}}{N_{Pallets}} \tag{2}$$

where:

D_{dwell} = the average number of dwell days a pallet spends in the facility (days)
$Capacity_{Facility}$ = the total pallet capacity of the facility (pallets)
$Days_{Period}$ = the number of days in the analyzed period (days)
$Utiliz_{Ave}$ = the average utilization of the facility in the time period (%)
$N_{Pallets}$ = the number of pallets moved during the analyzed time period (pallets)

3.3. Electricity Consumption Rate

To calculate the electricity consumption rate of a pallet (research aim 2), Equation (3) was used:

$$Electricity_{Pallet} = \frac{Q_{electricity}}{D_{dwell} \cdot N_{Pallets}} \tag{3}$$

where:

$Electricity_{Pallet}$ = the amount of electricity used per pallet-day (kWh pallet-d^{-1})
$Q_{electricity}$ = the total amount of electricity used by the cold store (kWh)
D_{dwell} = the average dwell days a pallet spends in the facility (days) (Equation (2))
$N_{Pallets}$ = the number of pallets moved during the time period (pallets)

3.4. Diesel Consumption Rate

The diesel consumption rate per pallet was calculated by using Equation (4):

$$Diesel_{Pallet} = \frac{Q_{diesel}}{D_{dwell} \cdot N_{Pallets}} \tag{4}$$

where:

$Electricity_{Pallet}$ = the amount of diesel used per pallet-day (ℓ pallet-d^{-1})
Q_{diesel} = the total amount of diesel used by the cold store (ℓ)
D_{dwell} = the average dwell days a pallet spends in the facility (days) (Equation (2))
$N_{Pallets}$ = the number of pallets moved during the time period (pallets)

3.5. Emission Intensity Factor

To calculate the emission intensity factor (research aim 3) of a pallet, Equation (5) was used:

$$EIF_{Pallet} = \frac{Emission_{Total}}{D_{dwell} \cdot N_{Pallets}} \quad (5)$$

where:

EIF_{Pallet} = the average emission intensity factor for a pallet-day (kg CO_2e pallet-d^{-1})
$Emission_{Total}$ = the total GHG emissions of the cold store (kg CO_2e)
D_{dwell} = the average number of dwell days a pallet spends in the facility (days)
$N_{Pallets}$ = the number of pallets moved during the time period (pallets)

3.6. Average Values

Equation (6) can be used to calculate the average or arithmetic mean of monthly or yearly values. For this study, this equation was used to calculate the average rate of electricity consumption and average emission intensity factor for the various months and years.

$$Average_{period} = \frac{\sum_{i=1}^{n} X_i}{n} \quad (6)$$

where:

$Average_{Period}$ = the average value for the period assessed
X_i = the individual data values to be averaged
n = the number of data values to be summed

Finally, to calculate the weighted average dwell days in Section 4.2, Equation (7) was used. The weight (w_i) applied to different dwell-day values indicates the importance of the specific value; for example, if 19 of the 21 data points had an average of 6.72 dwell days, w_i would be 19/21 for the value of 6.72 days.

$$Weighted_{Ave} = \frac{\sum_{i=1}^{n} w_i \cdot X_i}{\sum_{i=1}^{n} w_i} \quad (7)$$

where:

$Weighted_{Ave}$ = the weighted average value
n = the number of terms to be averaged in the calculation
w_i = the weight applied to each X_i value
X_i = the data value to be averaged

4. Results

The results of the analysis are given in three different sections. Section 4.1 states the annual results for a small seasonal cold store that only operates a few months per year. In Section 4.2, both the monthly and the annual results of several large commercial cold stores that operate year-round are given. Section 4.3 indicates the monthly and annual results for two cold stores that are regarded as exceptions to the status quo. These results are included to illustrate the extent of possible results.

4.1. Seasonal Cold Stores

The results for a small seasonal cold store with a pallet capacity of 345 pallets are given in Table 3. This cold store (Facility A) emitted 448.41 t of CO_2e over a three-year analysis period. It is deemed seasonal since it only operates from December to March during the harvest season of the production region. After the harvest season, the facility is closed since there are no other products or produce in the region that require cold storage. The results in Table 3 are based on three years of data, during which 9 428 pallets of fruit were moved through the facility. Because the cold store is closed for a large portion of the year (April to November), the assessment was performed on an annual basis instead of specifying results for the different months. Subsequently, it is assumed that the results in Table 3 are representative of any working month of the year.

Table 3. Annual results for a small seasonal cold store.

	Dwell Days						
	1	2	3	4	5	6	7
Electricity consumption rate (kWh pallet-d^{-1}) [1]	57.49	28.75	19.16	14.37	11.50	9.58	8.21
Diesel consumption rate (ℓ pallet-d^{-1})	0.20	0.10	0.07	0.05	0.04	0.03	0.03
Emission intensity factor (kg CO_2e pallet-d^{-1})	56.99	28.50	19.00	14.25	11.40	9.50	8.14
Utilization percentage of facility	8.95%	17.89%	26.84%	35.79%	44.73%	53.68%	62.63%

[1] If the unit should be changed to kWh pallet^{-1}, multiply the dwell day number by the value in the column.

From the cold store's data and a discussion with the facility manager, it was evident that the actual dwell days varied considerably. This variation in dwell days is due to several logistical reasons beyond the scope of this article. Nevertheless, as a consequence of the erratic dwell days, the calculations were performed for a varying number of dwell days ranging from one to seven. This range represents all possible dwell days of fruit moving through this facility.

The electricity consumption rate in Table 3 states the total amount of electricity required to handle and store a pallet in the facility for a single day, given that all other pallets in the facility have the same dwell period (as stated in each column). Likewise, the diesel consumption rate, with units of ℓ pallet-d^{-1}, states the total amount of diesel fuel "consumed" by a pallet during a single day in the cold store. The amount of diesel used at a facility is dependent on power outages (loadshedding); thus the diesel consumption varied considerably during the three analyzed years. The authors therefore advise that the diesel consumption results not be analyzed in any further depth or detail, such as evaluating trends or correlations. The emission intensity factor states the actual weight, in kg, of GHG emitted by a pallet in a day. Finally, the utilization of the facility is indicated as a percentage to provide the reader with a gauge of the logistical performance of the cold store. Note that no fugitive emissions are stated in Table 3 since no refilling of refrigerants occurred at the facility during the three-year analysis period.

4.2. Large-Scale Commercial Facilities

4.2.1. Monthly Assessment Results

The three large commercial cold stores (Facility B, C, and D) assessed in this section have a very large pallet capacity and handle significant volumes of fresh fruit. Based on the 2020 data of the three analyzed facilities, a total of 360,000 pallets of fruit were handled and stored in the three facilities in this year. In the same period, a total of 260 million cartons of fresh fruit were exported from South Africa [32]. If approximated (assume that a pallet consists of 80 cartons of fruit), the 260 million cartons translate to 3.25 million pallets of fresh fruit. This means the three analyzed facilities in this section were responsible for 11.07% of the total fresh fruit exported from South Africa during 2020.

The smallest facility analyzed in this section (Facility B) has a pallet capacity of 5000 pallets, with all three facilities having a combined pallet capacity of 16,100 pallets. During the analysis period, the assessed facilities collectively handled and stored a total of 1.73 million pallets of fruit. All three facilities handle various types of fruit (citrus, table grapes, pome fruit, stone fruit, subtropical fruit, etc.) from several production regions across the country and operate 12 months per year. Each average monthly value displayed in Table 4 is based on approximately 16 data points for that specific month. All results are calculated for the actual recorded dwell days of 6.72 d that fruit spent in the facility.

Table 4. Monthly results for large commercial cold stores.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity consumption rate (kWh pallet-d^{-1}) [1]	6.62	8.87	8.01	10.92	7.92	9.16	7.21	8.35	11.41	19.77	10.94	5.90
Diesel consumption rate (ℓ pallet-d^{-1})	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.05	0.05	0.05
Hypothetical emission intensity factor—assuming no solar (kg CO_2e pallet-d^{-1})	6.52	8.74	7.91	10.74	7.81	9.00	7.09	8.20	11.22	19.49	10.82	5.92
Actual emission intensity factor—with solar (kg CO_2e pallet-d^{-1})	4.03	6.78	6.55	6.60	6.05	4.91	5.64	5.67	6.06	13.49	7.02	3.22
Utilization percentage of facility	49.74%	42.63%	40.70%	37.23%	49.83%	47.60%	53.62%	46.02%	40.49%	14.64%	15.86%	41.73%

[1] If the unit should be changed to kWh pallet^{-1}, multiply the values in the table by 6.72.

In terms of the total emissions, Facility B emitted 28,262 t of CO_2e in order to move 931,320 pallets of fruit during the 83 months analyzed. Facility C emitted 32,283 t of CO_2e during an 88-month period, during which it moved 539,187 pallets. For Facility D, data were only available for 23 months. During this period, the facility moved 260,042 pallets, which emitted 10,364 t of CO_2e.

The electricity consumption rate in Table 4, with units of kWh pallet-d^{-1}, states the total amount of electricity required by a pallet during a single day, regardless of the source of electricity. Since all three of the analyzed facilities have solar plants installed, a large proportion of the required electrical energy was generated and supplied by solar. This renewable energy reduces the use of grid electricity and leads to a lower emission intensity factor. The authors deemed it appropriate to state a dual emission intensity factor (kg CO_2e pallet-d^{-1}): a higher hypothetical value, which assumes that no solar energy is used, and an actual emission intensity factor, which incorporates the use of solar power. This differentiation was done to allow benchmarking with other cold stores that do not have solar systems installed. The diesel consumption rate, with units of ℓ pallet-d^{-1}, is once again dependent on power outages, and should therefore not be analyzed further. Also, note that no refrigerant leaks were reported, and no refrigerant gas was refilled at any of the three facilities. However, if a leak were to occur, the emissions contribution would still be negligible since Ammonia (NH3), which has a global-warming potential of zero, is used as refrigerant at all three cold stores.

Figure 2 provides a visual representation of the results given in Table 4. From Figure 2, it is evident that the actual emission intensity factor is significantly lower than the hypothetical emission intensity factor. On average, the solar system reduced the dependence on grid electricity by 24.5% across all months. In particular, solar electricity reduced the amount of grid electricity consumed by 45.9% and 45.7% in September and December, respectively. Note that the emission intensity factor is the highest during October and November since a small volume of fruit moves through the facilities during these months. This means the total emissions during these months are apportioned to a smaller number of pallets, which leads to the higher value.

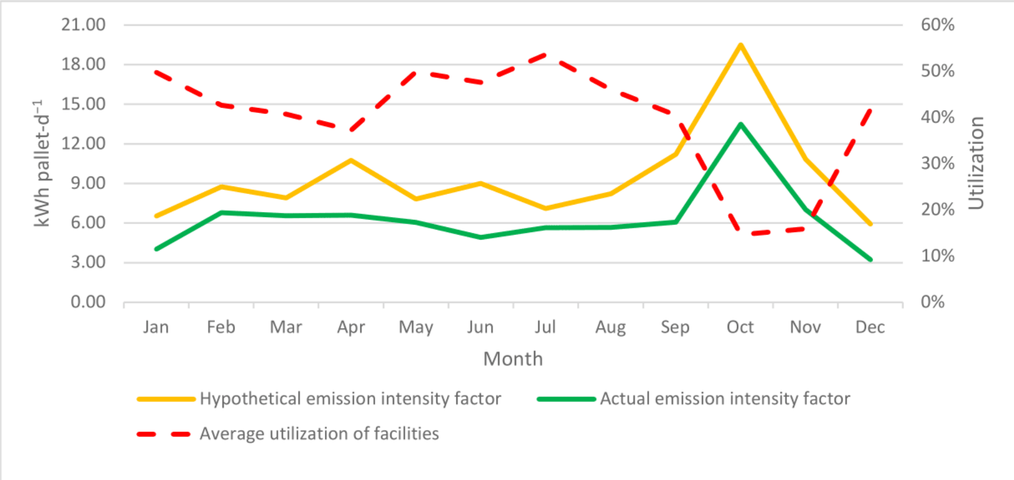

Figure 2. Average hypothetical and actual emission intensity factors versus utilization of facilities for various months.

Figure 3 displays the total megawatt-hours (MWh) generated by each facility since the installation of the solar systems. Each facility has a different installed capacity, hence the difference in generated values between facilities. From Figure 3, a general trend is apparent: during the summer months (October to April), the solar system generates more electricity than during the winter months (typically May to August). In June, the least amount of electricity is generated by the solar plants, presumably due to weather-related conditions during the South African winter.

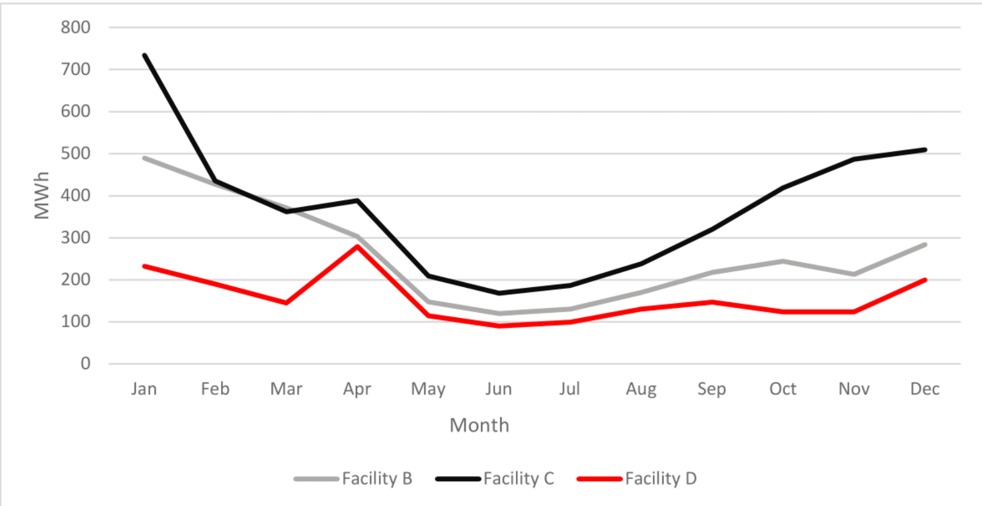

Figure 3. Total megawatt hours (MWh) of electricity generated by each facility over the installed lifetime of the solar system.

4.2.2. Annual Assessment Results

Apart from assessing and reporting the results on a monthly basis, an assessment was also done of annual data. For this, Facility B, C, and D as well as two other facilities, E and F, were analyzed on a yearly basis. Facilities E and F have a combined pallet capacity of 10,000 pallets, which allows for comparison to Facilities B, C, and D in terms of capacity. This means all the analyzed facilities have a combined capacity of 26,100 pallets. Both Facility E and F, however, only supplied data for a one-year period as no other historical data were available for either facility. During the one-year period, Facility E had a throughput of 143,000 pallets and emitted 7012 t of CO_2e emissions. During the same period, Facility F moved 109,000 pallets of fruit and emitted 6190 t of CO_2e. All five facilities (B, C, D, E, and F) collectively moved 1.98 million pallets of fruit and emitted 84,114 t of CO_2e during the period of analysis.

Based on the collected data from facilities, 612,000 pallets of fruit moved through the analyzed facilities in 2020 alone. This means the analyzed facilities in this section were responsible for 18.8% of the total fresh fruit exported from South Africa during 2020.

Table 5 states the average values of the five analyzed facilities. The averages are based on 21 data points, with each data point representing one year's data for a cold store. In terms of the dwell days, the weighted average dwell days of the 21 data points were used in all calculations. In total, 19 of the 21 data points had an average of 6.72 dwell days, while the remaining two had a dwell period of 6.89 d and 7.51 d, respectively. The results in Table 5 have been calculated for a weighted average dwell days value of 6.76 d.

Table 5. Annual results for large cold stores.

	Average Annual Value
Electricity consumption rate (kWh pallet-d^{-1}) [1]	7.62
Diesel consumption rate (ℓ pallet-d^{-1})	0.014
Hypothetical emission intensity factor—assuming no solar (kg CO_2e pallet-d^{-1})	7.52
Actual emission intensity factor—with solar (kg CO_2e pallet-d^{-1})	5.72
Utilization percentage of facility	40.25%

[1] If the unit should be changed to kWh pallet^{-1}, simply multiply the value in the table by 6.76.

If the results of Table 5 are to be used in a simulation study (agent-based modelling or discrete event modelling), Appendix A should be consulted. In Appendix A, a statistical distribution is fitted to the annual results of Table 5.

Due to the installation of solar plants at three of the five cold stores at the beginning of 2018, a total of 9.45 GWh of electricity was generated over a three-year period. This substitution of 9.45 GWh of "dirty" South African grid electricity by clean renewable energy led to a cumulative emissions saving of 9260 t of CO_2e, as shown in Figure 4. If the solar plants had been absent, the 9260 t of CO_2e would have been emitted into the atmosphere. It is interesting to note that the emissions trajectory of the analyzed facilities changed dramatically in 2020 due to the effect of the Covid-19 pandemic. It is, however, yet to be seen if this emissions reduction will be recouped in years to come.

Using a combination of solar and grid electricity has a major impact on the emission intensity factor. From Figure 5, it is apparent that the actual emission intensity factor decreased by nearly 2 kg CO_2e pallet-d^{-1} from 2018 onwards owing to the installation of solar systems. Solar systems are, therefore, a relevant decarbonization strategy for cold-store facilities. All facilities have the potential space and capability to expand their solar systems. The practicality of becoming completely self-sufficient with solar electricity is, however, debatable. Power generation only occurs during daytime, meaning that electricity has to be stored for night-time consumption. None of the analyzed facilities store electrical energy as batteries are extremely expensive and have a limited lifespan. In addition, the required battery capacity to store this amount of energy would be significant and impractical. Furthermore, due to reduced generation in winter months, the required capacity would need to be increased exponentially to remain self-sufficient, which would lead to overproduction during the summer months.

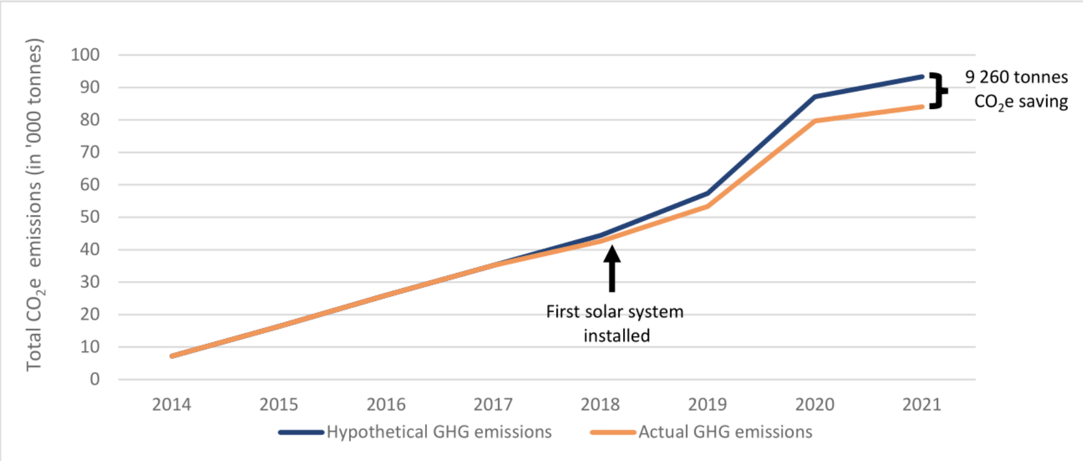

Figure 4. Total cumulative GHG emissions of large analyzed cold stores.

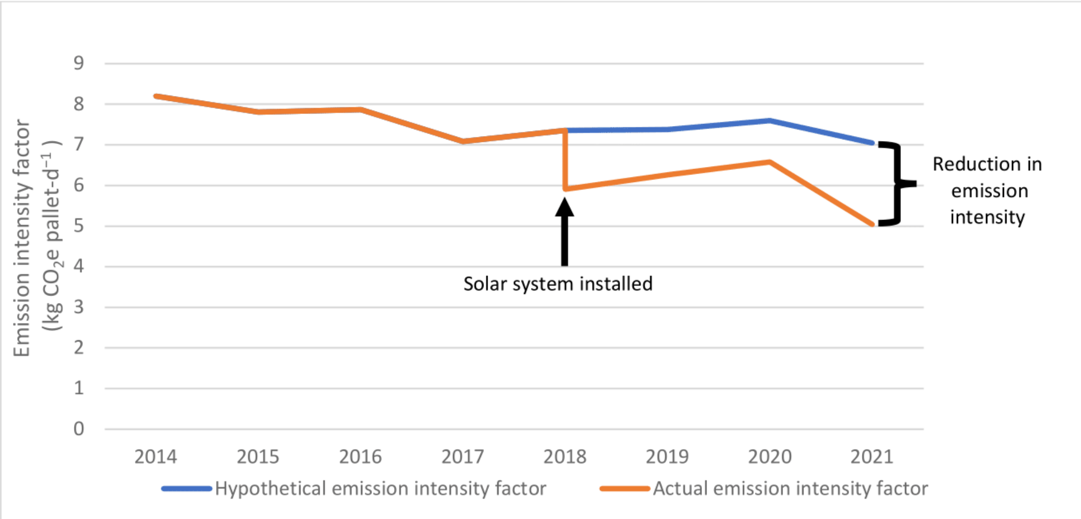

Figure 5. Change in emission intensity factor due to solar energy.

4.3. Cold Stores Regarded as Exceptions

The two cold stores analyzed in this section, Facilities G and H, are regarded as exceptions. These cold stores were built several decades ago and have not been upgraded or equipped with newer technology as is the case for Facilities A to F. The use of old refrigeration technology inevitably led to reduced energy efficiency and high emissions values. In particular, the potential impact that refrigerant leakage can have on the emissions of a facility was evident at these facilities. (It should be noted that both cold stores have in the meantime been closed due to age and inefficiency.) The analysis and results of Facility G and H are only stated on a monthly basis to emphasize the seasonal movement of cargo through the facilities.

Facility G had a pallet capacity of approximately 1000 pallet locations and handled 406,905 pallets over a period of 5 years and 7 months. The facility emitted 9600 t of CO_2e over the analysis period of 67 months. The results of a monthly analysis for facility G are indicated in Table 6. Note that no diesel fuel data was reported as no generators were present at the facility due to the exemption of this facility from loadshedding. Also, no fugitive emissions were reported since no refilling of NH3 refrigerant had occurred at the facility in the 67 months. For facility G, the results in Table 6 were calculated for a dwell-days period of two days.

Table 6. Monthly results for exception cold store G.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity consumption rate (kWh pallet-d^{-1}) [1]	20.51	34.27	12.92	8.74	8.10	7.74	7.75	10.56	13.83	47.12	32.12	9.63
Emission intensity factor (kg CO_2e pallet-d^{-1})	20.10	33.58	12.67	8.57	7.93	7.59	7.59	10.35	13.55	46.18	31.48	9.44
Utilization percentage of facility	30.22%	18.16%	37.98%	57.83%	55.13%	52.24%	52.12%	43.07%	33.79%	9.41%	13.77%	31.07%

[1] If the unit should be changed to kWh pallet^{-1}, simply multiply the values in the table by 2.

The second exception cold store, Facility H, is a typical example of the potential effect of fugitive emissions. This cold store has a pallet capacity of approximately 3000 pallets and emitted 24,839 t of CO_2e during an eight-year period, during which the facility moved 347,059 pallets. In total, 33% or 8197 t of this facility's total annual emissions are due to the leakage of 2.1 t of refrigerant (R-507 and R-22). These two refrigerants have a very high global-warming potential and the leakage of even a small amount of refrigerant leads to a significant increase in emissions.

The results for a monthly assessment of Facility H are shown in Table 7. The results were calculated for a dwell-day period of eight days. Apart from the high electricity consumption rate during some months, the fugitive emissions in Table 7 are responsible for between 43% and 78% of the total emission intensity factor for August and April respectively. Fugitive emissions are, therefore, a significant contributor to the emission intensity factor across all months. Once again, note that no diesel consumption is reported for the same reason as was the case with Facility G.

Table 7. Monthly results for exception cold store H.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity consumption rate (kWh pallet-d^{-1}) [1]	24.54	25.82	17.79	12.73	5.40	4.07	3.02	2.96	4.11	23.89	24.46	33.24
Fugitive emissions (kg CO_2e pallet-d^{-1})	75.47	64.31	58.43	44.14	9.34	5.22	3.12	2.17	7.13	36.22	43.03	49.88
Emission intensity factor (kg CO_2e pallet-d^{-1})	99.52	89.61	75.87	56.62	14.64	9.21	6.08	5.07	11.16	59.63	67.01	82.46
Utilization percentage of facility	9.45%	8.33%	8.76%	19.34%	46.42%	61.40%	84.24%	96.12%	51.67%	13.37%	15.21%	13.98%

[1] If the unit should be changed to kWh pallet^{-1}, simply multiply the values in the table by 8.

5. Discussion

The discussion of the results is grouped into three parts: Section 5.1 examines the impact of various sources of emissions; Section 5.2 recommends the most appropriate results for future research; and Section 5.3 provides a reflection on the assessment as a whole.

5.1. Sources of Emissions

Electricity is the largest contributor to the total emissions of all the analyzed facilities. All eight facilities depend on carbon-intensive grid electricity from Eskom. When benchmarked against international peers that also use predominantly coal in the energy mix, Eskom has the highest emission factor (kg CO_2e kWh^{-1}) of all utilities [28]. The installation of solar systems at cold-storage facilities as an alternative to grid electricity will become increasingly important in future. Solar energy not only reduces the emissions of a cold store, but also makes the facilities less vulnerable to loadshedding and power outages. Despite only having generation capability during daytime, solar energy will become important to ensure the sustainability of cold stores. These facilities are also easier to decarbonize compared to transport vehicles. Future emissions reduction efforts in the distribution chain should be focused on cold-storage facilities.

Fugitive emissions and the use of old refrigeration technology can have a significant impact on the total emissions and emission intensity factor of a cold store, as was shown in Section 4.3. The choice of refrigerant used at refrigerated facilities is extremely important and requires careful consideration. In future, refrigeration systems that use refrigerants with a low or zero global-warming potential, such as NH3, N2 or water, should be used. Furthermore, the use of new refrigeration technology is essential to improve the energy efficiency of a facility. The leakage of refrigerants leads to higher electricity consumption and hence to higher emissions. Facilities normally only realize that a leakage has occurred once they see a spike in electricity consumption.

All facilities use relatively little or no *diesel fuel* to run back-up generators in the case of loadshedding. When the effects of electricity and diesel on emissions are compared, it is evident that diesel has been responsible for less than 1% of the total emissions of any cold store. This may, however, change if more diesel has to be used to run generators to supply electricity.

5.2. Results

It is recommended that the results of the *large-scale commercial facilities be used in all future research or analysis* (Section 4.2) of carbon emissions for fruit exports. These results best reflect the current cold-storage industry in South Africa, which is responsible for the export of fresh fruit. Most of the fruit exported from South Africa moves through one of the large-scale commercial facilities. Hence, it is better to use the results of these large-scale facilities.

Due to the seasonal nature of values, emission calculations on a shipment level should preferably be based on the monthly values in Table 4. However, if the month is unknown, the annual values in Table 5 must be used.

Based on the annual results that were presented in Section 4.2, storing a pallet of any type of fruit for a day in cold storage requires 7.62 kWh of electricity. If cold stores have no solar system installed, a hypothetical emissions value of 7.52 kg CO_2e pallet-d^{-1} is possible. However, due to installed solar systems, the actual emission intensity factor declines to 5.72 kg CO_2e pallet-d^{-1}. This factor will differ for each cold store depending on the capacity of solar systems available, if any.

5.3. Reflection on Assessment

This section lists some important considerations that affected the assessment process and associated results. These include:

- *Sensitive nature of organizational data:* Due to the sensitive nature of organizational data, it is often difficult or impossible to obtain *high-quality primary data*. In the majority of cases, cold-store managers or other members of senior management are the only individuals who have access to the required data. These individuals are reluctant to share data for privacy reasons or due to a lack of understanding of the potential value of an assessment. In terms of the quality of data, some facilities do not record or keep records of all the required data for an emissions assessment. In some instances, as was the case for the diesel consumption at one of the cold stores in this study, the quantity of fuel used per month was not recorded and had to be derived from fuel invoices. This lack of quality data hampers emissions assessments since missing data cannot be substituted from literature, even if such data were available. Better capturing of the appropriate data elements mentioned in Section 2.4 is, therefore, required for more accurate assessments.

- *A lack of a standard methodology for cold stores as logistical sites:* There are still considerable research challenges with assessing, quantifying and gauging GHG emissions at a facility level, even when using the methodology developed by [20]. This lack of a prescriptive standard leaves room for erroneous assumptions and leads to both inaccurate and incomparable results.
- *Allocation of emissions among logistical units:* The process of fairly allocating the total emissions among all goods that moved through the cold store is a major problem (the allocation problem). The allocation of refrigeration energy should not only be fair but also practical to apply. Some shipments of fresh fruit are stored for a short duration and others for extended periods. The dwell days will certainly have an impact on the emissions value of a specific shipment. In addition to a time aspect, pallets of fruit have different configurations (prepared for standard or high-cube containers) or sizes, which lead to different weights.
- *Dwell days and utilization:* The number of dwell days and the utilization percentage of a facility have a major impact on the assessment results. Allocating emissions fairly to pallets that spend a couple of days in the cold store should be different to pallets that do so for weeks. The consumption rate of electricity (kWh pallet-d^{-1}) and the emission intensity factor (kg CO_2e pallet-d^{-1}) are inversely related to the number of dwell days. If a time-based element is incorporated in an assessment, the dwell days must be accurate.
- *Availability of emission factors:* The accurate quantification of emissions is dependent on the availability of applicable emission factors, as stated in Section 2.5. Emission factors for fuels such as diesel are not available for South Africa. Since the feedstock and production process of fossil fuels differ from one geographical location to another, the emission factor could potentially be much higher in South Africa, particularly since South Africa's fuel is partly derived from coal. If newer emission factors for South African electricity or diesel becomes available, the energy consumption in Table 3 can be multiplied by the new factors to provide a timelier hypothetical emission intensity factor.

6. Conclusions

This article is the first to use a top-down approach to assess and apportion the emissions of a cold store that handles and stores fresh fruit. The results revealed that cold stores that handle and store fresh fruit emit significant amounts of GHG. In total, the eight cold stores analyzed in this article collectively emitted 119,001 t of CO_2e while moving 2.74 million pallets of fresh fruit. This large emissions value is due to a combination of the high electrical energy required for refrigeration, the carbon intensity of South Africa's electricity and, finally, the sheer volume of fruit that moved through the analyzed facilities. Solar systems are, however, a good decarbonizing strategy to reduce the overall emissions of a cold store. To realize the ambitious United Nations Sustainable Development Goals and to meet the GHG reduction targets of the Paris Agreement, more action than the installation of solar panels is required.

The analysis of cold-store data revealed that storing and handling a pallet of fruit for a day in a large commercial cold store requires 7.62 kWh of electricity. This value is dependent on the volume and type of fruit that moves through the cold store. If the cold store has no solar system installed, a hypothetical emission intensity factor of 7.52 kg CO_2e pallet-d^{-1} is possible. These results are valuable since they make it possible to quantify the emissions when a shipment of fresh fruit is moved through a cold store. However, emissions assessments for logistical facilities, including this study, are hampered by the absence of prescriptive standards.

Finally, it is recommended that a representative organization be established to represent and further the interest of cold stores or refrigerated facilities. This organization should prescribe a standard methodology for different types of cold stores to assist and enable organizations to collect, assess and prepare data and accurately calculate meaningful results. Furthermore, a representative organization could—and should—become an anonymous repository for all results in order to generate benchmarks for the cold-store industry.

Author Contributions: Conceptualization, M.J.d.P., J.v.E. and L.L.G.-G.; methodology, M.J.d.P. and J.v.E.; software, M.J.d.P.; validation, M.J.d.P. and J.v.E.; formal analysis, M.J.d.P.; investigation, M.J.d.P.; resources, L.L.G.-G.; data curation, M.J.d.P.; writing—original draft preparation, M.J.d.P.; writing—review and editing, J.v.E. and L.L.G.-G.; visualization, M.J.d.P.; supervision, J.v.E. and L.L.G.-G.; project administration, J.v.E. and L.L.G.-G.; funding acquisition, J.v.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Royal Academy of Engineering, UK: TSP2021 100310, and also the Stellenbosch University, Faculty of Engineering's Postgraduate Support Program.

Institutional Review Board Statement: Ethical clearance was obtained from the Research and Ethics Committee of Stellenbosch University—Project ID 19464. The research was not linked to individuals or any personal accounts (or information). The research was deemed as low ethical risk and Mr du Plessis was granted permission to conduct the research as part of his PhD.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The researchers are grateful to all cold-store stakeholders for their interest and support in the research.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

This appendix discusses the process and results of fitting a statistical distribution to the electricity consumption rate (kWh pallet-d^{-1}) and emission intensity factor (kg CO_2e pallet-d^{-1}) of a large-scale commercial cold store. It should be noted that only 21 data points were available—far too few values for confidence in the results. This means any goodness-of-fit test may not have the capability to detect significant deviations from the suggested statistical distribution. This may result in wrongfully selecting a distribution that supposedly fits the data. Nevertheless, as more data values become available in future, the sample size can be increased. Until then, the suggested distributions in Table A1 are regarded as the "least wrong". Table A1 states the parameters required to describe both the electricity consumption rate and the emission intensity factor in terms of a lognormal distribution.

In order to fit the distribution and determine the goodness-of-fit test, the statistical software package Minitab was used. An analysis of 16 different statistical distributions showed that the lognormal distribution describes both the electricity consumption rate and emission intensity factor with the least error. Figure A1 shows that the observed electricity consumption rate values fall within the upper and lower confidence bound lines, indicating a relatively good fit, except for the "head" and "tail" values. Likewise, the same is true for the emission intensity factor probability plot shown in Figure A2. It should be noted in Figures A1 and A2 that the p-values are larger than 0.05. This means that we fail to reject the null hypothesis that the data values follow a lognormal distribution with parameters μ and σ as stated in Table A1.

Table A1. Suggested statistical distributions and associated parameters.

		Parameters	
	Statistical Distribution	**Location (μ)**	**Scale (σ)**
Electricity consumption rate (kWh pallet-d^{-1})	Lognormal	1.98360	0.32025
Emission intensity factor (kg CO_2e pallet-d^{-1})	Lognormal	1.98360	0.32025

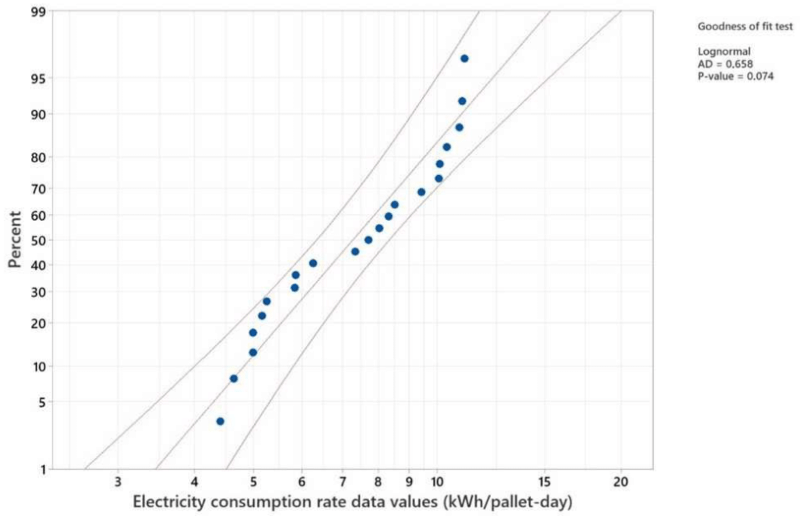

Figure A1. Probability plot of the electricity consumption rate for a 95% confidence interval.

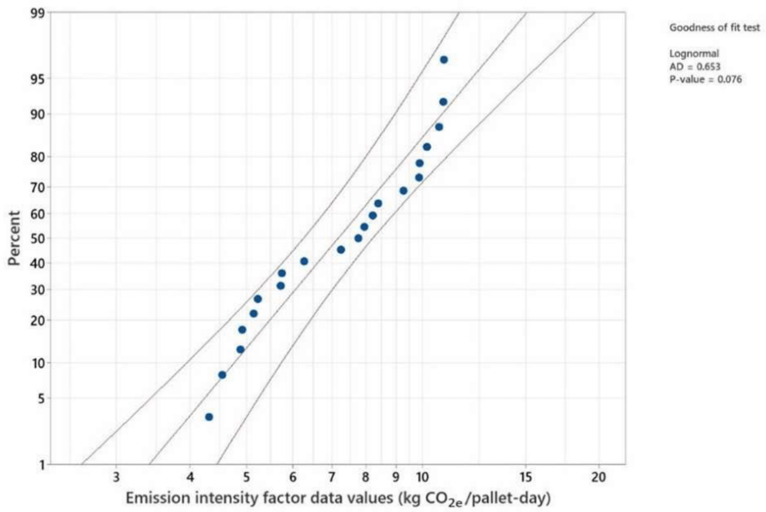

Figure A2. Probability plot of the emission intensity factor for a 95% confidence interval.

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6.2.2 Break-bulk terminal

Break-bulk terminals are located in maritime ports and are an exception compared to other facilities that handle pallets since fruit can be offloaded from a road transport vehicle and loaded directly into a conventional vessel meaning no storage is applicable. Alternatively, pallets of fruit can be offloaded from a road transport vehicle and stored in a cold store located in the break-bulk terminal. This second alternative is currently only possible in South Africa in the Port of Durban's break-bulk terminal.

For the first scenario, where pallets of fruit are handled, and no storage is applicable, the emission intensity factor is included in the reefer vessel emission intensity factor in Section 5.3.2. This factor incorporates the emissions of onboard vessel cranes, quayside cranes, and forklifts used to offload pallets from road trucks and position pallets for loading by cranes.

A combined factor for handling and storage is suggested in the second scenario since 'no storage without handling' is applicable. This factor is derived from the journal article in Section 6.2.1, which suggested that a value of 7.52 kg CO_2e pallet-day^{-1} be used for large-scale commercial cold storage facilities. However, this emission intensity of 7.52 kg CO_2e pallet-day^{-1} assumes that all pallets spend an average of 6.76 days in a facility. The factor needs to be adjusted[17] since fruit's average dwell day period in a break-bulk terminal's cold store is closer to two days rather than 6.76 days. The two-day dwell-day period was confirmed by the interviewees in Section 3.2 and the chief operating officer (COO) of a large cold store group, which provided data for the article in Section 6.2.1. The 7.52 kg CO_2e pallet-day^{-1} factor is multiplied by 6.76 to give a value of 50.84 kg CO_2e pallet-day^{-1}. Since the cold store dwell days were used to “allocate” all emissions across pallet-days, this “adjusts” the emission intensity factor to a per pallet value. To allocate the per pallet value back to per pallet-days, the average dwell day period for the facility is applied by adjusting the days from one to two days. This is achieved by dividing the 50.84 kg CO_2e pallet value by two to yield an emission intensity factor of 25.42 kg CO_2e pallet-day^{-1}. This factor assumes that all pallets stored in a break-bulk terminal’s cold store have an average dwell day period of two days.

6.2.3 Airport facility

Apart from repacking cartons of fruit onto airline pallets or ULDs, an airport facility's functioning and subsequent emission intensity is believed to be similar to cold stores. To confirm that the emissions intensity of fresh fruit handling and storage in an airport facility is similar to that of a normal cold store, two airport facilities in Cape Town International Airport’s cargo terminal were approached to collaborate in a study. Unfortunately, both facilities declined to participate in such a study. However, the primary researcher is confident that the emission intensity of fruit handling and storage in an airport facility is comparable to an inland fruit facility or cold store since the same industrial-scale refrigeration plants are used.

The only significant difference between an inland fruit facility and an airport facility's emission intensity factor is the average dwell day period of the fruit. Fruit is seldom stored in an airport facility for more than two days; however, a dwell day period of one day is more realistic, which was confirmed by the interviewees in Section 3.2 and during a facility visit to the Cape Town

[17] Recall from the article in Section 6.2.1, Equation 5, that the emission intensity factor for storing a pallet is calculated by dividing the total emissions of a facility by the product of the number of pallets stored, and the average storage duration of these pallets. The average dwell days of an emission intensity factor can therefore be adjusted by altering the dwell days value.

International Airport's cargo terminal. Once again, the 'no storage without handling' and vice versa principle is applicable, and subsequently, a combined factor for handling and storage is suggested.

The emission intensity factor for large-scale commercial cold store facilities from Section 6.2.1 is again used. The 7.52 kg CO_2e pallet-day^{-1} value is multiplied by 6.76 days and divided by the proposed average dwell day period of one day. This yields an emission intensity factor of 50.84 kg CO_2e pallet-day^{-1}, which assumes all refrigerated goods that move through the facility have a dwell day period of one day.

6.2.4 Recommended factors for pallets

The recommended emission intensity factors for the three types of facilities are summarised in Table 6.1. These factors are used in the carbon mapping framework stated in Chapter 7 (**Part V** of the dissertation document).

Table 6.1: Recommended emission intensity factors for facilities that handle pallets

	Handling (kg CO_2e pallet^{-1})	**Combination of handling and storage** (kg CO_2e pallet-day^{-1})
Cold Store or inland fruit facility	-	7,52[A]
Break-bulk terminal	Included in the reefer vessel emission intensity factor (no storage – offload on the quayside)	25,4[B]
Airport facility	-	50,8[C]

Source: developed by the author.
[A] Large-scale commercial cold storage facility with an average dwell day of 6.76 days.
[B] Large-scale commercial cold store with an average dwell day of 2 days.
[C] Large-scale commercial facility with an average dwell day of 1 day.

6.3 Containers

The emission intensity factors of logistical facilities or sites handling and storing containers are discussed across two sections. Section 6.3.1 assesses the refrigerated storage of integral reefer containers, while Section 6.3.2 addresses the handling of containers at various facilities. This differentiation is suitable since an integral reefer container, on average, consumes the same amount of electricity (and subsequently produces the same amount of emissions) independent of the facility where the reefer container is used. There are, however, a few disclaimers to the latter statement, which are addressed in Section 6.3.1.

6.3.1 Container storage

In order to suggest an emission intensity factor (kg CO_2e day^{-1}) for storing an integral reefer container filled with fruit, it is necessary to establish the average power consumption of a reefer during usage. It should be noted that several factors influence the average power consumption during the steady-state use phase of a reefer container. This includes, but is not limited to, the following:

- the setpoint temperature (internal temperature) to which the reefer container must be cooled;
- the ambient temperature outside the container;
- the rate of air changes or circulation required to regulate the concentrations of gaseous substances due to fruit respiration and atmospheric control;
- the temperature of the fruit when loaded into the reefer container (precooled or not);
- type of fruit packaging used;
- the size of the container (20-ft, 40-ft or 40-foot high cube);
- the type of technology in the containers' integral system;
- the type of refrigerant used by the refrigeration system;
- the age of the integral refrigerated container, which affects wear on parts such as door seals, and wall insulation efficiency;
- the control mode of the container;
- the position or location of the container in the reefer container stack.

From the above list, which was adapted from (Tassou, De-Lille & Ge, 2009; Spengler & Wilmsmeier, 2016; Getahun, 2017; Budiyanto & Shinoda, 2018; Stellingwerf, Kanellopoulos, van der Vorst & Bloemhof, 2018; Filina-Dawidowicz & Filin, 2019; Maiorino, Petruzziello & Aprea, 2021), it is clear that many variables potentially influence the power consumption of an integral reefer container. Ideally, a bottom-up analysis should be performed to determine each variable's influence on the average power consumption of a container. Although an assessment will lead to a more accurate average value for various scenarios, such an in-depth assessment is beyond the scope of this research.

Subsequently, Transnet Port Terminals (TPT) and three LSPs that own and operate intermodal terminals were approached to either provide an average power consumption value for their facility or partner for a comprehensive study. Two of the three intermodal terminal operators failed to respond to several requests to assist with the research, while TPT stated that it could not assist in providing the required data, nor did it plan to collect the data in the foreseeable future.

One of the LSPs, however, provided an average power consumption value for their terminal where citrus fruit was refrigerated in reefer containers from ambient temperatures (in winter) to 8 °C. The sample of 274 high-cube integral FEUs had an average power consumption value of 5.8 kWh – translating to 132.2 kWh day^{-1}.

A review of the literature to confirm if this power consumption value is representative is shown in Table 6.2. Results in Table 6.2 show that an FEU integral refrigerated container's average power consumption is 110 to 182 kWh day^{-1} which validates the value provided by the LSP. This means that an FEU integral refrigerated container can use up to 182 kWh of electricity per day (24 hr) to maintain the cold chain requirements. From Table 6.2, it is also evident that the peak power consumption is considerably higher than the average power consumption. These peak values occur when cargo is initially loaded into the reefer container or when the reefer container's refrigeration unit is switched on after a period where it was not operating. This peak power consumption later reduces when the container's internal temperature stabilises and approaches the setpoint temperature. Note that no distinctive power consumption value for high-cube containers could be found in the literature. The author recommends that further research is needed to establish more accurate average power consumption values of integral reefer containers.

Table 6.2: The power consumption of integral refrigerated containers

Source	Type of goods	Container size	Peak power consumption (kWh day^{-1})	Average power consumption (kWh day^{-1})
(Wilmsmeier & Spengler, 2016)	Various – frozen and chilled	TEU	-	38 – 88
(Wilmsmeier, Zotz, Froese & Meyer, 2014)	Various – frozen and chilled	TEU	-	35 – 42
(Getahun, 2017)	Apples	TEU	47 – 65	35 – 46
(Fitzgerald, Howitt, Smith & Hume, 2011)	Various – frozen and chilled	TEU	-	64,8
(Spengler & Wilmsmeier, 2016)	Various – frozen and chilled	TEU	-	34 – 71
(Budiyanto & Shinoda, 2018)	Unknown	FEU	180	175,2
(Wild, 2009)	Chilled goods	FEU	218,4 – 252	168
(Filina-Dawidowicz & Filin, 2019)	Various – frozen and chilled	FEU	-	180
(European Commission Directorate-General for Energy, 2020)	Various – frozen and chilled	FEU	-	158,4
(Van Der Sman & Verdijck, 2003)	Apples	FEU	-	110 – 182

In light of Table 6.2 and the LSP's value, a higher conservative power consumption value of 180 kWh day^{-1} is assumed as the average for an FEU, while a TEU uses 90 kWh day^{-1}. This higher conservative value is aligned with the overall "more conservative" trend of the GLEC framework (Smart Freight Centre, 2019) to prevent the underestimation of emissions.

Now that the average power consumption has been established, an emission intensity factor can be determined for both sizes of integral reefer containers. Almost all[18] integral reefer containers at

[18] Although electricity can be supplied by renewable sources such as solar or wind, this represents a negligibly small proportion of the industry. Also, the emissions effect of using diesel generators when power outages occur was deemed to be negligible.

logistical facilities in SA are powered by Eskom grid electricity. This necessitates using the fuel emission factor for SA grid electricity of 0.97 kg CO_2e kWh^{-1}, as discussed in Section 4.2. Table 6.3 indicates the resulting emission intensity factor for storing a TEU or FEU integral reefer container for 24 hours. The factors in Table 6.3 should be used to calculate the emissions from refrigerated storage of a reefer container filled with fruit.

Table 6.3: Emission intensity factor for the storage of an integral reefer container

Size of container	Emission intensity factor (kg CO_2e day^{-1})
Twenty-foot equivalent unit (TEU)	87
Forty-foot equivalent unit (FEU)	175

6.3.2 Container handling

The three types of facilities that handle containers are an inland container facility, an inland rail facility, and a maritime container terminal. According to the published article in Section 3.3, which analysed the various distribution activities, there is a notable difference between these facilities. This difference is due to the scale of operations and the type of handling equipment used at the facility. This inevitably results in each facility having a different handling emission intensity factor, as suggested below.

6.3.2.1 Inland container facility

Inland container facilities typically use reach-stackers to load or offload containers from road transport vehicles. Although onboard truck cranes can be used to load and offload containers from a truck, it is seldom that trucks transporting fruit destined for export are equipped with such cranes. Therefore, the emission intensity factor for inland container facilities is determined by analysing only reach stackers.

Two LSPs were contacted to provide data of their facilities' reach stacker. One of the LSPs, which operates a small seasonal container facility, provided fuel usage data and the total amount of containers handled by the reach stacker per year, as shown in Table 6.4. During the two years under study, 266 and 274 containers were offloaded from road transport vehicles and reloaded once required, meaning each container was handled twice (offloading and loading). This resulted in 532 container moves in 2019 and 548 in 2020. From the two years' data, it is evident that the average fuel consumption per container move is in the range of 1.4 to 2.1 ℓ of diesel.

To validate the fuel consumption, the minimum and maximum times that different models of reach stackers can operate with the calculated amount of fuel was also determined and this is shown in Table 6.4. The minimum time represents the minimum number of minutes a reach stacker can operate with the corresponding amount of fuel. Likewise, the maximum time states the maximum running time of a reach stacker with that calculated fuel consumption. Table 6.4 shows that, on average, a reach stacker can operate between 5 and 10 minutes on the calculated amount of fuel, which is a realistic time duration to load or offload a container.

Compared to literature, Wilmsmeier and Spengler (2016) estimate that horizontal activities in a maritime port collectively consume 4.7 ℓ of diesel per box moved. This includes moving containers by rubber-tyred and rail-mounted gantries, reach stackers, and Mafi tractors. The only other authors analysing the energy consumption of a reach stacker are Van Duin and Geerlings (2011). Unfortunately, the consumption factor is based on distance and not on time. The primary researcher could not find any other published peer-reviewed literature focusing on reach stackers.

Subsequently, it is deemed reasonable to assume that a reach stacker at an intermodal terminal, such as the LSPs, will consume 3.54 ℓ per container handled (loading and offloading).

Table 6.4: The average fuel consumption of a reach stacker and expected operating time

Year	Containers handled	Diesel consumed (ℓ)	Fuel consumed (ℓ) per container move (loading or offloading)	Calculated operating time (minutes) with various types of reach stackers capable of lifting a 34-tonne container			
				Kalmar Eco Reachstacker with Volvo engine		Konecranes reach stackers models SMV 4127-4545 TBX5 to SMV 4123-4545 CBX5 with various types of engines	
				Min	Max	Min	Max
2019	266	1129	2,12	8,49	12,73	6,37	10,61
2020	274	777	1,42	5,67	8,51	4,25	7,09
		Average	**1,77**	**7,08**	**10,62**	**5,31**	**7,09**

Using the value of 3.54 ℓ per container handled and the fuel emission factor for diesel, as stated in Section 4.2, yields an emission intensity factor of 11.5 kg CO_2e per container handled at an inland container facility using reach stackers.

6.3.2.2 Inland Rail Facility

According to the article in Section 3.3, reach stackers and fixed-tracked gantry cranes are used at inland rail terminals such as Belcon and City Deep. However, smaller rail facilities or sidings such as Worcester, Pienaarsrivier, and Newcon, only use reach stackers to handle containers.

In line with the GLEC framework, a more conservative (on the high side) emission intensity value is suggested, incorporating a rail-mounted gantry crane and reach stackers emissions. As a departure point, Transnet Freight Rail (TFR) was requested to provide data for the Belcon facility. Unfortunately, TFR stated that it could not assist in providing the required data, nor did it plan to collect the data in the foreseeable future.

However, authors such as Geerlings & Van Duin (2011) estimate that rail-mounted gantries consume 7 kWh per box moved. Using the emission factor for South African grid electricity of 0.97 kg CO_2e per kWh (see Section 4.2) results in 6.8 kg CO_2e emitted per rail-mounted gantry crane move. Assuming this value is representative and economies of scale do not change the diesel fuel consumption and subsequent emissions of a reach-stacker (11.5 kg CO_2e per container handled, as stated in Section 6.3.2.1), results in an emission intensity factor of 18.3 kg CO_2e per container handled at a rail terminal facility.

6.3.2.3 Maritime container terminal

Maritime container terminals have the highest emission intensity factor of all facilities that handle containers. This is due to the scale of activities and the considerable horizontal distance that port machinery has to travel. Several types of equipment, such as straddle carriers, reach stackers, rubber-wheeled and fixed track gantries, and Mafi tractors, are collectively used to load and offload containers in a port and to enable hinterland transport. The combination of equipment which predominantly uses diesel, with the exception of fixed track gantry cranes, results in these facilities having a large emission intensity.

The researcher and primary supervisor are working on a final-year Industrial Engineering research project to estimate an emission intensity factor for the Cape Town Container Terminal. The project uses a bottom-up approach utilising literature data since TPT was unwilling to provide primary data of equipment energy usage. Similar projects are also envisaged for other terminals in SA, preferably in collaboration with terminal operators.

Until the project is completed, the emission intensity factor of 30.1 kg CO_2e per container handle should be used as suggested in the GLEC frameworks (Smart Freight Centre, 2019). This factor should, however, be used with caution since the emission intensity of electricity for the suggested factor is different from that of electricity in SA.

6.3.3 Recommended factors for containers

Table 6.5 states the recommended emission intensity factors for handling and storing integral reefer containers at the various facilities. Two factors are suggested for handling – one if the container is shipped in only one direction (the container did not reposition empty), and another which includes the movement in both directions (filled with fruit in one direction and empty return). This differentiation is required due to the carbon mapping framework's assessing the complete round movement of reefer containers (see Chapter 7). Also note that the handling factors suggested are for all container sizes, while the emission intensity factor for refrigerated storage is for different-sized containers.

Table 6.5: Recommended emission intensity factors for the handling and storage of integral reefer containers

	Handling **(kg CO_2e/container)** (Source: Author developed from LSP data and (Smart Freight Centre, 2019))		**Storage** **(kg CO_2e day^{-1})** (Source: Author established from literature)	
	Container in one direction	Container in both directions (forward and empty return)	Twenty-foot equivalent unit (TEU)	Forty-foot equivalent unit (FEU)
Inland container facility	11,5	22,9	87,0	175,0
Inland rail facility	18,3	36,5		
Maritime container terminal	30,1	60,2		

6.4 Conclusion

The purpose of this chapter was to establish emission intensity factors for the various logistical facilities through which fresh fruit is exported from SA (**RO1(d)** and **RO5**). As antecedent to the chapter, Section 6.1 stated that a fundamental shift in how the emissions of refrigerated products are accounted for is needed. This shift requires that the emission intensity factors of refrigerated logistical facilities should consist of two parts – one for handling the cargo and the second for refrigerated storage. This is necessary since refrigerated products' emissions at a facility are a function of the storage duration. Further, this is also necessary to provide fair and accurate emission results since carbon assessment should be based on the actual storage durations of a shipment instead of industry averages.

Section 6.2 discusses the logistical facilities that handle and store pallets of fruit as a functional unit. The section presented a published peer-reviewed journal article that established an emission intensity factor of 7.52 kg CO_2e pallet-day^{-1} for storing pallets of fresh fruit in cold stores (**RO6**). Apart from the emission intensity factor, the article proposes a revolutionary new methodology that enables industry and other researchers to perform similar assessments for refrigerated logistical facilities. The section also suggested emission intensity factors for a maritime break-bulk terminal and an airport facility where fruit is handled and stored as part of the distribution process of pallets.

Section 6.3 suggested emission intensity factors for all the facilities or sites that handle and store reefer containers as functional unit. The section first discussed the emissions due to the refrigerated storage of integral reefer containers, whereafter factors for handling at the various facilities were suggested.

Table 6.6 summarises the various logistical facilities' emission intensity factors discussed and developed in this chapter. The table assesses the available literature factor and its suitability, and also indicates if a factor is derived from primary data. Finally, Table 6.6 states the confidence level in the recommended emission intensity factor.

Table 6.6: Summative assessment of logistical facilities emission intensity factors

		Factors available in literature	**Suitability of factors in literature**	**Factors calculated or derived from primary data in this project**	**Confidence level in recommended emission intensity factor**
Logistical facilities	**Pallets (storage and handling)**				
	Cold store or inland fruit facility	Some factors for refrigerated facilities exist.	Factors do not incorporate the duration of storage nor the emission intensity of SA energy. Not representative of fruit storage and handling.	Yes	High
	Break-bulk terminal	Some factors for refrigerated facilities exist.		Yes	Medium
	Airport facility	None specific to airport facilities.		Yes	Medium

		Factors available in literature	Suitability of factors in literature	Factors calculated or derived from primary data in this project	Confidence level in recommended emission intensity factor
	Containers (storage)				
	Storage	Energy consumption is found in the literature.	Energy consumption can be extrapolated to create an SA-specific factor.	No	Medium
	Containers (handling)				
	Inland container facility	No factors of these facilities exist in the literature.	NA	Yes	Medium
	Inland rail facility			Yes	Medium
	Maritime container terminal	Factors available in literature	Do not reflect the emission intensity of SA electricity	No. Project is, however, underway to determine factor.	Low

The following chapter presents the developed carbon mapping framework for the international distribution of fresh fruit (**Part V** of the dissertation document). The chapter also discusses the validation and presents a general discussion of the framework.

7. A carbon mapping framework for the international distribution of fresh fruit

This chapter falls into **Part V** of the dissertation document and presents the developed carbon mapping framework. The framework binds together all previous chapters of the dissertation document and is the apex of the research project. The developed framework provides specific guidance in determining a shipment of fresh fruits' total emissions (kg CO_2e) and the carbon footprint (kg CO_2e/kg of fruit) due to the distribution of the fruit. The chapter addresses the following research objective:

RO7: *Develop, verify* and *validate* a carbon mapping framework for the international distribution of fresh fruit.

Section 7.1 discusses general principles that the envisaged carbon mapping framework must incorporate to ensure that the framework is meaningful, compliant with existing literature, and potentially serve as an industry standard. Section 7.2 summarises the various inputs used to design and develop the carbon mapping framework.

Section 7.3 presents the developed carbon mapping framework for the international distribution of fresh fruit. The framework can function as an independent document and is therefore inserted in the dissertation document with a double border to indicate that this is a standalone document.

The objectives and expected outcomes of the verification and validation process are discussed in Section 7.4.1. This is followed by discussing the verification and validation of the individual steps of the framework in Section 7.4.2. In contrast, Section 7.4.3 discusses the verification and validation of the framework as a whole. Section 7.4.3 also introduces the individuals interviewed to validate the framework. Interviewees belonging to two different spheres (carbon realm and fruit or agricultural sector) were purposefully chosen to ensure the framework is valid from both an academic and an industry perspective. Finally, Section 7.5 consists of a brief discussion of aspects relating to the framework.

7.1 Emission accounting principles: a foundation of the framework

The *Greenhouse Gas Protocol* (WBCSD & WRI, 2004; WBCSD & WRI, 2011; WBCSD & WRI, 2013) prescribes five basic accounting principles that must be adhered to when accounting GHG emissions. These five principles apply to national, corporate, product, and service emissions accounting and reporting and are, therefore, essential for any emission assessment project. Table 7.1 states the five principles and describes them in terms of this research project. These principles form a cornerstone of the developed framework since they ensure that its results are a true, fair, and consistent representation of the emissions of different fresh fruit shipments.

Table 7.1: General principles for emission accounting

General principles for emission accounting	Description of principle
Relevance	The information and results of a carbon footprinting assessment must include all emission-generating activities in the distribution process to enable sound decision-making and analysis.
Completeness	The assessment must include all direct operational emissions – independent of the size. A minimum threshold value for exclusion of certain emission-generating activities may not be applied.

General principles for emission accounting	Description of principle
Consistency	The developed framework must prescribe a consistent emission accounting approach or methodology to enable comparison and performance tracking.
Accuracy	The collected and suggested data must be sufficiently precise to enable meaningful decision-making and confidence in the results. The emissions should be a true reflection of the real-world process emissions.
Transparency	The entire carbon footprinting process and associated information must be clear, understandable, and unbiased. The framework must describe all processes, assumptions, procedures, and limitations to allow for an auditable trail. The emission estimation process should be reviewed and verified by both internal stakeholders and external verifiers.

Source: Adapted from (WBCSD & WRI, 2004; WBCSD & WRI, 2011; WBCSD & WRI, 2013).

Apart from the general principles for emission accounting in Table 7.1, the research of Craig, Blanco and Caplice (2013) is an important input to the proposed framework. Craig *et al.'s* (2013) report titled '*Carbon Footprint of Supply Chains: A Scoping Study'* provides criteria for a standardised approach to calculating transportation emissions that should form the foundational elements of future research, such as the present envisaged framework. These five criteria are similar to the principles stated in Table 7.1 but are, however, focused on the logistical realm.

The five criteria suggested by Craig *et al.* (2013) are *breadth* (scope of emission-generating activities included), *depth* (extent of an activity's emissions included), *precision* (level of detail of the assessment), *comparability* (how well the results can be compared to other studies), and *verifiability* (degree of assurance of the methodology and results). According to the report by Craig *et al.* (2013), comparability is the most important criterion, at 39%, while breadth (19%), verifiability (18%), precision (13%), and depth (11%) are deemed to be less important criteria.

Apart from comparability, Craig *et al.* (2013) iterate the importance that future frameworks, tools, or methodologies contain a comprehensive and consistent set of WTW emission intensity factors for the various emission-generating activities included in the scope.

The proposed carbon mapping framework is, therefore, built on the general principles for emission accounting in Table 7.1 and the various criteria and requirements stated by Craig *et al.* (2013).

7.2 Inputs to develop the framework

The carbon mapping framework uses the research results and methodologies of Chapters 2 through 6 and typical distribution scenarios (addressed in Chapter 8) to design and develop the framework. The various inputs from Chapters 2 to 6 are summarised in Figure 7.1. All the inputs in Figure 7.1 are equally important since they contribute to one or more aspects or elements of the framework. The large number of inputs in Figure 7.1 used to develop the framework strengthens the overall research design and rigour since the various inputs can be triangulated. This triangulation of input data enables constant internal verification of the framework and ensures the validity of subsequent results.

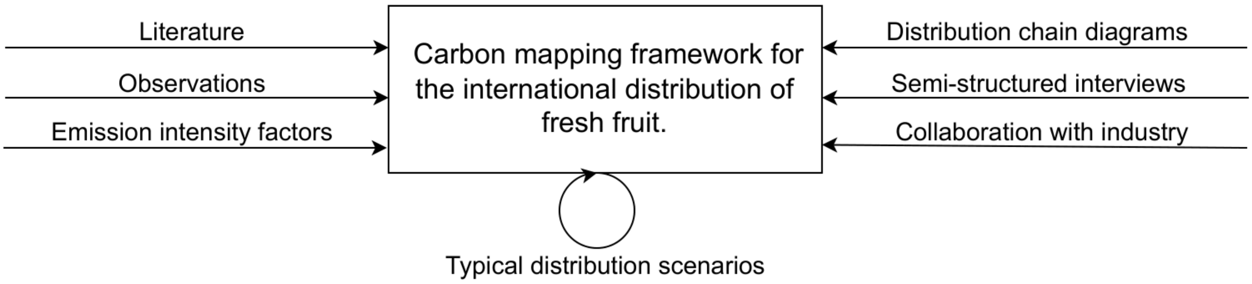

Figure 7.1: The various inputs used to develop the carbon mapping framework

An important and valuable source of *literature* used to develop the framework is the GLEC framework (Smart Freight Centre, 2019), which provides general guidance for determining distribution chain and individual distribution activities' emissions. However, the literature in Chapter 2, particularly the research conducted to develop the journal article in Section 2.3, is indispensable input for the framework. Building the framework on existing literature is important for conformance to existing emission accounting principles and ensures that the best elements of existing literature are used to develop the framework.

Observations of logistical activities and the export process (see Section 3.2) were fundamental to understanding how export fruit distribution occurs in the real world. No literature or other source could provide the researcher with the same insight and understanding as first-hand experience. These observations are vital to ensure the framework is developed to reflect the real-world distribution process.

A simple yet comprehensive set of *emission intensity factors* for all emission-generating activities are fundamental to the framework's value. Prescribing a framework without the means to quantify emissions results in the framework being less useful and user-friendly since emission intensity factors have to be retrieved from the literature. Including emission intensity factors in the framework also potentially increases the framework's accuracy since emission intensity factors relevant to the industry or specific emission-generating activities are prescribed.

The various *distribution chain diagrams* in Section 3.3 provide a consistent scope or breadth of emission assessment in the framework. This ensures that independent carbon footprinting projects assess the same emission-generating activities in a distribution chain. The diagrams and associated activities are a fundamental element of the framework and ensure that the results can be benchmarked or compared to other distribution scenarios.

Semi-structured interviews with subject matter experts (SMEs) in different research fields also provided essential input for the framework. The various individuals' opinions, recommendations, and critiques were incorporated into the framework to improve the framework and its usability. Note that semi-structured interviews used for the framework also include those described in Section 3.2.

Collaboration with industry partners, such as the representative fruit export bodies such as CGA, SATI, Hortgro, and BerriesZA, LSPs, fruit producers, fruit-packing facilities, packaging suppliers, fruit exporters, and logistics consultants, provided indispensable input to the framework. Continued interaction and consultation with these stakeholders throughout the project allowed the primary researcher to understand the macro-logistical process of fruit exports and to develop a framework that incorporates the small yet essential elements that affect emissions.

The final input used to develop the framework was the iterative application of preliminary versions of the framework to *typical distribution scenarios*. The entire framework was developed in parallel to estimating the emissions of typical distribution scenarios. These validated distribution scenarios (discussed in Section 8.1) ensure that the framework addresses all emission assessment aspects and potential anomalies. Applying draft versions of the framework to example case studies during development ensured that the framework covers all "gaps" that might exist.

7.3 Framework

A Carbon Mapping Framework for the International Distribution of Fresh Fruit

A Standard for Estimating GHG Emissions

Martin Johannes du Plessis

October 2022

Stellenbosch University

Introduction

This carbon mapping framework provides specific guidance in assessing the greenhouse gas (GHG) emissions due to the international distribution of fresh fruit from South Africa. The framework suggests a consistent and standard method for calculating the total emissions (kg CO_2e) and carbon footprint (kg CO_2e/kg of fruit) at a shipment level. The framework's scope includes all emission-generating distribution activities of packed fruit from the gate of a South African fruit-packing facility up to the international destination port. This includes round trips associated with empty vehicle movement and reefer container repositioning. All direct operational emissions generated by distribution activities are assessed on a Well-to-Wheel (WTW) basis. The framework allows any user with reasonable knowledge of the entire distribution process to estimate the emissions of fresh fruit. The framework is aligned with the broader guidance provided by the Global Logistics Emission Council's (GLEC) framework and follows the specified methodology for each mode of transport. The framework consists of six steps, as summarised in Figure 1.

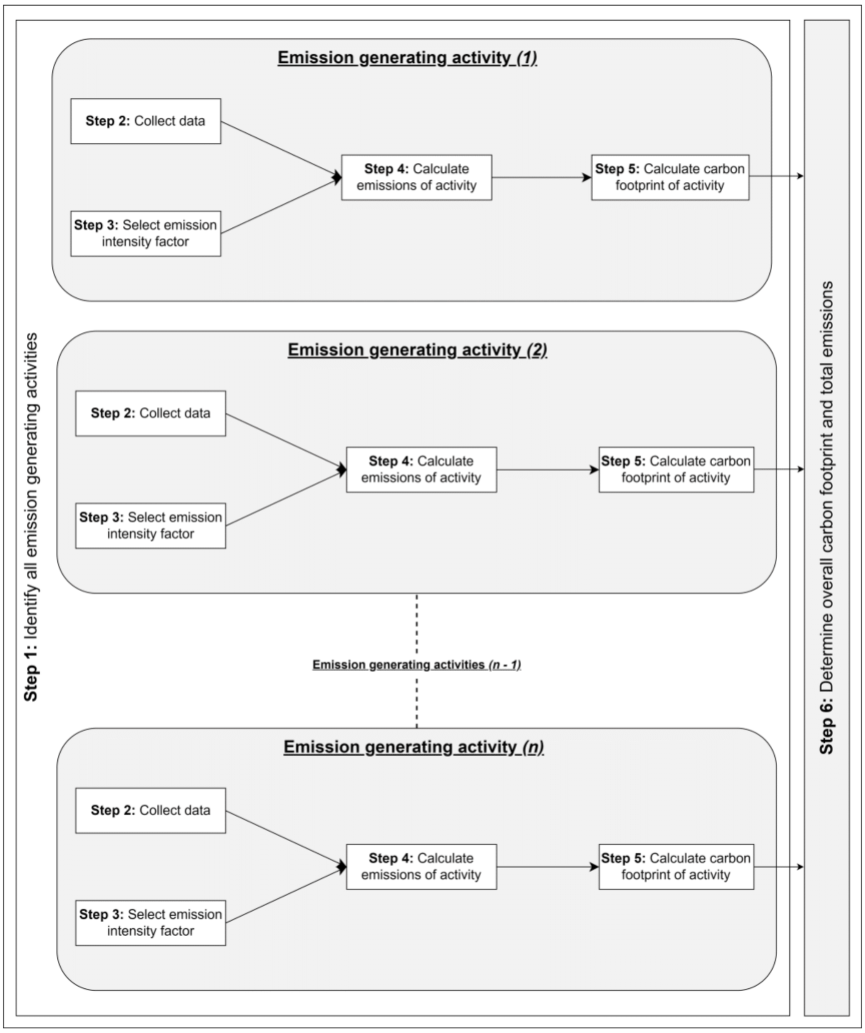

Figure 1: A visual exposition of the various steps in the framework

Each of the six steps in Figure 1 is discussed in detail in the remainder of the framework. In addition, the framework includes detailed emission intensity factors specific to South Africa in Appendix C of the framework document. Appendix D in this framework document states the framework's various assumptions and/or disclaimers.

Step 1: Identify all emission-generating activities

The first step entails the identification of the entire string of activities by which the fruit is distributed. Identifying the correct distribution activities is essential since this forms the basis of the framework. To identify all emission-generating activities, the first step is divided into two sub-steps, as discussed below.

1.1 Choose a diagram

Refer to du Plessis, van Eeden and Goedhals-Gerber's (2022a) journal article: *Distribution Chain Diagrams for Fresh Fruit Supply Chains: A Baseline for Emission Assessment*. Du Plessis et al. (2022a) propose five diagrams (see Appendix A) which depict all possible scenarios by which fresh fruit can be distributed. A summary of du Plessis et al.'s (2022a) distribution chain diagrams is listed for easy reference:

- Figure A.1 – distribute fruit directly from a packing facility to an ocean port of export using road transportation;
- Figure A.2 – distribute fruit from a packing facility to an airport of export using road transport;
- Figure A.3 – use road transportation to an ocean port of export via *n*-logistical facilities. A logistical facility refers to any site where pallets or containers are handled or stored.
- Figure A.4 – distribute fruit by road and rail to an ocean port of export via *n*-logistical facilities;
- Figure A.5 – distribute fruit using road transport to an airport of export via *n*-logistical facilities.

Choose one of the five diagrams from Appendix A which represents the shipment's distribution process.

1.2 Map the distribution activities

After choosing a diagram in Step 1.1, select the chain of activities (left to right) by which the fruit is distributed. This identifies all the activities in the 'downstream' movement of fruit from a packing facility to the destination port. Each column in a diagram represents an emission-generating activity for which data is collected and a calculation performed in the subsequent steps of the framework. **List and number each activity identified in the diagram from *1* to *n*, starting with the leftmost transport via road transport. The first activity in all diagrams, the loading of fruit, is therefore omitted. Note that *n* denotes the total number of activities in the diagram.**

Step 2: Collect data

Information must now be collected for each activity identified in Step 1. Before the minimum data requirements for each activity and mode are stated, some requirements for weight, distance and fruit losses are discussed.

2.1 Weight

The framework makes use of two different weights – *nett* and *gross weight*. The *nett weight* represents the actual weight of edible fruit that a consumer can purchase and is typically displayed on a carton of fruit. However, the *gross weight* includes the weight of all packing materials and additional fruit packed to compensate for moisture loss during the distribution of the fruit. **The only variables required are the nett weight (kg) per carton of fruit and the number of cartons per pallet. These two values**

must be collected and may not be estimated. Equations (1-3) should be used to determine the gross and nett weight per pallet.

Gross weight per carton
Equation (1) should be used to determine the gross weight of a single carton of fruit. Equation (1) accounts for the weight of additional fruit packed into a carton to compensate for fruit moisture loss during distribution. The weight of this additional fruit typically ranges between 3–5% of the nett carton weight. Equation (1) also includes the weight of a carton's packaging material.

$$Carton\ Gross\ Weight = Carton\ Nett\ Weight + Moisture\ Loss\ Provision + Packing\ Material\ Weight \quad (1)$$

Where:
Carton Gross Weight = the gross weight (kg) per carton at the start of distribution
Carton Nett Weight = the nett weight (kg) per carton as displayed on the packaging
Moisture Loss Provision = the weight (kg) of additional fruit to compensate for moisture loss
Packaging Material Weight = the weight (kg) of all packaging materials used per carton

Note that if a value for weight loss provision and the packaging material weight cannot be obtained, a value of 1 kg should be used to collectively account for these two variables.

Gross weight per pallet
Equation (2) should be used to determine the gross weight per pallet of fruit. Equation (2) accounts for the weight of a pallet's base.

$$Pallet\ Gross\ Weight = \frac{Cartons\ per\ Pallet * Carton\ Gross\ Weight + Pallet\ Base\ Weight}{1000} \quad (2)$$

Where:
Pallet Gross Weight = the gross weight (t) per pallet at the start of distribution
Cartons per Pallet = the number of cartons stacked onto a pallet
Carton Gross Weight = the gross weight (kg) per carton as calculated from Equation (1)
Pallet Base Weight = the weight (kg) of the pallet base

If the weight of the pallet base in Equation (2) cannot be obtained, a value of 28 kg should be used. This represents the weight of a typical wooden pallet with dimensions of 1 200 x 1 000 mm.

Note that the gross shipment weight (weight involved in an activity) is the gross pallet weight according to Equation (2) times the number of pallets in the activity.

Nett weight per pallet
Equation (3) shall be used to determine the nett weight per pallet of fruit. Note that this is the total edible weight of all fruit per pallet, meaning the weight of a pallet base, packaging and moisture losses are excluded. This weight is calculated in kilograms.

$$Pallet\ Nett\ Weight = Cartons\ per\ Pallet * Carton\ Nett\ Weight \quad (3)$$

Where:
Pallet Nett Weight = the nett weight (kg) per pallet
Cartons per Pallet = the number of cartons stacked onto a pallet
Carton Nett Weight = the nett weight (kg) per carton as displayed on the packaging

Note that the nett shipment weight (weight involved in an activity) is the nett pallet weight according to Equation (3) times the number of pallets in the activity.

The gross weight should be used to determine the total emissions (kg CO_2e) generated by an activity in Step 4. The nett weight of fruit should be used when emissions are apportioned or allocated to determine the carbon footprint (kg CO_2e/kg fruit) in Step 5. If a shipment consists of different fruit or packaging types, repeat Step 2.1 for each type of fruit or packaging variation in a shipment. The total shipment nett and gross weight must be recorded at each emission generating activity identified in Step 1.

2.2 Distance

The framework uses the distance travelled (km) between the point of loading and offloading as distance. Therefore, the travel distance does not refer to the round-trip distance travelled by a vehicle.

An estimated distance between the point of loading and offloading may only be used if the actual distance that a vehicle travelled cannot be retrieved. If distances are to be estimated, the distance recommended by the following sources for each transportation mode should be used and adjusted as required according to the GLEC framework (Smart Freight Centre, 2019)**:**

- Road transport: Google Maps (https://maps.google.com/) distance + 5%;
- Rail transportation: See Table B in the framework's Appendix B for a recommended rail distance matrix;
- Deep-sea ocean transport: SeaRoutes (https://classic.searoutes.com) distance + 15%;
- Air transportation: Distance (https://www.distance.to) distance + 95km.

All distances in the framework should be in kilometres. If a distance is in nautical miles, it should be converted to kilometres by multiplying by 1.852. For distances in miles, the value should be converted to kilometres by multiplying it by 1.609.

2.3 Accounting for losses during distribution

Since fresh fruit has precise handling, storage and transportation requirements, there is a possibility that fruit losses can occur during each step of the distribution process. These losses lead to a reduction in the amount of fruit that eventually reaches the port of import. Therefore, the term "losses" does not refer to the loss of the entire consignment of fruit but rather the percentage difference between what the distribution process starts with and what arrives in acceptable quality at the port of import.

Losses in a consignment can occur due to spoilage (temperature breaks in the cold chain or incorrect storage conditions), damage due to incorrect handling, theft during transport or other calamities such as transportation accidents. **In the distribution process, this loss typically ranges between 0 – 5% for a shipment of fruit.** The actual loss per consignment can typically only be determined by fruit exporters who have visibility of the entire distribution process. This means it is difficult to accurately estimate the actual loss per consignment. **If the user cannot obtain a specific loss percentage value, a loss value of 3% should be used in the framework.** Note that the losses are only accounted for at the end of the distribution process (see Step 6) and not per activity.

2.4 Required data per activity

The data requirements for all possible distribution activities are stated below. Note that this is the minimum data required for each activity to use the framework. **For each activity identified in Step 1, collect the data stated below.**

<u>Transportation</u>

- Road transportation – vehicle description (e.g. articulated truck with 40-foot reefer container, interlink tautliner, or flat deck truck), maximum payload capacity (t), loading conditions (refrigerated or ambient), unit of transport (pallets or container), distance travelled (km), gross shipment weight (t), nett shipment weight (kg), repositioning circumstances (loaded with alternative cargo or empty).

- Air transportation – the type of aeroplane (dedicated cargo plane or combination plane), distance travelled (km), gross shipment weight (t), nett shipment weight (kg).
- Rail transportation – distance travelled (km), gross shipment weight (t), nett shipment weight (kg).
- Deep-sea ocean transport –
    - Container vessel: distance travelled (km), size of reefer container (20- or 40-foot), container height (standard height or hi-cube), equivalent TEU capacity (40-foot standard = 2 TEU, 40-foot hi-cube = 2.25 TEU), route or trade lane the vessel travels, repositioning of container (loaded with alternative cargo or empty), nett shipment weight (kg).
    - Conventional reefer vessel: distance travelled (km), gross shipment weight (t), nett shipment weight (kg), repositioning circumstances (loaded with alternative cargo or empty).

<u>Loading, offloading and storage</u>

Since all loading and offloading activities are performed at a site or facility, the loading and offloading activities are grouped with the site where these activities occur. Subsequently, each instance of offloading, storage and loading is analysed as a single activity in the remainder of the framework. The data requirements for the various types of logistical facilities and ports of export are different due to the function of the site and the unit of handling (pallet of fruit or a reefer container). The following list states the minimum data requirements for the different types of logistical facilities and ports of export.

- Logistical facilities or sites
    - Inland fruit facility or cold store – number of pallets stored, storage duration (days), nett shipment weight (kg);
    - Inland container facility – was container handled or not, size of reefer container (20- or 40-foot), storage duration (days), nett shipment weight (kg);
    - Inland rail facility – the size of reefer container (20 or 40-foot), storage duration (days), nett shipment weight (kg).

- Port of export
    - Maritime container terminal – the size of reefer container (20- or 40-foot), storage duration (days), repositioning of container (loaded with alternative cargo or empty), nett shipment weight (kg);
    - Break-bulk terminal – loaded directly into a reefer vessel or stored in the break-bulk terminal cold store, number of pallets if stored and storage duration (days) if applicable, nett shipment weight (kg).

<u>Step 3: Select emission intensity factors</u>

A suitable emission intensity factor must be selected for each activity identified in Step 1. Use the developed emission intensity factors stated in Appendix C of the framework document. These factors are specific to South African fruit export conditions. Existing emission intensity factors, developed by international researchers for African conditions, prove to be less than ideal. Although the emission intensity factors in Appendix C are not perfect, they are currently the most relevant and accurate factors for South African fruit export conditions. Pay attention to the information collected in Step 2 to ensure that the most relevant factor is selected. The chosen emission intensity factor must reflect the loading conditions (load factor) and the vehicle's empty repositioning (empty running). It is essential to select the correct factor for all distribution activities.

Some considerations with regard to the choice of an emission intensity factor:
If there is uncertainty about which factor to choose for a specific mode of transportation in Appendix C, always choose the higher emission intensity factor for the mode. In the absence of sufficient information regarding the repositioning of vehicles or empty containers, the higher emission intensity factor should be chosen.

State the factor that was selected for an activity. It is essential to describe the chosen emission intensity factor for future reference and verification purposes. Note that two emission intensity factors, one each for handling and storage, are required for facilities or sites that handle containers. All other activities require only a single emission intensity factor.

Step 4: Calculate emissions for each activity

For each activity identified in Step 1, a calculation is now performed using the collected data from Step 2 and the selected emission intensity factor from Step 3. This calculation states the total CO_2e emissions (kg) due to that activity. The formulas that should be used to quantify the emissions of all transportation, handling and storage activities are stated below.

4.1 Transportation

Equations (4) and (5) should be used to determine the emissions for all transportation activities.

Transport via road-, rail-, air- and conventional reefer vessel
The emissions of road-, rail-, air- and conventional reefer vessel are based on the gross shipment weight and the distance travelled and are calculated as shown in Equation (4):

$$Emissions = \frac{Gross\ Shipment\ Weight * Distance * Emission\ Intensity\ Factor}{1000} \quad (4)$$

Where:
Emissions = total CO_2e emissions emitted by the transport vehicle during the transport activity (kg)
Gross Shipment Weight = the gross weight of the shipped fruit (t)
Distance = the distance travelled by the vehicle between loading and offloading points (km)
Emission Intensity Factor = the emission intensity factor for the transport vehicle (g CO_2e/t-km)

Remember to deduct the weight of a pallet base when calculating the Gross Shipment Weight during air transport. Also, in the scenario where a reefer container is used to transport fruit via a conventional vessel, Equation (4) should still be used.

Transport via deep-sea container vessel
The calculation method for a container vessel is not based on the gross shipment weight (t) but on the number of twenty-foot equivalent units (TEUs) shipped. Note the following conversion factors as stated in the GLEC framework (Smart Freight Centre, 2019): a standard 40-foot container is equivalent to two TEUs, while a high-cube container is equivalent to 2.25 TEUs.

$$Emissions = \frac{TEUs * Distance * Emission\ Intensity\ Factor}{1000} \quad (5)$$

Where:
Emissions = the total CO_2e emissions emitted by the vessel during the transport activity (kg)
TEUs = the equivalent number of TEUs shipped

Distance = the distance travelled by the vehicle between loading and offloading points (km)
Emission Intensity Factor = the emission intensity factor for the transport vehicle (g CO_2e/TEU-km)

4.2 Loading, offloading and storage

To calculate the handling and storage emissions of a logistical facility or port of export, Equations (6) and (7) should be used. Equation (6) must be used for all sites that handle and store pallets of fruit as functional units, while Equation (7) should be used for all sites that handle and store containers. If pallets or containers are transshipped (storage duration of fewer than 24 hours) through a facility, a storage duration of one (1) day should be used. If the storage duration is more than one day and is a decimal value (e.g. 36 hours is 1.5 days), the decimal value must be used in Equations (6) and (7).

Handling and storage of pallets:

$$Emissions = Pallets * Storage\ Duration * Emission\ Intensity\ Factor \quad (6)$$

Where:
Emissions = the total CO_2e emissions due to the handling and storage activity (kg)
Pallets = the number of pallets stored in the facility
Storage Duration = the number of days the pallets are stored (days)
Emission Intensity Factor = the emission intensity factor for the facility or site (kg CO_2e pallet-day^{-1})

If pallets are moved through a break-bulk terminal without storage, the emissions due to loading are accounted for by the reefer vessel's transportation calculation. This means that Equation (6) does not have to be applied.

Handling and storage of containers:

$$Emissions = Emission\ Intensity\ Factor_{Handling} + (Emission\ Intensity\ Factor_{Storage} * Storage\ Duration) \quad (7)$$

Where:
Emissions = the total CO_2e emissions due to handling and storage of a container (kg)
Emission Intensity Factor$_{Handling}$ = emission intensity factor for handling a container (kg CO_2e/container)
Emission Intensity Factor$_{Storage}$ = emission intensity factor for storing a container (kg CO_2e day^{-1})
Storage Duration = the storage duration (days)

Step 5: Calculate carbon footprint for each activity

For each emission generating activity in Step 1, the carbon footprint should be calculated based on the nett weight of fruit involved in the activity. This is done by dividing the activities emissions amongst the nett weight of fruit involved in the activity, as shown in Equation (8). The carbon footprint should be calculated for each activity in Step 1.

$$Carbon\ Footprint = \frac{Emissions}{Nett\ Weight\ of\ Fruit} \quad (8)$$

Where:
Carbon Footprint = the carbon footprint of the analysed activity (kg CO_2e/kg fruit)
Emissions = the emissions of the analysed activity from Step 4 (kg CO_2e)
Nett Weight of Fruit = the nett weight of fruit involved in the activity (kg)

Step 6: Determine overall carbon footprint and total emissions

In this step, the overall carbon footprint of the entire distribution chain is determined and used to calculate the total distribution emissions of the shipment. The carbon footprint of each activity (Step 5) is used to determine the overall emissions of all distribution activities since this avoids the ambiguity of a change in the number of pallets distributed.

6.1 Overall carbon footprint

The total carbon footprint of the entire distribution process should be calculated using Equation (9).

$$Carbon\ Footprint_{Total} = \frac{\sum_{1}^{i}(Carbon\ Footprint)}{(1 - Losses)} \qquad (9)$$

Where:

$Carbon\ Footprint_{Total}$ = the total carbon footprint of the entire distribution chain (kg CO_2e/kg fruit)
i = the total number of activities in the distribution process
$Carbon\ Footprint$ = the carbon footprint of each activity from Step 5 (kg CO_2e/kg fruit)
$Losses$ = the percentage of fruit loss during the entire distribution process (%)

6.2 Total distribution chain emissions

The total emissions of the entire distribution process are calculated using the nett weight of fruit at the end of the destination process. The nett weight of fruit that arrives at the international destination port is the nett weight of fruit moved during the last distribution activity. Equation (10) should be used to calculate the total distributional emissions of the shipment or consignment.

$$Emission_{Total} = \frac{Carbon\ Footprint_{Total} * Nett\ Weight\ of\ Fruit_{Destination}}{1000} \qquad (10)$$

Where:

$Emission_{Total}$ = the total emissions of the entire distribution process (t CO_2e)
$Carbon\ Footprint_{Total}$ = the total carbon footprint of the entire distribution chain (kg CO_2e/kg fruit)
$Nett\ Weight\ of\ Fruit_{Destination}$ = the nett weight of fruit arriving at the destination port (kg)

End of framework

Recommendations when using the framework

- Use software such as Excel for all calculations in Steps 3 to 6.
- Do not round any preliminary answers during any step of the framework. Rounding will have a significant impact on the final results. Work with at least five significant figures throughout all calculations if decimal numbers are used.
- Since the actual distance travelled provides the most accurate results, using actual distances is preferred. However, if the actual distance values cannot be obtained from an LSP, the data values may be estimated as specified in Step 2.

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Appendix A: Distribution Chain Diagrams

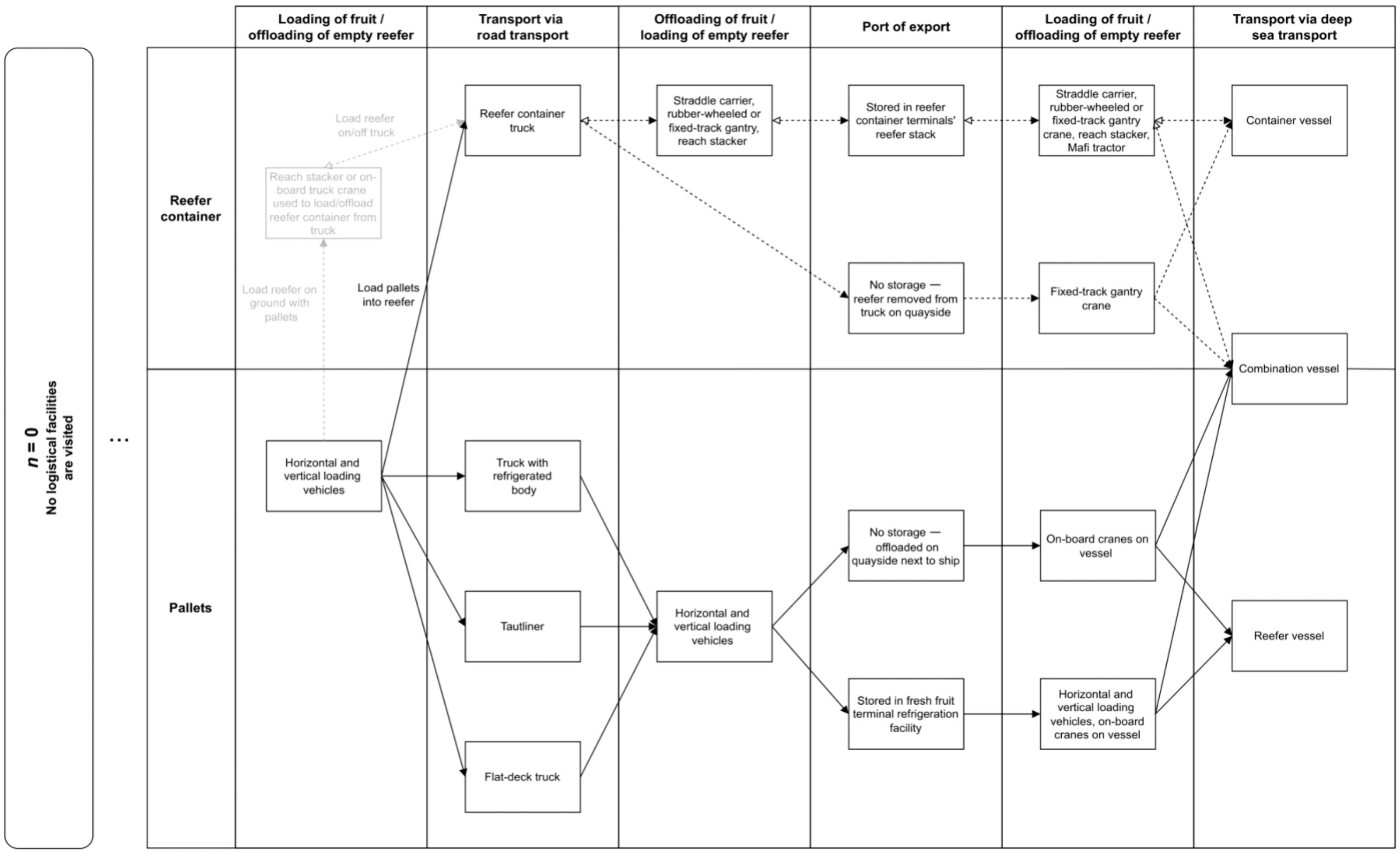


Figure A.1: Distribute fruit directly from a packing facility to an ocean port of export using road transportation

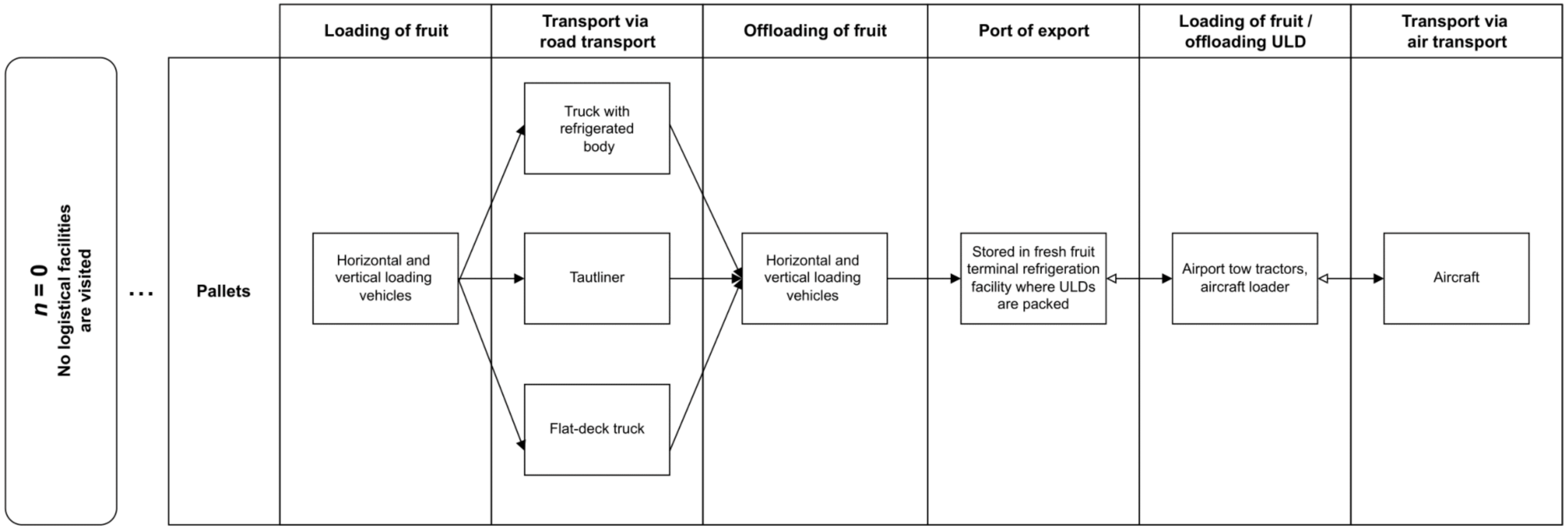


Figure A.2: Distribute fruit from a packing facility to an airport of export using road transport

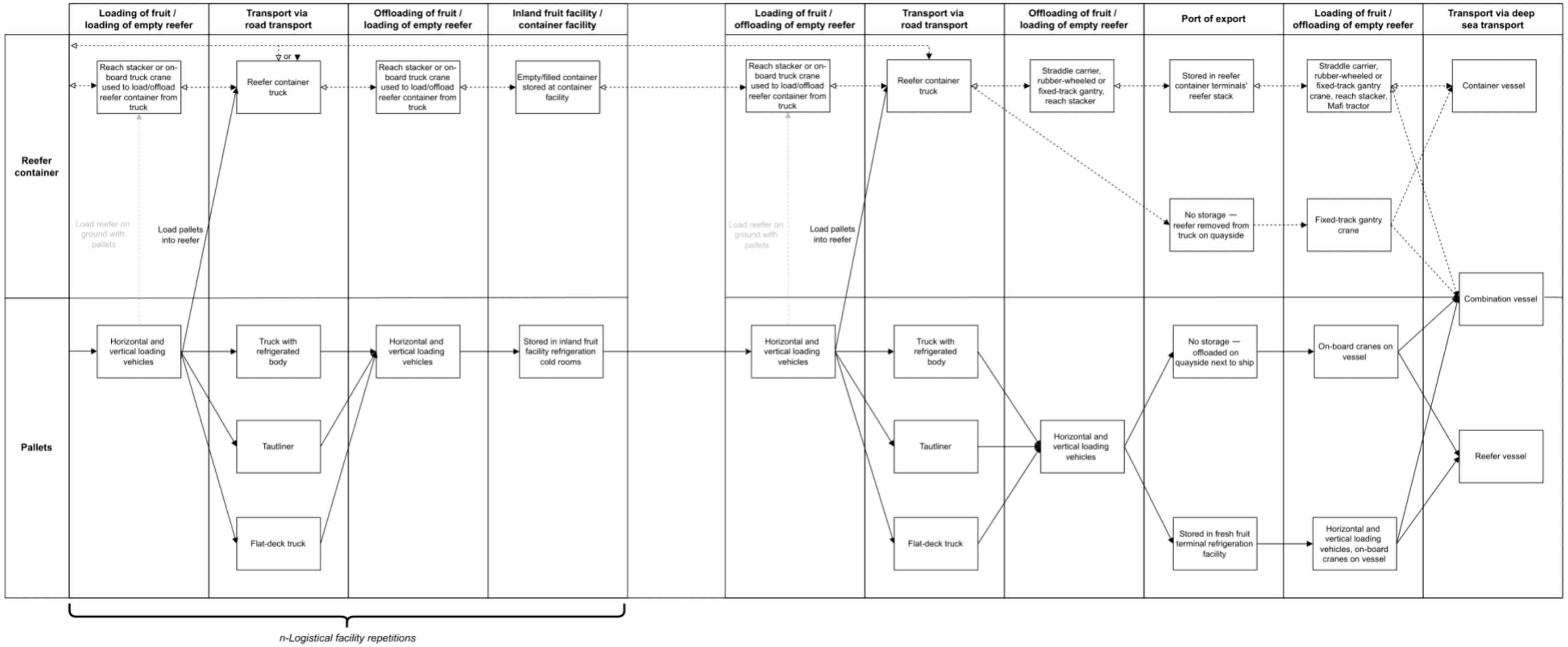


Figure A.3: Road transportation to an ocean port of export via n-logistical facilities (n = 1, 2, 3…)

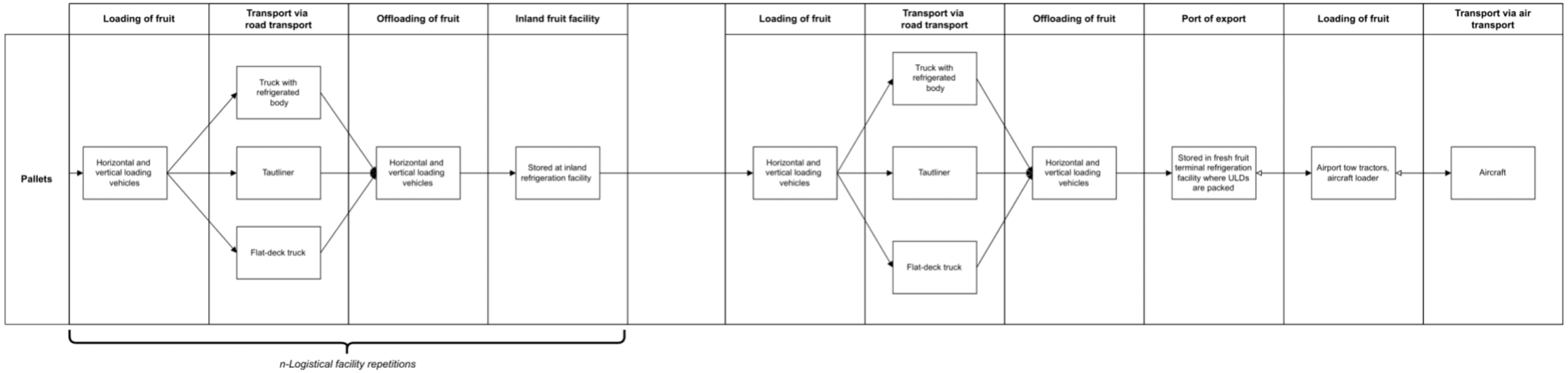


Figure A.4: Distribute fruit by road and rail to an ocean port of export via n-logistical facilities (n = 0, 1, 2…)

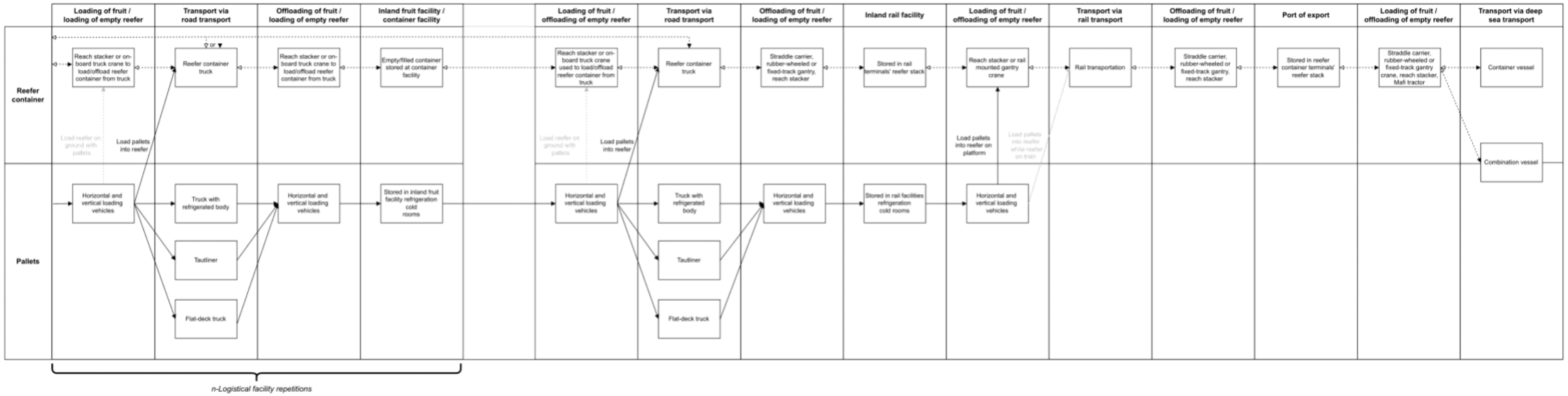


Figure A.5: Distribute fruit using road transport to an airport of export via n-logistical facilities (n = 1, 2, 3…)

Appendix B: Relevant fruit terminal rail distances

Table B indicates the rail distance between various South African railway terminals or sidings that handle containers and ports of export. The distance matrix in Table B shows the actual travel distance in kilometres for feasible combination pairs. Unfeasible container facility and port of export pairs are indicated with a dash (-). Note that the services required for reefer containers do not currently exist on all the railway lines. However, the prospect of future development is possible and they are therefore included.

The following link (Rail Terminal Facilities) displays the location of several railway stations or sidings in South Africa that frequently or occasionally handle containers and or grain products. These locations were determined using Transnet Freight Rail (TFR) data and the Freight Demand Model (FDM™) data. Note that no ore or coal rail terminal facilities are indicated in the suggested map.

Table B: Distance matrix indicating the distance to various ports of export via rail

		Port of export				
		Durban	Cape Town	Port Elizabeth	East London	Maputo
Rail container facility or siding	Bela Bela	867	1686	1249	1161	644
	Belcon (Bellville)	1965	26	1040	1370	-
	Bloemcon (Bloemfontein)	784	1184	695	607	-
	City Deep	714	1526	1084	1017	581
	Musina	1265	2093	1656	1568	775
	Nelspruit	835	1885	1437	1349	216
	Newcon (Newcastle)	406	-	-	-	-
	Pienaarsrivier (Marble Hall)	828	1646	1209	1121	675
	Polokwane	1040	1868	1431	1343	550
	Sentrarand	736	1552	1115	1027	578
	Tzaneen	1161	-	-	-	438
	Worcester	1787	171	862	1212	-

Source: adapted from FDM™ data.

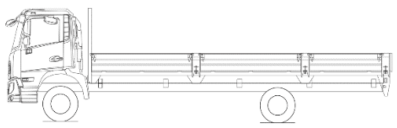
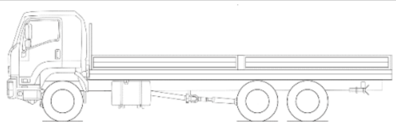
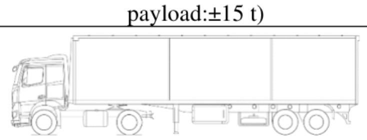
Appendix C: Emission intensity factors for the South African fruit export industry

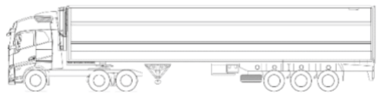
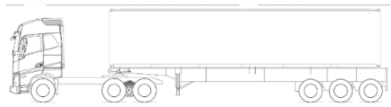
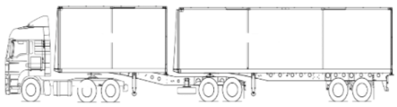
This appendix states the emission intensity factors required in Step 3 of the framework. All the listed emission intensity factors were developed explicitly for the South African fresh fruit export sector, and therefore incorporate the real-world operating conditions. These factors are the most suitable emission intensity factors currently available and will best reflect the actual emissions of fresh fruit distribution. If there is uncertainty about which factor to choose for a specific activity, it is advised to always choose the higher emission intensity factor. In the absence of sufficient information regarding the repositioning of vehicles or empty containers, it is advised that the higher emission intensity factor should also be chosen.

Road transportation

Table C states emission intensity factors for various types of road transport vehicles. These vehicles are the most common on-road trucks used to transport fruit destined for export. A description of each vehicle is stated in Table C to aid in choosing the most appropriate factor. In addition, different options are stated for the type of load, load factor, and empty running of the vehicle to describe the appropriate conditions of the emission intensity factor. Two emission intensity factors are given for each truck – one for dry cargo transported at ambient temperatures and a second for refrigerated cargo. Note that the *refrigerated* factor must be chosen if the fruit is refrigerated during transportation. The emission intensity factors suggested are based on original research reported in two journal articles (du Plessis, van Eeden & Botha, 2022c, *in press*; du Plessis, van Eeden, Goedhals-Gerber & Else, 2022d, *in review*) developed by the authors using industry input from LSPs, fruit export stakeholders, TruckScience data, and the EcoTransIT emission calculator.

Table C: Emission intensity factors for road transportation of fresh fruit

Vehicle description	**Description of factor**			**Emission intensity factor (g CO_2e/t-km)**	
	Load type	**Empty Running**	**Load factor**	**Dry**	**Refrigerated**
 4x2 Rigid (GVM:±14 t, max payload:±8 t)	Pallets	45%	55%	150	171
			85%	107	128
 6x4 Rigid (GVM:±24 t, max payload:±15 t)	Pallets	45%	55%	121	143
			85%	86	100
 4x2 truck tractor and tandem semi-trailer (GCM: ±34 t, max payload: ±15 t)	Pallets	10%	55%	174	184
			85%	116	122

 6x4 truck tractor and tridem semi-trailer (GVM: ±49.5 t, max payload: ±32 t)	Pallets	10%	55%	87	91
			85%	59	62
		50%	55%	148	157
			85%	99	105
 6x4 truck tractor and tridem semi-trailer loaded with 40-foot reefer container (GCM: ±49 t, max payload excl. container: ±28 t)	Container	10%	55%	98	103
			85%	66	70
		50%	55%	168	173
			85%	112	115
 Standard interlink tautliner - 6x4 truck tractor with tandem- tandem trailer (GCM: ±56 t, max payload: ±36 t)	Pallets	10%	55%	99	-
			85%	67	-

Source: developed by the author.
Diagrams used with permission from TruckScience.

Rail transportation

The emission intensity factor for rail transportation of reefer containers is stated in Table D. The suggested emission intensity factor was calculated according to the EcoTransIT methodology using the EcoTransIT emission calculator (EcoTransIT, 2022). The factor is based on the actual operating conditions of a few pilot projects where citrus fruit was transported in 40-foot (FEU) hi-cube integral refrigerated containers, each loaded with 24 tons of cargo. The suggested emission intensity factor considers the actual operating conditions, such as the train weight, the load factor, the repositioning of empty reefer containers, and the time duration of the trip. The emission intensity factor assumes containers were repositioned empty by rail transport, hence a 50% empty running. The factor includes the refrigeration of fruit on board the train during transportation.

Table D: Emission intensity factor for rail transport of reefer containers

Traction type	Load factor	Empty running	Emission intensity (g CO_2e/t-km)
Diesel	80%	50%	31.5

Source: developed by the author.

Deep-sea ocean transport

The emission intensity factors for deep-sea ocean transport are categorised according to the two types of vessels, as shown in Table E – container vessels and conventional reefer vessels.

The emission intensity factors for container vessels were derived from the *2021 Global Ocean Container Greenhouse Gas Emission Intensities* (Smart Freight Centre, 2021). Two emission intensity factors for each trade lane or route are suggested for container vessels. The first emission intensity factor should be used when shipping a reefer container filled with fruit in one direction. This assumes the reefer container does not return empty to South Africa. The second factor represents the emission intensity factor of shipping a reefer container filled with fruit in one direction and returning the empty container to South Africa. Note that the emission intensity factor's unit for container vessels is g CO_2e/TEU-km and not g CO_2e/t-km. The emission intensity factor suggested by the Smart Freight Centre (2021) assumes that vessels operated at 70% capacity utilisation.

Table E also suggests an emission intensity factor for conventional reefer vessels that transport pallets of fruit. The suggested emission intensity factor was calculated based on data provided by an LSP that owns and operates a fleet of reefer vessels. The emission intensity factor was calculated according to the EN 16258:2012 methodology and is aligned with the GLEC framework. This emission intensity factor has an average empty running of 21.5% and a load factor of 91.7%.

Table E: Emission intensity factors for deep-sea transportation

Vessel type and source	Trade lane or route	Emission intensity factor (g CO_2e/TEU-km)	
		Refrigerated container in one direction (filled with fruit)	Refrigerated (filled with fruit) in one direction and empty return
Container vessel Adapted from (Smart Freight Centre, 2021)	Africa to-from Asia	155.4	243.1
	Africa to-from Europe	174	276.2
	Africa to-from North America (East Coast/Gulf/West Coast)	193.5	327.7
	Intra-Africa	233	368.2
	Other (only used when origin-destination pair is not listed)	179.2	285.9
Conventional reefer vessel (Source: Author developed from LSP data)	All routes	**Emission intensity factor (g CO_2e/t-km)**	
		48.6	

Air transportation

The emission intensity factors for air transport are shown in Table F. Three possible planes can be used to air freight fruit from South Africa – a belly freight or hybrid aircraft (commonly referred to as a combi plane), a dedicated freight aircraft, and a third class if the aircraft type is unknown. The third type of aircraft should be selected if there is uncertainty. The factors are based on the EN 16258 methodology and assume a load factor of 70% for freight and 80% for passengers.

Table F: Emission intensity factor for air transport

Type of aircraft	Emission intensity (g CO_2e/t-km)
Combi	990
Freighter	560
Unknown	800

Source: GLEC framework (Smart Freight Centre, 2019).

Logistical facilities

All factors for logistical facilities consist of two parts: an emission intensity factor for the physical handling at a facility and a second emission intensity factor for the storage in or at the facility. The emission intensity factors for sites that handle pallets and reefer containers are discussed below.

Pallets

Three types of facilities handle and store pallets of fruit – an inland fruit facility or cold store, the break-bulk terminal in a maritime port, and an airport facility. A combined factor for handling and storage is suggested for all three types of facilities since no storage can essentially be performed without handling a pallet. Also, pallets of fruit never move through a cold store without being stored, and the energy allocated to storage and handling are often inseparable, making separate calculations nearly impossible. Subsequently, a separate emission intensity factor for handling and storing pallets is not suggested. The exception is a break-bulk terminal where pallets of fruit are offloaded from a truck on the quayside and reloaded directly into a reefer vessel. The factors suggested for the three types of facilities are stated in Table G. Note that the unit of the emission intensity factor is per pallet and not tonnes.

Table G: Emission intensity factors for facilities that handle pallets

	Handling (kg CO_2e $pallet^{-1}$)	**Combination of handling and storage** (kg CO_2e pallet-day^{-1})
Inland fruit facility or cold store	-	7.52[A]
Break-bulk terminal	Included in the conventional reefer vessel emission intensity factor (no storage – offload on the quayside)	25.4[B]
Airport facility	-	50.8[C]

Source: author calculations and (du Plessis, van Eeden & Goedhals-Gerber, 2022b).

[A] Large-scale commercial cold storage facility with an average dwell time of 6.76 days.

[B] Large-scale commercial cold store with an average dwell time of 2 days.

[C] Large-scale commercial facility with an average dwell time of 1 day.

The following link (Cold Stores in South Africa) provides a view of the location of some of the cold storage facilities in South Africa identified by the researcher.

Containers

The three types of facilities that handle or store containers are an inland container facility, an inland rail facility, and a maritime container terminal. A separate emission intensity factor for handling and storage is suggested for each of these facilities, as shown in Table H. Two factors are suggested for handling – one if the container is shipped in only one direction (the container did not reposition empty) and another which includes the movement in both directions (filled with fruit in one direction and empty on return). Note that the factors suggested for handling are for all sizes of containers. Table H also suggests an emission intensity factor for the refrigerated storage of different-sized containers.

Table H: Emission intensity factors for the handling and storage of integral reefer containers

	Handling (kg CO_2e/container) Source: author developed from LSP data and (Smart Freight Centre, 2019).		**Storage (kg CO_2e day^{-1})** Source: author established from literature.	
	Container in one direction	**Container in both directions (forward and empty return)**	**Twenty-foot equivalent unit (TEU)**	**Forty-foot equivalent unit (FEU)**
Inland container facility	11.5	22.9	87.0	175.0
Inland rail facility	18.3	36.5		
Maritime container terminal	30.1	60.2		

Appendix D: Assumptions and or disclaimers

The overall framework

1. Only the emissions of direct logistical activities involved in distributing fresh fruit are assessed.
2. The emissions due to infrastructure construction and manufacturing of vehicles or other equipment are not analysed.
3. The framework assumes the symmetrical movement of reefer containers during the forward and reverse distribution process. Therefore, the same handling equipment and vehicles move empty containers during repositioning as containers filled with fruit.
4. South Africa's fuel (diesel, petrol) is similar to European fuels. The emission factor for grid electricity is, however, specific to South Africa.
5. Vehicles and reefer containers are not refrigerated during empty repositioning and are, therefore, ambient.

Refrigeration

6. The energy and associated emissions effects due to different temperature ranges of refrigeration are negligible. All "refrigerated" activities at logistical facilities or during transport emit the same emissions – irrespective of temperature or use of controlled atmosphere.

Handling and storage activities

7. The emissions from loading and offloading pallets are included with the facility where they occur.
8. The emissions due to initial loading at a fruit-packing facility are negligibly small. This was confirmed by an analysis of LSP data.

Repositioning of transport vehicles and containers

9. If a vehicle or a reefer container is loaded with other cargo during the return trip, the emissions of the return trip are not accounted for by the framework. The emissions due to repositioning a container or vehicle while loaded with cargo other than fruit are allocated to that cargo being transported.

10. If any vehicle repositions empty or unladen after offloading fruit, the distance travelled by the vehicle on the return journey is the same as during the forward journey when the vehicle was loaded with fruit.
11. Empty containers are repositioned to the point of loading by the same process as in the forward distribution process. This means an empty reefer container returns from the destination port to the point of loading with the same set of distribution activities as when the container was filled with fruit.
12. Although du Plessis et al. (2022a) state many distribution possibilities for empty containers, these additional transport activities are not incorporated into the framework unless they occur in the forward distribution chain. This means that the contribution of additional distribution activities performed in the return process, such as container servicing, which is not in the forward process, is negligible.

Losses in the distribution chain

13. If the entire shipment is spoilt, the emissions of the shipment up to the point where spoilage has occurred must be allocated evenly amongst all future shipments sent to the specific client. This means an overall assessment of all consignments to the specific client is required before the emissions can be allocated amongst successful shipments.

Other aspects

14. If road transportation of two 20-foot (TEU) containers occurs, the same emission intensity factor for 40-foot (FEU) containers should be used.
15. The export fruit industry uses wooden pallets, commonly referred to as the UK standard pallet. These pallets have a dimension of 1 200 x 1 000 mm, tare weight of approximately 28 kg (depending on the type of wood and its moisture content) and a recommended load capacity of 1 500 kg. Although there are other pallets, such as plastic pallets with other dimensions and subsequent weights, 28 kg is assumed to be the weight of all standard pallets used for fruit export.
16. A moisture loss of 3–5% is accounted for by adding 1 kg to the nett weight of each carton of fruit, as stated in Equation (1). Independent of the fruit type and carton size, this 1 kg is assumed to be sufficient for moisture losses and packing material weight per carton.

7.4 Verification and validation

The verification and validation of the developed framework are discussed in three sections. The objectives and expected outcomes of the verification and validation process are discussed in Section 7.4.1. Section 7.4.2 evaluates the verification and validation strategies used for the framework's individual steps. This ensures that the various steps that collectively form the framework are each individually correct, reliable, and valid. Section 7.4.3 discusses the three methods used to validate and verify the framework as a whole. However, a general comment concerning verification and validation in this research is appropriate.

Morse, Barrett, Mayan, Olson and Spiers (2002) state that qualitative research has evolved to establish the trustworthiness, reliability, and validity of research results only once a study has been completed, instead of implementing strategies during the research process to ensure rigour. This "shifting" of responsibility for the reliability and validity of qualitative research results to external reviewers' judgements has resulted in a potential lack of self-correction during the research process, ultimately decreasing the quality and potential validity of the overall research outputs (Morse *et al.*, 2002).

Applying this thinking, continuous internal verification of the various steps of the framework and the holistic framework is essential to ensure rigour (trust and confidence) in the developed framework. Similarly, the external validation of the various steps and the entire framework is also essential. However, verifying the framework and the various steps throughout contributes more value towards ensuring research rigour than external validation alone by SMEs or industry partners that, in most cases, understand only one aspect of the complex end-to-end process (Mouton, 2001; Morse *et al.*, 2002).

Although external validation fulfils an important function, the continuous verification (questioning, theorising, and investigation) of the whole framework and various individual inputs ultimately ensures end-to-end validity and rigour. The only *sine qua non* for the verification process to be trustworthy and provide valid research outputs is that several different inputs, as shown in Figure 7.1, must be used to enable data triangulation. This ensures that the primary researcher can continuously verify each step individually and the total framework collectively.

7.4.1 Objectives and outcomes of verification and validation

Verification and validation are two separate but related processes used to ensure quality, trust and confidence in the developed carbon mapping framework and associated emission intensity factors. The following subsection summarises the objectives and outcomes of the verification and validation process

<u>Objectives of verification:</u>

- To ensure that the framework and associated emission intensity factors meet the requirements of relevance, completeness, consistency, accuracy, transparency and verifiability, usefulness, and robustness;
- To identify any inconsistencies or errors in the framework and emission intensity factors where deviation from the requirements takes place;
- To ensure that the framework and emission intensity factors are fit for their intended purpose;
- Ensure that the design is consistent with industry standards and best practices.

Expected outcomes of verification:

- The framework and emission intensity factors are relevant, complete, consistent, accurate, transparent and verifiable, useful, and robust;
- Any inconsistencies or errors in the framework and emission intensity factors from the requirements are identified and corrected.
- The framework and emission intensity factors is fit for its intended purpose.
- The design is consistent with industry standards and best practices.

Objectives of validation:

- To ensure that the framework and emission intensity factors enable the quantification of fresh fruit distributional emissions;
- To ensure that the framework and emission intensity factors can potentially serve as a standard for the fresh fruit export industry to determine emissions;
- To ensure that the user can effectively and efficiently use the framework and emission intensity factors to calculate distributional emissions.

Expected outcomes of validation:

- The framework and emission intensity factors can quantify the emissions of fresh fruit distribution;
- The framework and emission intensity factors can potentially serve as a standard for the fresh fruit export industry to determine emissions;
- The framework and emission intensity factors are efficient and effective when calculating fresh fruit distributional emissions.

7.4.2 Verification and validation of the various steps in the framework

The framework consists of six different steps, as shown in Figure 7.2. Each step of the framework builds on one or more ROs contained in this dissertation document. A summary of the various types of quantitative and qualitative data used for verification and validation is also indicated in Figure 7.2. Note that Figure 7.2 uses the various ROs indicated in Figure 1.3 and groups them according to the document structure defined in Table 1.3. The remainder of this section relates the different steps of the framework to the various parts of this dissertation document, thereby describing the corresponding chapter(s) on which the specific step was built.

Step 1 of the framework (identify all emission-generating activities) uses the five distribution chain diagrams from the published, peer-reviewed journal article (du Plessis, van Eeden & Goedhals-Gerber, 2022b) (see Section 3.3) and the contents of Parts III and V of the dissertation document. The article containing the five diagrams was developed using various types of data such as literature, observations, and unstructured and internet-mediated interviews to enable the internal verification of the various diagrams. Further, semi-structured interviews (see Section 3.2) with SMEs were also executed to validate that the diagrams capture all possible distribution scenarios by which fruit is exported from SA. Finally, the five distribution chain diagrams in Step 1 of the framework were internally verified by mapping the emission-generating activities identified from the validated typical distribution scenarios (see Chapter 8).

Step 2 of the framework pertains to the data collection of the activities identified in Step 1 and prescribes the minimum data requirements (net weight, gross weight, the distance of transportation, configuration of transport vehicle, time duration of storage, etc.) to use in the remainder of the framework. Stating the required data also increases the framework's accuracy since this ensures that the most suitable emission intensity factor is selected in Step 3 of the framework. The data requirements in Step 2 were primarily verified using the emission intensity factors in Part IV (Chapters 5 and 6) since the emission intensity factor’s unit determines the data required to quantify emissions. Furthermore, the data requirements in Step 2 were verified using literature, most notably those identified in the published peer-reviewed journal article in Section 2.3. Step 2 of the framework was also continuously verified using the validated typical distribution scenarios in Chapter 8 and the distribution chain diagrams from the published journal article in Chapter 3. Using a combination of emission intensity factors, the typical distribution scenarios, and the distribution chain diagrams, enabled the primary researcher to triangulate the data requirements, ensuring that the required data is comprehensive and valid.

The *framework's third step* concerns choosing a suitable emission intensity factor, as suggested in the appendix of the framework. The higher, more conservative approach (using the higher emission intensity factor if there is uncertainty) recommended in Step 3 is internally verified using Parts II, III, and IV of the dissertation documents. The higher, more conservative approach is aligned with the guidance provided in the GLEC framework (Smart Freight Centre, 2019).

Step 4 of the framework calculates the emissions of an activity. This step uses the recommended emission intensity factors in Chapters 5 and 6, explicitly developed for the research project. Where possible, the recommended emission intensity factors were compared to existing ones found in the literature to verify the recommended value. Alternatively, if no such factors were available in the literature, the source, quality, and credibility of the collected data, assessment method used, and resulting emission intensity factors were internally verified by the primary researcher and his two supervisors. This internal verification of emission intensity factors contributes more to research rigour than the brief validation of a final value by an SME. The validity of the recommended emission intensity factors in Chapters 5 and 6 is, however, confirmed by the three journal articles included in these chapters. Step 4 of the framework also builds on existing literature assessed for the journal article in Part II of the dissertation document, where the distribution chains and activities were assessed. In addition, Parts III and V, which contain the distribution chain diagrams and the validated typical distribution scenario, are used to continuously verify that the emissions of these activities can be calculated.

Step 5, which calculates the carbon footprint of each activity, was verified using existing literature from the body of knowledge analysed as part of the published journal article in Part II of the dissertation document. Finally, *Step 6* of the framework builds on all previous steps to establish a distribution scenario's total emissions and carbon footprint. Step 6 of the framework was continuously verified by applying the previous five steps to complex, in-depth validated distribution scenarios. This iterative application of the previous steps of the framework to several example distribution scenarios ensures the successful verification of the final step.

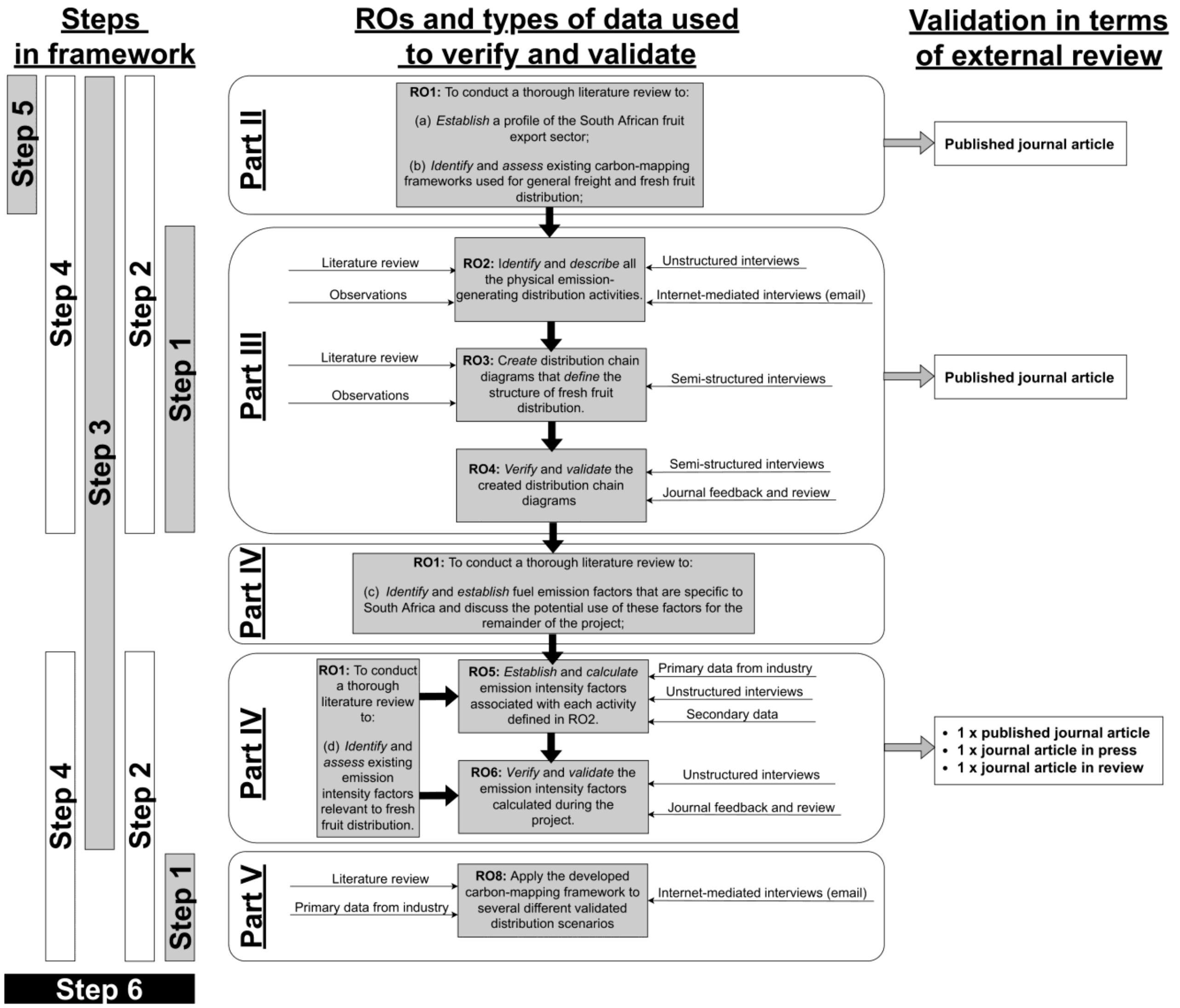


Figure 7.2: Verification and validation of the various steps in the framework

7.4.3 Verification and validation of the framework

The verification and validation of the holistic framework are fundamental to the project's overall success and credibility. Three different methods of verification and validation of the framework were used, as suggested by Mouton (2001). These three methods are indicated and briefly discussed in Table 7.2. The first two methods in Table 7.2 – *case studies* and *implementation evaluation* – are the primary methods used to verify and validate the framework. Applying the entire framework to complex and in-depth industry-validated distribution scenarios allowed the primary researcher to verify the framework as a whole and test its validity. Any potential anomalies or ambiguities that might arise from this application were addressed by this method in an iterative approach. This verification of the holistic framework ensured that the framework covers all potential and realistic scenarios by which fruit is exported from SA.

Table 7.2: Methods used to verify and validate the developed carbon mapping framework

Validation and verification methods	Description of method	Benefit	Restriction
Case studies	A case study strategy investigates a contemporary phenomenon, such as fruit exports, in its real-life context using multiple sources of evidence to understand and assess how the process occurs. The in-depth and detailed examination of seven typical fresh fruit distribution scenarios provided the primary researcher with explanatory data required to build, verify, and validate the framework.	• Provides in-depth insight into the fresh fruit distribution process to understand the framework's diverse requirements and potential anomalies. • High construct validity – an excellent way to verify and validate the framework. • The creation of typical scenarios to which the framework must be applied establishes a non-technical method of interaction with industry.	• The generalisation of the problem, potentially leading to the framework being too general. • Potential lack of generalisability, resulting in the framework being too specific for general scenarios.
Implementation evaluation	Implementation evaluation aims to review and assess the correctness of the developed framework based on the practical application thereof to seven real-world distribution scenarios.	• The successful application to real-world distribution scenarios confirms if the framework allows for practical application.	• The scope of implementation is limited to seven chosen distribution scenarios.
Interviews with SMEs	Semi-structured interviews, either via Microsoft Teams or in-person interviews, were used to validate the framework as a whole.	• Enables the assessment, questioning, theorising, investigation, and evaluation of the framework from a "new" perspective. • Interviews can potentially improve the framework by providing new valuable data or information.	• The number of individuals interviewed limits the value of this method. • Interviewees are unable to assess the end-to-end validity and rigour of the entire framework in-depth due to time, knowledge, and exposure limitations. • Potential bias of the interviewee or the collected data.

Source: Adapted from (Mouton, 2001).

The third method used to validate the entire framework was interviews with SMEs. Individuals involved in two different spheres (the carbon realm and fruit or agricultural sector) were interviewed, as shown in Table 7.3, to validate the framework. These individuals assessed and evaluated the framework from a different perspective since their fields of expertise differ. The individuals in these two groups were purposefully chosen to validate the framework. The validation of the developed carbon mapping framework by the various individuals in Table 7.3 confirms the potential value of the framework and the results thereof.

Table 7.3: SMEs interviewed to validate the developed carbon mapping framework

Interviewee	Description of validator
Carbon realm stakeholders	
Interviewee E	• Professor in Cold Economy, University of Birmingham (2016–present); • Visiting Research Fellow, University of Cambridge Birmingham (2021–present); • Visiting Professor, Heriot-Watt University (2016–present); • Clean Cooling, Innovation and Strategy Consultant (2017–present);
Interviewee F	• Professor of Logistics at Kühne Logistics University (2012–present); • Emeritus Professor of Logistics at Heriot-Watt University (1987–2013); • Co-author of *Green Logistics: Improving the Environmental Performance of Logistics*. • Author of *Decarbonizing Logistics: Distributing Goods in a Low Carbon World*.
Interviewee G	• Project Manager of Confronting Climate Change at Blue North Sustainability (2022–present); • Climate change and sustainability consultant at Blue North Sustainability (2020–2022).
Interviewee H	• Senior commercial manager at Blue North Sustainability (2022–present); • Project Manager of Confronting Climate Change at Blue North Sustainability (2014–2022); • Owner of Anel Blignaut Environmental Consultants.
Fruit or agricultural industry stakeholders	
Interviewee I	• Chairman of Food, Agriculture and Natural Resources Policy Analysis Network (2022); • Chairman of Southern African Agri Initiative (2019–present); • President of World Farmers Organisation (2017–2022); • President of The Southern African Confederation of Agricultural Unions (2012–2017); • President of PAN-African Farmers Organisation (2014–2017); • Vice-president of Agri-SA (2008–2015); • President of Agri Limpopo (2006–2008).

7.5 A brief discussion of aspects relating to the framework

The following section briefly discusses aspects such as the level of knowledge required to use the framework, the exclusion of initial loading emissions at a fruit-packing facility, the distributional losses incorporated into the framework, and the potential anomalies covered by the proposed framework in Section 7.3.

7.5.1 Prerequisite level of knowledge

The framework necessitates a reasonable level of knowledge of the entire distribution process of fresh fruit to estimate emissions. The primary researcher defines a *reasonable level of knowledge* as:

A level of understanding where an individual or group of people collectively have insight, practical experience, and theoretical understanding of a complex systems problem that enables them to assess and potentially solve a problem.

Potential users of the framework are, therefore, expected to have reasonable knowledge of the fruit export process and be able to supply some or all of the data required in Step 2 of the framework. The proposed framework is multi-faceted since alternative values for distance, weight, and distributional losses are recommended if actual shipment data is unavailable. The framework, however, gives preference to primary data as input since this will lead to more meaningful and accurate emissions results. This multi-faceted dimension in terms of input data required in Step 2 potentially reduces the framework's complexity while still retaining its accuracy.

7.5.2 The exclusion of initial loading emissions at a fruit-packing facility

The emissions due to initial loading at a packhouse are omitted for two reasons:

- The emissions contribution of loading a pallet onto a road transport vehicle is negligible. One of the cold stores analysed as part of the journal article in Section 6.2.1 enabled the primary researcher to determine the fuel use and emissions due to handling (offloading and reloading) pallets. Based on three years of data during which 8 043 pallets were moved, handling emits approximately 207 g CO_2e/pallet. If a pallet's nett weight is approximately 1 tonne, the carbon footprint due to initial loading is 0.000104 kg CO_2e/kg of fruit. This is a negligibly small contribution to the overall distributional emissions of a shipment.
- Adding the emissions due to loading at a cold store complicates and undermines the logic used in the remainder of the framework, where the loading and offloading activities are grouped with the logistical facility where they occur.

7.5.3 Distributional losses

It is most suitable to account for the distribution losses at the end of the distribution process since fruit is typically replenished if a loss occurs at any point in the distribution chain prior to the main carriage. If *x*% of fruit is lost before the main carriage, *x*% fruit will be drawn to replace the lost fruit. The latter is always true if full truckloads or containers cannot be loaded. Therefore, the loss percentage incorporated into Step 6 of the framework accounts for replenishing additional fruit before the main carriage.

Even if the fruit loss occurs during main carriage (the last activity in the distribution chain according to the framework), Equations (9) and (10) in the framework are still valid since this "loss" value effectively reduces the amount of edible fruit that can be sold at arrival at the destination port.

A conservative value of 3% is recommended in terms of the loss percentage. Personal correspondence with Blaauw (2022) confirms that a renowned and large South African exporter of avocados loses between 3-5% of their total fruit during distribution. Further, correspondence with several table grape farmers estimates that up to 4% of their total crop was lost in the distribution process during the 2020/21 season. However, this value of 3% is a recommendation; hence, users can use a different value if available.

7.5.4 Potential anomalies covered

<u>What if a vehicle transports fruit and other types of cargo?</u>
In most export fruit consignments, the entire vehicle is occupied by fruit. However, if the vehicle is shared by two or more different types of cargo, Step 2's weight will not be the gross and nett weight of fruit but rather the gross and nett weight of all loaded cargo. The remainder of the Steps, Steps 3 to 6, is still performed in the same way.

<u>What number of pallets should emissions in a cold store be based on if there is a change in the shipment size? For example, if 30 pallets are stored in a cold store, should the calculation be based on the 30 pallets stored or only the 20 pallets shipped further?</u>

The emissions due to storage can be based either on the 30 pallets stored or the 20 pallets distributed further since the emissions are calculated per kg of fruit. The only requirement is that the nett and gross weight are based on the same number of pallets in Steps 4 and 5 of the activity.

What if a shipment consists of different types of fruit or fruit is packed into different types of packaging?

If a shipment consists of different fruit or packaging types, Step 2.1 must be repeated for each type of fruit or packaging in a shipment. This is required since each pallet's gross and nett weight is different per fruit or packaging type. The remaining parts of the framework are still applied in the exact same way.

What if the shipment size (number of pallets) changes or differs for each activity? For example, a small rigid truck must make three trips of eight pallets each to supply enough pallets for a full container?

Since the emissions of activities are based on the carbon footprint (kg CO_2e/kg of fruit), users of the framework do not have to adjust or repeat any calculations to account for repeated shipments or a change in the number of pallets. This also means users do not have to repeat calculations where a vehicle transports less than the required number of pallets.

7.6 Conclusion

This chapter presented the developed carbon mapping framework for the international distribution of fresh fruit (**RO7**). The framework provides specific and consistent guidance in determining a shipment of fresh fruits' total emissions (kg CO_2e) and the carbon footprint (kg CO_2e/kg of fruit) due to the distribution of the fruit. To the primary researcher's knowledge and the published journal article in Section 2.3, this framework is the first known standard for any type of commodity which provides industry-specific guidance and emission intensity factors to quantify distribution emissions. The framework enables the fruit export industry to assess its emissions and also serves as an example framework for other types of commodities to develop similar industry-specific standards.

Section 7.1 discussed general emission accounting principles on which the developed carbon mapping framework was built to ensure that the framework is meaningful and compliant with existing literature. This was followed by Section 7.2, which summarised the various inputs used to design and develop the framework.

Section 7.3 presented the validated carbon mapping framework for the international distribution of fresh fruit. The verification and validation of the developed framework were discussed in detail across two subsections. Section 7.4.1 discussed the objectives and outcomes of the verification and validation process. Section 7.4.2 evaluated the verification and validation strategies used for the framework's individual steps. This ensured that the various steps that jointly formed the framework were correct, reliable, and valid. Section 7.4.3 stated the three methods used to validate and verify the framework as a whole. This section also introduced the individuals that validated the proposed framework. Although the validation of the developed carbon mapping framework by various individuals confirms the potential value of the framework and its validity, the continuous internal verification of the framework and associated steps contribute more to research rigour (trust and confidence) in the developed framework than the once-off validation by SMEs. The various objectives and expected outcomes listed in Section 7.4.1 were ultimately achieved.

Finally, Section 7.5 presented a brief discussion of aspects relating to the framework, such as the level of knowledge required to use the framework, the exclusion of initial loading emissions at a fruit-packing facility, the distributional losses incorporated into the framework, and the potential anomalies covered by the proposed framework.

The following chapter applies the validated carbon mapping framework for fresh fruit to seven typical validated distribution scenarios by which fresh fruit is exported. These example applications and results exhibit the potential value of the framework and the magnitude of emissions.

8. Framework application to typical distribution scenarios

This chapter addresses the following research objectives:

RO8: *Apply* the developed carbon mapping framework to typical validated distribution scenarios.

This chapter forms part of **Part V** of the dissertation document. The chapter applies the developed carbon mapping framework to seven typical distribution scenarios by which fresh fruit is exported from SA. As a precursor to the remainder of the chapter, Section 8.1 discusses the validation of the typical distribution scenarios to which the framework is applied. Section 8.2 presents the seven distribution scenarios and their respective carbon footprints (kg CO_2e/kg of fruit) and discusses why these seven typical scenarios are used. Section 8.3 presents a brief discussion of the various distribution scenarios emissions.

8.1 Validation of example scenarios

Each of the seven typical distribution scenarios was validated by either an industry expert or the representative body of the specific fruit, as indicated in Table 8.1. The researchers deem it most suitable that the representative organisations validate the scenarios since these institutions have a holistic overview of the specific fruits' export process and will inevitably be the most credible source for validation. The validation of these scenarios confirms that the examples in this chapter are factual, realistic and represent the real-world distribution process by which fresh fruit is exported from SA.

Table 8.1: Validation of seven typical distribution scenarios

Distribution scenario	Description of validator
Avocados	Head of logistics for 30 years at the largest avocado producer and exporter in the world (refer to the published journal article in Section 2.3)
Oranges	Logistics Development Manager at Citrus Growers Association (CGA) of Southern Africa
Soft citrus	Logistics Development Manager at Citrus Growers Association (CGA) of Southern Africa
Lemons	Logistics Development Manager at Citrus Growers Association (CGA) of Southern Africa
Blueberries	Operations Manager of the berry association in SA – BerriesZA
Table grapes	Manager of market access and technical aspects at the South African Table Grape Industry (SATI)
Pome fruit	General manager of trade and markets at Hortgro

8.2 Application to typical scenarios and results

Each typical scenario represents a unique chain or combination of distribution activities (see Figure 8.1) by which a different fruit type is exported between an origin-destination pair (see Figure 8.2). These seven scenarios were explicitly chosen since they demonstrate the extent and use of the framework and associated emission intensity factors. Apart from estimating the emissions of status quo distribution, these seven scenarios showcase the use of the recommended emission intensity factors for various modes of transport, configurations of transport vehicles, and the different types of logistical facilities. Refer to Appendix A to view the emission intensity factors used in each of the seven examples.

The seven typical distribution scenarios assessed in this section are deliberately very specific since they show the potential complexity of the distribution process. Each of the seven scenarios represents the in-depth distribution process on a waybill level, hence the specific transport hours, distances, and storage days in the scenarios. Although these scenarios are very specific, they are potentially representative of the *status quo* process by which the specific fruit type is exported. Applying the framework to these complex distribution scenarios shows the level of detail incorporated into the framework. Even though users of the framework might not assess the distribution process in this level of detail, the successful application of the framework to these seven distribution scenarios proves that the framework will work for “less complex” distribution scenarios.

Further, the typical scenarios address how the emissions of different functional units of distribution (pallets versus reefer containers) should be assessed and how to account for the repositioning of empty containers. Different fruit types are used due to the geographical difference in production regions and to illustrate the potential impact that packaging material and subsequent weight have on the overall carbon footprint. The remainder of the section presents the seven typical distribution scenarios and their resulting carbon footprint.

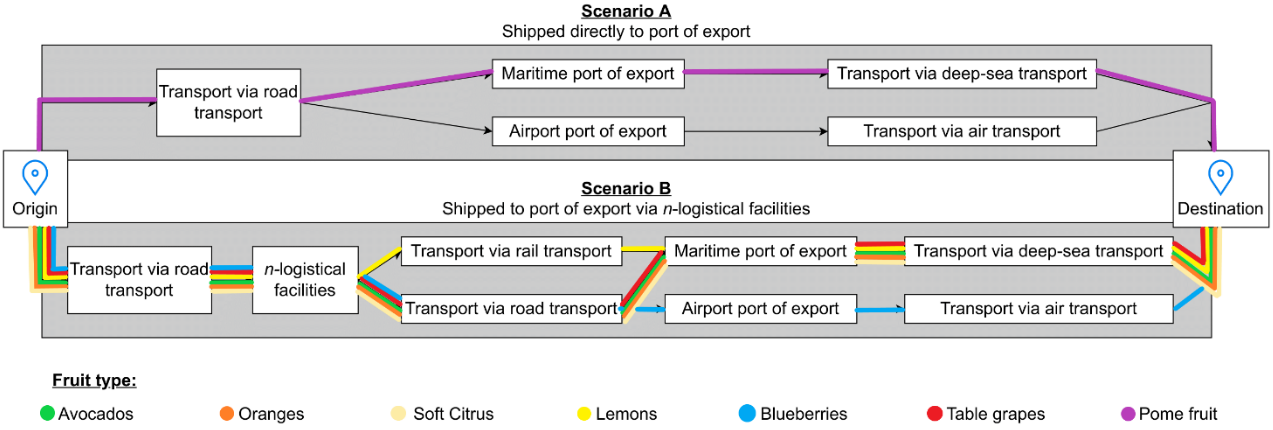


Figure 8.1: The activities analysed in each typical distribution chain

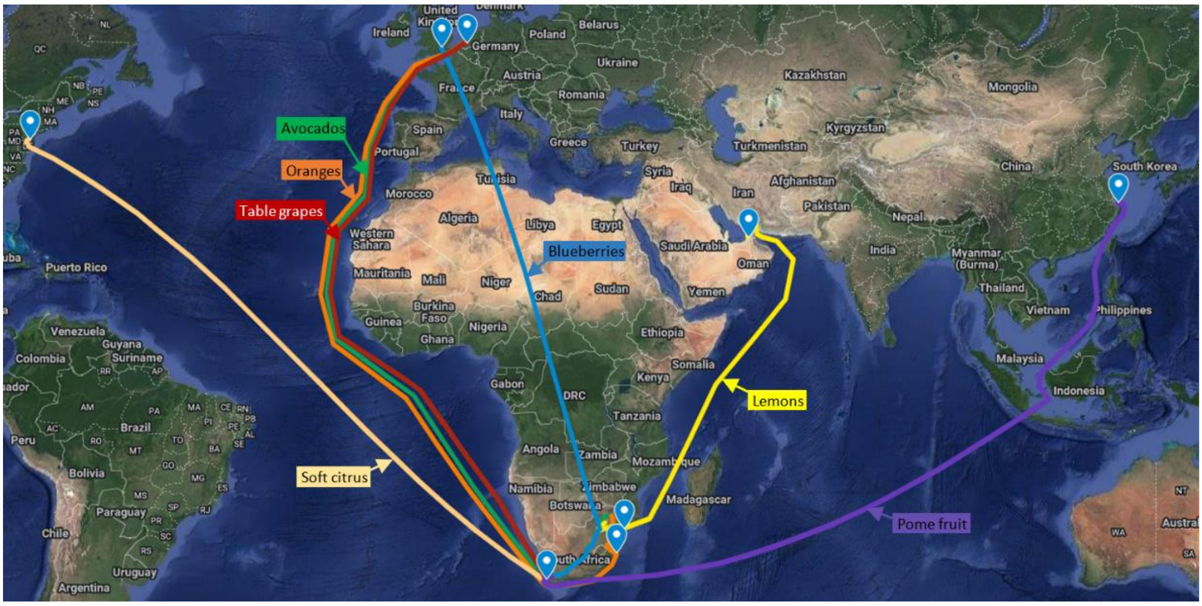


Figure 8.2: The origin-destination pairs of the seven distribution scenarios analysed

(https://www.google.com/maps/d/u/0/edit?mid=1BYvuuraNaqICxR-YgArQRKfuj_NkRPQ&usp=sharing)

8.2.1 Avocados

Fresh Hass avocados from the Letaba production region in South Africa are exported to Europe via the Port of Rotterdam, where the fruit is discharged for on-carriage to European retailers.

8.2.1.1 Distribution scenario

At a packhouse in the Letaba region, 264 boxes of avocados, each having a nett weight of 4 kg, are palletised into hi-cube pallets. Twenty-four pallets, each with a gross weight of 1348 kg, are loaded into an articulated refrigerated truck equipped with a diesel reefer unit to cool the fruit. The truck and reefer semi-trailer combination then transports the consignment of avocados 1800 km via the N1 route to Cape Town during a 38-hour journey. The fruit is then offloaded and stored for eight days at a cold store in the Cape Town region until loading into a reefer container commences. A 40-foot-high-cube integral controlled atmosphere container is loaded with twenty pallets, while the remaining four pallets are consolidated into a different container. The reefer container is transported 30 km by an articulated triaxle flatbed truck to the Port of Cape Town. Since the travel time is less than 2 hours until the reefer is plugged in, no genset to supply electricity to the integral reefer unit is required. Once the container arrives at the port, the reefer container is stored in the container terminal's reefer stack for one day until the container is drawn for loading. The container is loaded into a post-Panamax class container vessel, whereafter the vessel travels 13 564 km (7324 nautical miles) and finally arrives in the Port of Rotterdam in the Netherlands in 14 to 18 days. Note that the vessel calls at various ports along the route. Throughout the entire distribution process, the temperature in the cold chain is carefully maintained between 4,4 and 8 °C. In addition, the relative humidity is kept at 95%, oxygen levels maintained between 2% and 5% and carbon dioxide levels at 10%. The reefer container used in the distribution process was repositioned empty to the various points where loading occurred. The truck and reefer semi-trailer combination that transported the fruit from the Letaba region returns inland with a load.

8.2.1.2 Results

The carbon footprint of the avocado distribution scenario is shown in Table 8.2 and visually displayed in Figure 8.3. In order to ship 21.1 t (nett weight) of avocados from a packing facility in Letaba, South Africa, to the Port of Rotterdam emitted 13.4 t CO_2e emissions, resulting in the fruit having a carbon footprint due to the distribution of 0.63 kg CO_2e/kg of fruit.

Table 8.2: The carbon footprint of avocado distribution

Description of distribution activity	Carbon footprint (kg CO_2e/kg of fruit)
Transport via road transport (Tzaneen to Cape Town)	0,1425
Offloading, inland fruit facility, loading (cold store)	0,0570
Transport via road transport (cold store to port)	0,0043
Offloading, port of export, Loading (maritime port)	0,0111
Transport via deep-sea transport (Port of Cape Town to the Port of Rotterdam)	0,3991
Loss percentage of 3% during the distribution chain	0,0190
Total	**0,6330**

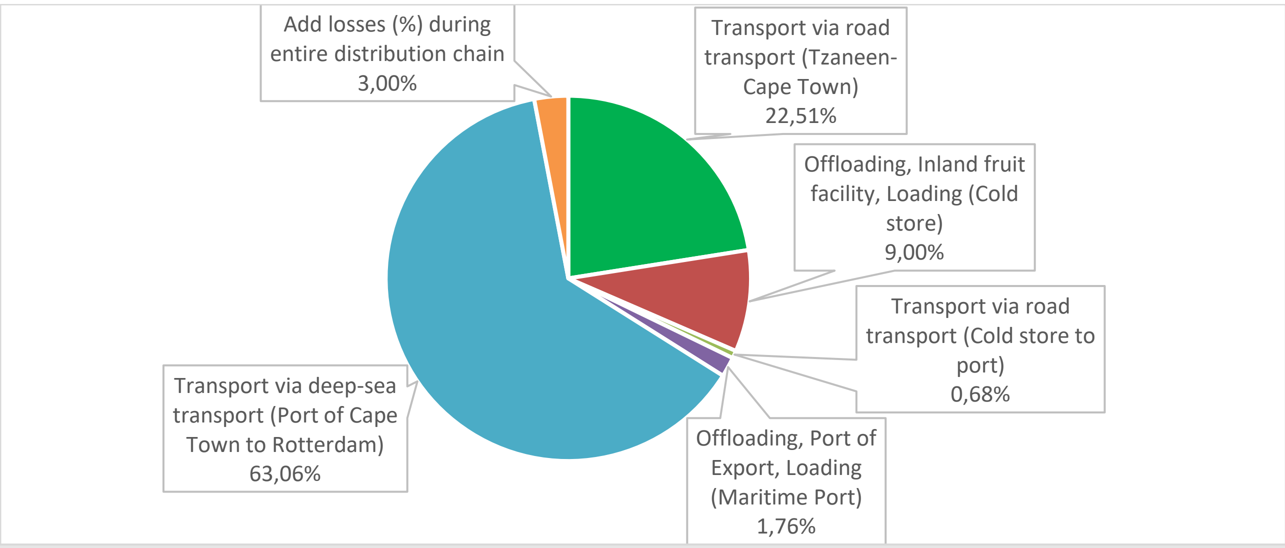


Figure 8.3: The contribution of each distribution activity toward the overall emissions of the avocado shipment

8.2.2 Oranges

The scenario used for oranges pertains to Valencia oranges being exported via the Port of Durban to the European market, with the Port of Rotterdam as a discharge point. The distribution process utilises ambient road transport and refrigerated deep-sea ocean transport by reefer container.

8.2.2.1 Distribution scenario

Oranges are harvested in the Letsitele region in the Limpopo province and packed into 15 kg (nett weight) telescopic cartons. High-cube pallets with a gross weight of 1308 kg are built by packing 80 boxes of oranges onto a pallet. Since citrus is harvested during the colder winter months and oranges are not prone to quick spoilage, the fruit is transported by interlink tautliner (curtain side) truck under ambient conditions. The truck is loaded with twenty-six pallets resulting in a payload of 34,008 tonnes. The truck then travels 855 km via the R36, N11 and N3 routes to a cold store located in the Port of Durban. The pallets are offloaded from the truck and, after being inspected, stored at a temperature of 2 °C. In addition, minimum ventilation of 15 cubic meters per hour and relative humidity of 95% is maintained. From this point onwards, the refrigeration requirements must be maintained throughout the cold chain. The fruit is stored for nine days in the cold store, where 20 of the high-cube pallets are loaded into an integral reefer container. Since the cold store is only 25 km from the port of export, a genset to power the reefer is not required. A tri-axle truck tractor with a semi-trailer then transports the container from the cold store to the reefer stack in the port. Once offloaded, the reefer is stored in the reefer terminals reefer stack for four days, whereafter, it is loaded into a container vessel. The vessel then travels 7456 nautical miles (13 808 km) via several ports to the point of discharge in the Port of Rotterdam. This deep-sea voyage will take approximately 28 days from the Port of Durban to the Port of Rotterdam. For this specific scenario, it is deemed that the reefer container is repositioned empty back to South Africa while the interlink tautliner truck loads a return load in the port before returning to the vicinity of Letsitele, resulting in an average empty running of 10%.

8.2.2.2 Results

The fresh oranges distribution scenario's carbon footprint is shown in Table 8.3 and visually displayed in Figure 8.4. In order to ship 24 t (nett weight) of oranges from a packing facility in Letsitele, South Africa, to the Port of Rotterdam emitted 12.6 t CO_2e emissions, resulting in the fruit having a carbon footprint due to the distribution of 0.53 kg CO_2e/kg of fruit.

Table 8.3: The carbon footprint of fresh oranges distribution

Description of distribution activity	**Carbon footprint (kg CO_2e/kg of fruit)**
Transport via road transport (Letsitele to Durban)	0,0624
Offloading, inland fruit facility, loading (cold store)	0,0564
Transport via road transport (cold store to port)	0,0031
Offloading, port of export, loading (maritime port)	0,0317
Transport via deep-sea transport (Port of Durban to the Port of Rotterdam)	0,3576
Loss percentage of 3% during the distribution chain	0,0158
Total	**0,5269**

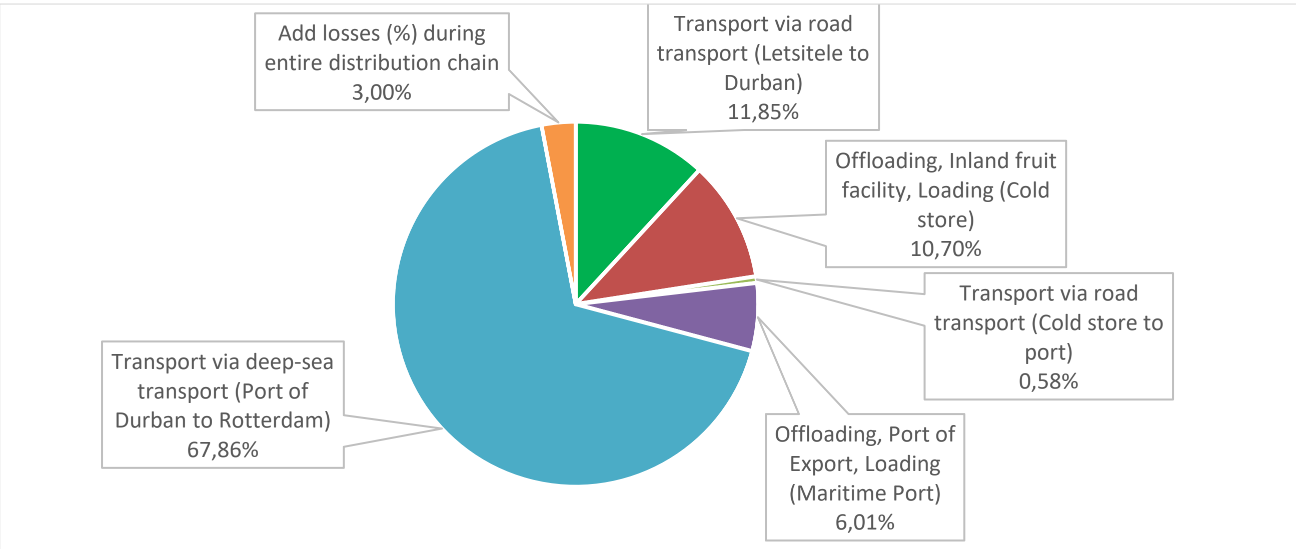


Figure 8.4: The contribution of each distribution activity towards the total emissions of the oranges' shipment

8.2.3 Soft Citrus

Mandarins, destined for the US market, are exported from the Citrusdal region in the Western Cape of South Africa by means of road transport and conventional reefer vessel. Throughout the distribution process, the unit of handling remains pallets since reefer containers are not used.

8.2.3.1 Distribution scenario

Ten kilograms of fruit (nett weight) is packed into open display cartons, resulting in a gross carton weight of 11 kg. Since a conventional vessel is used for the main carriage, standard pallets with a maximum height of 2,1 m must be used. Pallets are built by palletising 88 cartons, producing a gross weight of 996 kg per pallet. A reefer semi-trailer, drawn by a 6x4 truck tractor, is loaded with 24 pallets of fruit. Soft citrus such as mandarins may not be transported ambiently due to the high risk of spoiling, and, subsequently, the reefer unit of the trailer is turned on and set to a temperature of 3,5 °C to cool the fruit. In addition, the reefer unit is also adjusted to allow fresh air to be circulated in the cargo hold to keep carbon dioxide levels below 0,5%. The truck and trailer combination then travels 165 km via the N7 (4-hour journey) to offload the citrus at a cold store near the Port of Cape Town. Due to strict sanitary requirements and the imbalance of freight movement, the empty truck cannot source a load for the return trip to the Citrusdal region, and therefore, returns empty. The reefer vessel is only calling at the Port of Cape Town in 11 days since the vessel is currently enroute to the Port of Matadi, the Democratic Republic of Congo, to deliver cargo. Subsequently, the fruit is stored in the facility until the vessel calls in the Port of Cape Town. After eleven days of storage, the vessel calls in the Port of Cape Town and loading commences. The twenty-four pallets of fruit are loaded into a similar reefer semi-trailer and truck combination and transported 20 km to the break-bulk terminal in the Port of Cape Town. Due to port congestion, the trip takes 3 hours to complete, meaning the fruit requires refrigeration during transport. Once the truck arrives at the break-bulk terminal, the truck drives directly onto the quayside. All pallets are offloaded from the truck and placed on the quayside next to the ship, whereafter the truck returns empty to load another load at the cold store. Onboard cranes on the reefer vessel are then used to load the pallets into the various decks of the cargo hold. Once loading at the port is complete, the vessel sets sail to the Port of Philadelphia without calling at any port enroute. This results in an ocean voyage of 6878 nautical miles (12 738 km). Upon arrival at the Port of Philadelphia, all cargo in the vessel is discharged for distribution to various US retailers. The vessel then loads other food-related cargo and travels to the Port of Matadi in the Democratic

Republic of Congo. However, the reefer truck transporting the fruit from Citrusdal to Cape Town returns empty to the Citrusdal region.

8.2.3.2 Results

The carbon footprint of the soft citrus distribution scenario is shown in Table 8.4 and visually displayed in Figure 8.5. In total, 17.8 t CO_2e was emitted to distribute 21.1 t of soft citrus from the Citrusdal region to the Port of Philadelphia. This results in the fruit having a carbon footprint of 0.84 CO_2e/kg of fruit.

Table 8.4 The carbon footprint of soft citrus distribution

Description of distribution activity	**Carbon footprint (kg CO_2e/kg of fruit)**
Transport via road transport (Citrusdal to Cape Town)	0,0196
Offloading, inland fruit facility, loading (cold store)	0,0940
Transport via road transport (cold store to port)	0,0024
Offloading, port of export, loading (maritime port)	Included in the reefer vessels emissions
Transport via deep-sea transport (Port of Cape Town to Port Philadelphia)	0,7007
Loss percentage of 3% during the distribution chain	0,0253
Total	**0,8419**

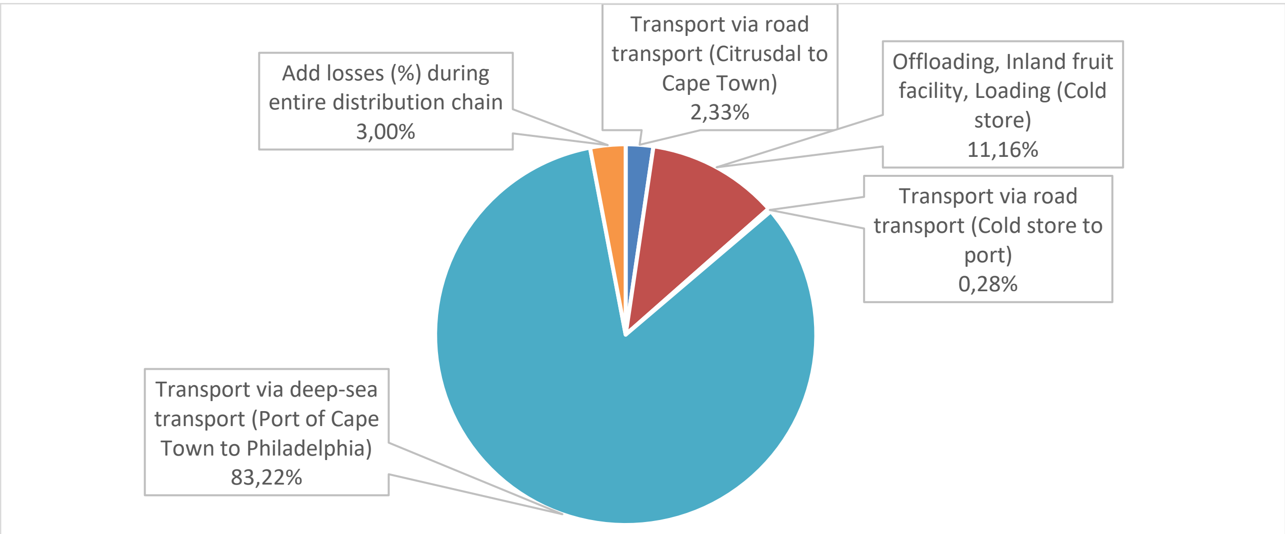


Figure 8.5: The contribution of each distribution activity towards the total emissions of the soft citrus shipment

8.2.4 Lemons

To test the framework for rail transportation, lemons produced and packed in the Marble Hall region are shipped to the Middle Eastern Port of Jebel Ali via the Port of Maputo, using a combination of rail and road transportation.

8.2.4.1 Distribution scenario

Lemons are packed into 10 kg open display cartons (nett weight), whereafter 104 cartons are stacked to create a high-cube pallet with a height of approximately 2,4 m. Each pallet has a gross weight of 1172 kg, which includes the wooden pallet's weight. Twenty pallets are then stuffed into a 40-foot-hi-cube integral reefer container loaded on a tri-axle flat deck truck. The trailer is drawn by a 6x4 truck tractor. The trailer is equipped with an underslug genset unit to supply electricity to the integral unit. The genset is started, and the temperature on the controller is set to 7 °C, ventilation to 15 m^3/h. The reefer container is then transported 275 km to City Deep rail station. Due to congestion in the city centre of Johannesburg, the journey takes 5 hours. On arrival, the reefer container is immediately offloaded from the truck and stored in the reefer stack for an 18-hour period. The reefer container is then plugged into the facility's grid electricity to maintain the cold chain while the rest of the train is loaded. The train consists of 37 railway cars loaded with reefer containers of citrus. The train is drawn by a diesel locomotive since the railway line is no longer entirely electrified. Before departure, the reefer container is unplugged and loaded onto a train wagon, where it is reconnected to the train's diesel generator. The train then travels 581 km to the Port of Maputo in a journey that takes 18 hours. The reefer with lemons is offloaded from the train and stored in the reefer terminal’s reefer stack for seven days. The reefer is then loaded onto a container vessel, which transports the reefer 4063 nautical miles (7525 km) to the Port of Jebel Ali, Dubai. The container vessel calls at various ports along the route to load and offload containers. Note that the container was repositioned empty throughout the distribution chain using the same vehicles described above.

8.2.4.2 Results

The carbon footprint of distributing lemons via road, rail and deep-sea transportation to the Port of Jebel Ali is indicated in Table 8.5, while the proportional contribution of each activity is shown in Figure 8.6. Exporting 20.8 t (nett weight) of fresh lemons using the above scenario emits approximately 7.7 t CO_2e, resulting in the fruit having a carbon footprint of 0.37 kg CO_2e/kg of fruit.

Table 8.5: The carbon footprint of fresh lemon distribution

Description of distribution activity	Carbon footprint (kg CO_2e/kg of fruit)
Transport via road transport (Marble Hall to City Deep)	0,0356
Offloading, inland rail facility, loading (inland rail facility)	0,0095
Transport via rail transport (City Deep to Maputo)	0,0206
Offloading, port of export, loading (maritime port)	0,0618
Transport via deep-sea transport (Port of Maputo to the Port of Jebel Ali)	0,2327
Loss percentage of 3% during the distribution chain	0,0111
Total	**0,3714**

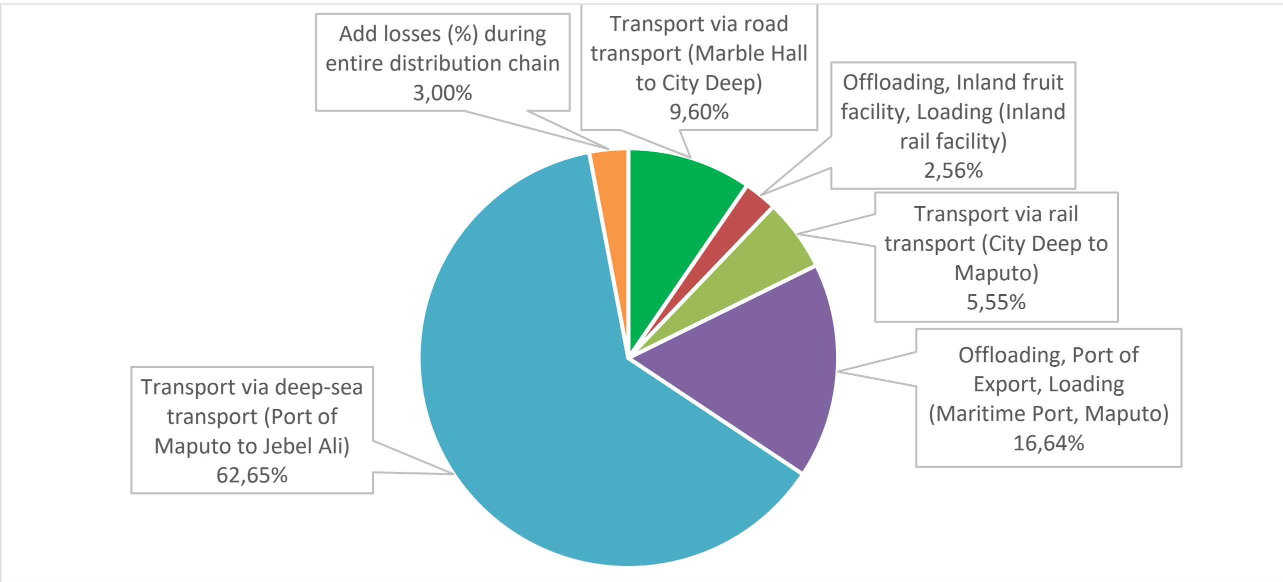


Figure 8.6: The contribution of each distribution activity towards the emissions of the fresh lemon shipment

8.2.5 Blueberries

Blueberries are exported from the Paarl region in South Africa to the United Kingdom using road and air transport.

8.2.5.1 Distribution scenario

At a packing facility on a farm in the Paarl region, 5 kg (10 punnets of 500 g) of berries are packed into cartons. The berries are then palletised by stacking 125 cartons on a pallet to create a high-cube-pallet with a gross weight of 778 kg. A forklift is used to load eight pallets of berries into a rigid truck with a refrigerated body. This truck makes four trips per day while loaded with eight pallets to a cold store in the Paarl region, 15 km away. The truck is equipped with a reefer unit to cool the fruit to an optimal temperature of 0 °C and allow for minimum ventilation of 15 m^3/hour. After the truck arrives at the cold store, the fruit is offloaded and stored for two days. Due to the lack of direct flights from the Cape Town International Airport to Heathrow, the berries are shipped to OR Tambo International Airport using road freight. A reefer semi-trailer, drawn by a 6x4 truck tractor, loads 24 pallets and travels 1390 km via the N1 route (travel time of 26 hours) to a freight forwarder in OR Tambo International Airport's cargo terminal. The 24 pallets of fruit are offloaded and stored in the freight forwarders' cold storage facility until the fruit is loaded into an aeroplane for the main carriage. While in the freight forwarders' cold storage facility, the pallets are repacked onto airline pallets. Each airline pallet is packed with the content of two pallets (250 cartons of blueberries). Due to the limited capacity of the plane, the freight forwarder can only ship six airline pallets per flight. These six airline pallets are stored for one day in the cold storage facility at 0 °C. The remaining blueberries are exported on a flight at a later stage and are not relevant for the remainder of the example. The six airline pallets packed with blueberries are removed from the cold storage facility and transported by an airport tow tractor and dolly trailer to the apron next to the plane. The airline pallets are then loaded into the cargo hold of a combi plane (a plane that transports both passengers and cargo). Since the plane's cargo hold transports many types of cargo, the temperature of the cargo hold is kept at an average of 12 °C. The plane then travels 9 045 km to Heathrow International Airport, where the fruit is offloaded from the plane and distributed through various channels to retailers. The small rigid truck used to transport fruit to the cold store in Paarl repositions empty back to the packing facility, while the reefer semi-truck finds a return load back to Cape Town after the delivery at OR Tambo International Airport.

8.2.5.2 Results

The blueberry distribution scenario results are shown in Table 8.6 and visually displayed in Figure 8.7. In order to ship 7.5 t (nett weight) of blueberries from a packing facility in Paarl to the United Kingdom, emitted 85.1 t CO_2e emissions, resulting in the fruit having a significant carbon footprint of 11.4 kg CO_2e/kg of fruit.

Table 8.6: The carbon footprint of blueberry distribution

Description of distribution activity	**Carbon footprint (kg CO_2e/kg of fruit)**
Transport via road transport (Packing facility to Paarl)	0,0032
Offloading, inland fruit facility, loading (cold store)	0,0241
Transport via road transport (Paarl to Johannesburg)	0,1575
Offloading, port of export, loading (airport facility)	0,0813
Transport via air transport (Johannesburg to Heathrow)	10,7455
Loss percentage of 3% during the distribution chain	0,3406
Total	**11,3520**

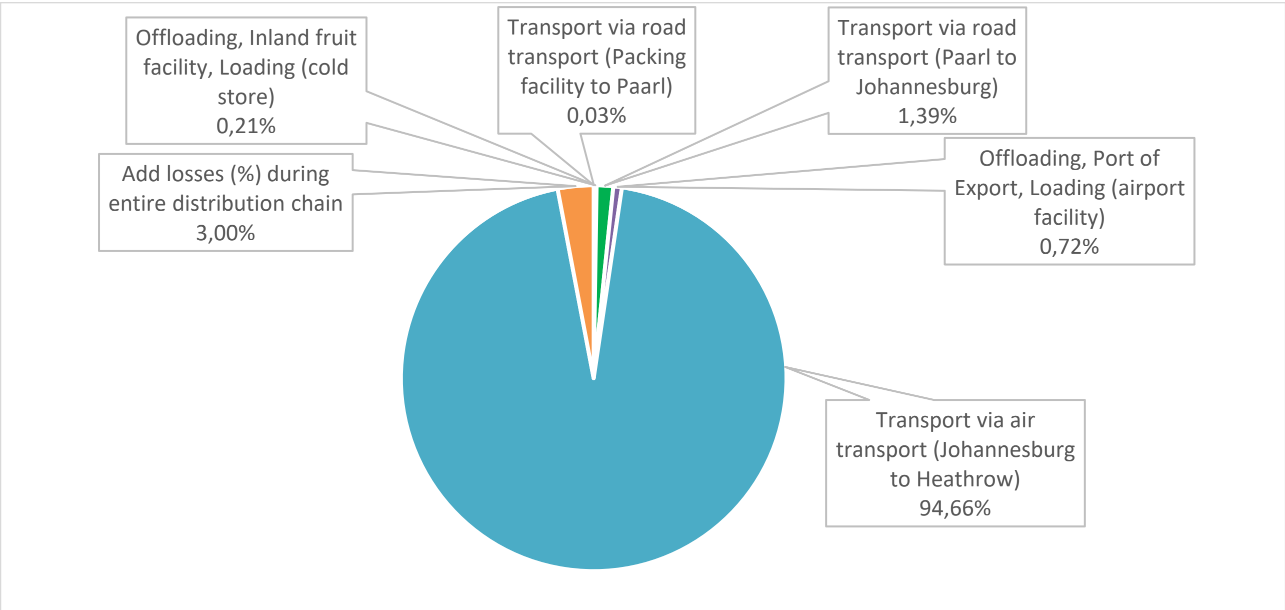


Figure 8.7: The contribution of each distribution activity towards the total emissions of the blueberry shipment

8.2.6 Table grapes

Red seedless table grapes are produced in the Hex River region in South Africa and exported to the European market via the Port of Rotterdam by road and deep-sea transport.

8.2.6.1 Distribution scenario

Once ripe, the grapes are harvested and packed into 4.5 kg cartons (nett weight of fruit) at a packing facility. High-cube pallets weighing 908 kg (gross weight) are built by packing 160 boxes of grapes on a pallet. The pallets are then transported to a cold store located 20 km away from the packing facility in Worcester. Since the cold store is nearby, a double-axle rigid flatbed truck is used to transport eight pallets at a time. The load is covered with tarpaulins (sails) to protect the fruit during the short trip. Once the truck arrives at the cold store, the fruit is offloaded from the truck and moved into the cold store. The empty truck returns to the packing facility to collect and deliver three loads per day. All grapes are stored in the facility for ten days until further shipping commences. Twenty pallets of fruit are loaded into a 40-foot-high-cube integral reefer container carried by an articulated truck with a skeletal trailer. The trailer is equipped with a genset to power the reefer during transport. The reefer-container-truck combination then travels 135 km in four hours to the Port of Cape Town via the N1 route, where the container is offloaded and stored in the reefer terminal's reefer stack for two days. The reefer is then drawn from the reefer container stack and loaded onto a container vessel. The vessel then travels 13 564 km to the Port of Rotterdam in 16 days. The grapes are stored at an optimal temperature of minus 0.5 °C and relative humidity of 90 – 95% throughout the cold chain process. No controlled atmosphere is required since grapes do not ripen further after harvest (non-climatic). The reefer container and all trucks were repositioned empty to the point of loading through the same distribution activities as was the case in the forward distribution chain.

8.2.6.2 Results

The table grape distribution scenario results are shown in Table 8.7 and visually displayed in Figure 8.8. In order to ship 14.4 t (nett weight) of fruit from a packing facility in Worcester to the Port of Rotterdam emitted 11 t CO_2e emissions, resulting in the fruit having a carbon footprint of 0.76 kg CO_2e/kg of fruit.

Table 8.7: The carbon footprint of table grape distribution

Description of distribution activity	**Carbon footprint (kg CO_2e/kg of fruit)**
Transport via road transport (Packing Facility to Worcester)	0,0027
Offloading, Inland fruit facility, Loading (Cold store)	0,1044
Transport via road transport (Worcester to Port of Cape Town)	0,0196
Offloading, Port of Export, Loading (Maritime Port)	0,0285
Transport via deep-sea transport (Port of Cape Town to Rotterdam)	0,5854
Loss percentage of 3% during the distribution chain	0,0229
Total	**0,7635**

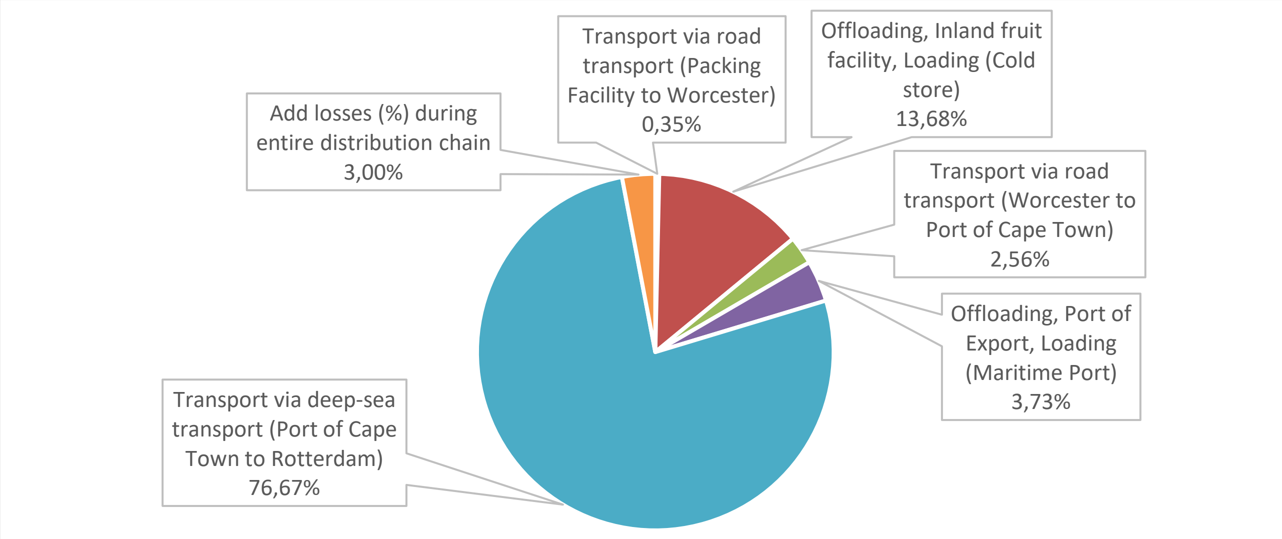


Figure 8.8: The contribution of each distribution activity toward the total emissions of the table grape shipment

8.2.7 Pome fruit

In the Ceres region in the Western Cape, Royal Gala apples are harvested and stored for several months in large bins in a controlled atmosphere (CA) environment until packing begins. The apples are destined for the Far East and Asian market and shipped via the Port of Shanghai.

8.2.7.1 Distribution scenario

Bins of apples are removed from the controlled atmosphere storage rooms and packed into 18.25 kg cartons (nett weight). Fifty-six cartons are then packed onto a pallet to create a high-cube pallet weighing 1106 kg (gross weight). A 40-foot-high-cube integral reefer container, transported by an articulated truck, is loaded with twenty pallets. The truck's trailer has an underslug genset to power the reefer container during the 4-hour road journey between the packing facility in Ceres and the Port of Cape Town. After the 155 km journey, the reefer container is offloaded and stored for three days in the container terminal's reefer stack, where the reefer unit is plugged in. The container is then drawn and loaded onto a container vessel (Post-Panamax vessel) and travels 8415 nautical miles in 25 days to the Port of Shanghai, China. The vessel makes several port calls en route to Shanghai. An optimal temperature of minus 0,5 °C and relative humidity of 95% is maintained throughout the distribution process. After arrival at the Port of Shanghai, the reefer container is offloaded and distributed to retailers. The reefer container used for distribution was loaded with packing material during the repositioning from China to South Africa. This reefer container was picked up at the Port of Cape Town and travelled directly to the packing facility in Ceres, where the packing material was offloaded before loading the fruit.

8.2.7.2 Results

The emission results for the distribution of Royal Gala apples are shown in Table 8.8 and displayed in Figure 8.9. In order to export 20.4 t (nett weight) of fruit from a packing facility in Ceres to the Port of Shanghai, China, emitted 6.4 t CO_2e emissions, resulting in the fruit having a carbon footprint due to the distribution of 0.31 kg CO_2e/kg of fruit. This low carbon footprint, for this scenario, is due to the reefer container being repositioned while loaded with packing material.

Table 8.8: The carbon footprint of pome fruit distribution

Description of distribution activity	Carbon footprint (kg CO_2e/kg of fruit)
Transport via road transport (Ceres to Cape Town)	0,0117
Offloading, port of export, loading (maritime port)	0,0272
Transport via deep-sea transport (Port of Cape Town to the Port of Shanghai)	0,2666
Loss percentage of 3% during the distribution chain	0,0094
Total	**0,3149**

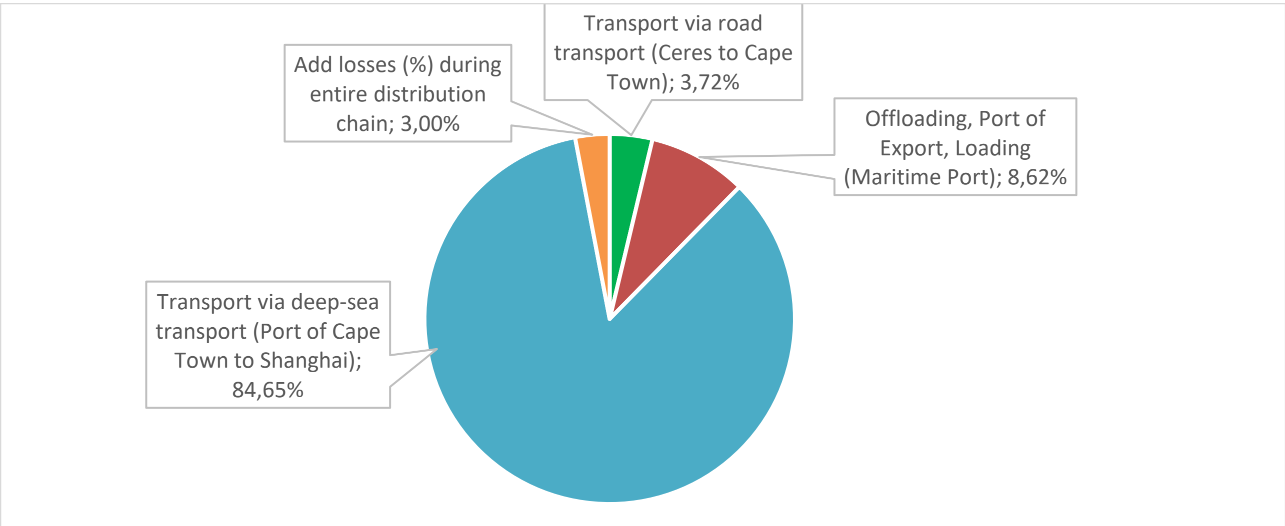


Figure 8.9: The contribution of each distribution activity toward the total emissions of the Royal Gala shipment

8.3 Discussion of deep-sea scenarios

A comparison of the various distribution scenarios results from Section 8.2 is presented in Figure 8.10. Note that Figure 8.10 excludes the blueberry example, which uses air as the mode of transport. Figure 8.10 shows that the main carriage by deep-sea vessels is responsible for 63% to 85% of the total carbon footprint of a distribution scenario. However, other distribution activities' impact varies substantially depending on the mode used for pre-carriage, the distance of transportation, and the storage duration at a logistical facility. Cold stores, maritime ports, and road transportation during pre-carriage could contribute up to 37% of the total carbon footprint of fresh fruit distribution.

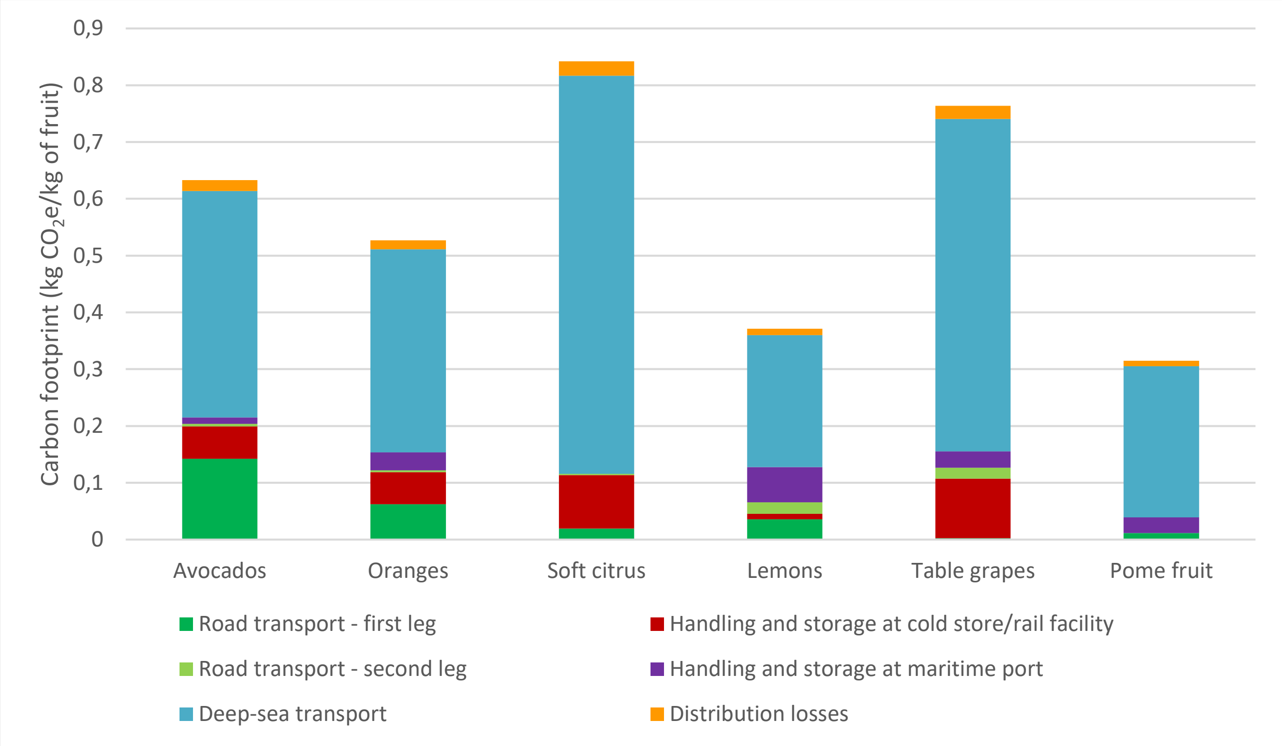


Figure 8.10: A summary of the analysed distribution scenarios (excluding blueberries)

8.4 Conclusion

The purpose of this chapter was, as part of the verification process, to apply the developed carbon mapping framework to typical distribution scenarios by which fresh fruit is exported from SA (**RO8**). The chapter demonstrates the framework's extent, potential use, and value of the developed emission intensity factors in calculating the carbon footprint of the international distribution of fresh fruit. Section 8.1 discussed the validation aspect of the seven typical distribution scenarios used in the chapter. The validation of the scenarios is essential to ensure that the carbon mapping framework and emission intensity factors are applied to factual and realistic distribution scenarios. Apart from the avocado distribution scenario, which was validated by the largest avocado exporter in the world, the other six fruits' typical distribution scenarios were validated by the specific fruits' representative organisations, such as CGA, SATI, Hortgro, and BerriesZA.

This is followed by Section 8.2, which provides an overview of the seven typical distribution scenarios and the carbon footprint (kg CO_2e/kg of fruit) of each. The validated distribution scenarios and their results in Section 8.2 form the basis of a future journal article for the *International Journal of Logistics Management.* This future article uses the carbon mapping framework stated in Section 7.3 as methodology and summarises the overall research conducted in this dissertation. The article emphasises the importance of logistical decisions and related aspects influencing fresh fruit export distributional emissions.

Section 8.3 presented a brief discussion of the proportional emissions contribution of scenarios using deep-sea ocean transport as mode for the main carriage. Although scenario-specific, the discussion showed that the emissions of cold stores, maritime ports, and road transportation during pre-carriage could contribute up to 37% of the total carbon footprint of fresh fruit distribution.

The following chapter presents the dissertation document's conclusion and discusses the research project's achievements, the research's unique contribution, potential future work, and recommendations.

9. Conclusions

This final chapter of the dissertation document provides a conclusion to the research project. Section 9.1 provides an overview and summary of the various parts of the research project, while Section 9.2 reviews the research design and how well the proposed methodology was followed to achieve the various ROs. Section 9.3 briefly states the primary achievements of the research project. The unique contributions of the research to society, literature, and industry are discussed in Section 9.4. Several recommendations and future work to improve the framework and increase its accuracy are suggested in Section 9.5. The final section presents some concluding remarks on the project.

9.1 Overview of the research project

The research project consisted of five parts, as shown in Figure 9.1. The five parts of the research project were discussed across eight chapters using a combination of published and in-process journal articles integrated through bridging text to create one coherent narrative.

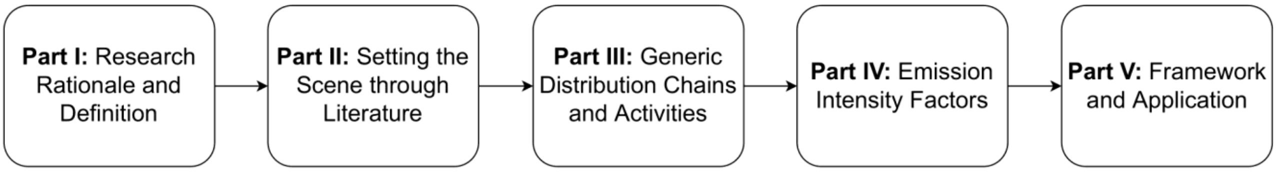


Figure 9.1: A summary of the five parts of the research project and dissertation document

Part I (Chapter 1) of this dissertation document provided background and defined the research project and rationale. This chapter also stated the research design and types of primary and secondary data collected to achieve the various ROs and answer the RQs.

In **Part II** (Chapter 2), the need for the research project was confirmed by a published journal article (du Plessis, van Eeden & Goedhals-Gerber, 2022a), in which a systematic literature review (SLR) was conducted. This peer-reviewed journal article showed that there is no carbon mapping framework for any commodity and that future frameworks should be developed for each industry with appropriate emission intensity factors. The article also identified relevant literature or existing emission accounting research that serves as input for the remaining research. The remainder of Chapter 2 provided an overview of the South African fruit export sector and the importance of the industry. The chapter also discussed other literature relevant to the dissertation.

In **Part III** (Chapter 3), a published, peer-reviewed journal article (du Plessis *et al.*, 2022b) defined the various distribution chains through diagrams, which identified all the emission-generating activities. These diagrams identified the realistic combination of activities by which fresh fruit is exported from SA. Part III formed the foundation for the remaining research, since this defined the relevant distribution activities for which emission intensity factors are required in Chapters 5 and 6. Further, these diagrams are the basis of the developed carbon mapping framework since they prescribe the scope of activities that should be assessed in the framework.

Part IV (Chapters 4, 5, and 6), elaborated on the emission intensity factors developed in this project. Chapter 4 serves as a precursor to discuss the use of emission intensity factors. This chapter discussed the two emissions accounting approaches (activity- and fuel-based) used in the logistical realm and explained how they differ in terms of usability and accuracy. The fuel-based method was used in this project as well as the field of research to develop accurate and credible emission intensity factors, as shown in Chapters 5 and 6. The activity-based approach then uses the developed emission intensity factors to calculate the emissions of logistical activities, as is the case in Chapter 7's carbon mapping framework. Chapter 5 discussed the emission intensity factors developed for each mode of transport (road, rail, air, and deep sea). This chapter consisted of two published journal articles (du Plessis, van Eeden and Botha, 2022; du Plessis, (du Plessis, van Eeden, Goedhals-Gerber & Else, 2023). According to the primary researcher's knowledge, the various emission intensity factors developed in this chapter are the first factors specific to SA or any African country. Chapter 6 elaborated on the emission intensity factors developed for logistical facilities or sites that handle and store fresh fruit. This chapter contained one published journal article (du Plessis, van Eeden & Goedhals-Gerber, 2022c), establishing an emission intensity factor for cold stores. To the best of the knowledge of the primary researcher, this is the first ever assessment of the emission intensity of cold storage of fresh fruit. In addition, the chapter and journal article emphasised the importance of a fundamental shift to include the storage duration as a parameter when the emissions of refrigerated products are calculated.

Part V (Chapters 7 and 8) consisted of the developed carbon mapping framework and its application to seven typical example distribution scenarios. Chapter 7 began by discussing the design requirements of the framework, the various inputs used to design and develop the framework, and the verification and validation of the developed framework. Chapter 7 contains the validated carbon mapping framework – the first known standard for any type of commodity that provides industry-specific guidance and emission intensity factors to quantify emissions. Chapter 8 applied the framework and developed emission intensity factors from Part IV to seven validated real-world distribution scenarios. Each example scenario assessed is unique since the fruit type, functional unit (pallets of fruit or reefer containers filled with fruit), mode of transport, type of logistical facility used, and country of import are different. Chapter 8 exhibited the potential value of the developed carbon mapping framework to determine the emissions of complex, in-depth distribution scenarios by which fruit is exported from South Africa. The chapter is the content required for an envisaged sixth journal article.

9.2 Review of research design

The two sections below briefly review the research philosophy and methodology.

9.2.1 The researcher philosophy

The researcher followed a *critical realist paradigm* as research philosophy, which implies that the environment and the primary researcher were independent and that the researcher needed to look for a "bigger picture" of which only a small part is observed. This philosophy ensured that the primary researcher maintained a systems perspective of the various parts of the research project indicated in Figure 9.1. This also warranted that the results, recommendations, or guidance provided due to the research were unbiased and are a true reflection of the fruit export sector's emissions.

9.2.2 Review of research methodology

The research project used a *mixed methods approach* since both quantitative and qualitative methods were employed throughout the research. A mixed methods approach was ideal as it strengthened the overall research design and rigour since various types of qualitative and quantitative input data enable triangulation. This triangulation of input data enabled constant and continuous internal verification of each part of the research and ensured the subsequent results' validity. Although external validation fulfils an important function, the continuous verification (questioning, theorising, and investigation) of each part of the research through triangulation contributed more to validity and rigour than the once-off validation by an SME. However, qualitative methods, such as interviews with stakeholders, SMEs, or journal reviewers' feedback, were still used to validate the research results and vice versa. This ensured that a broad spectrum of data was collected and analysed to ensure a reliable outcome and non-biased results.

Regarding the *research strategy* used to execute the mixed methods approach, this research utilised a *case study strategy* and *archival research* to achieve the ROs stated in Section 1.3 and answer the RQs defined in Section 1.5. The case study strategy was used to investigate, understand, and assess how fruit exports from SA occur in a real-life context. This case study strategy ensured that the research results used as input for the envisaged framework and the development of the emission intensity factors reflect the real-world distribution of fresh fruit. Furthermore, archival research was used in parallel throughout the project to ensure the case study strategy produced realistic and valid results. Where applicable and possible, archival research was also used for the continuous internal verification of research results and concepts.

9.2.2.1 Data and the collection thereof

Since the research project consisted of numerous semi-independent parts, several different *data collection techniques* were used, as discussed in Chapters 2 through 8. Different data collection techniques were necessary due to the variability between data sources and due to the difference in data types. However, using multiple data collection techniques for each part of the research ensured that one or more researchers could verify the assessment process and results internally. Examples of primary data collected from industry included data from eight cold storage facilities, a rail terminal facility and associated rail services, several LSPs, fruit exporters and representative organisations, a maritime shipping company, and commercial airline pilots. Primary data was also collected through interviews with stakeholders or subject matter experts (SMEs) in the fruit export industry. Observations also played an essential role in collecting primary data since this gave meaning to the collected data, and the business process and method behind the data were understood. Secondary data used in the project includes data from EcoInvent, the Smart Freight Centre (SFC), the Food and Agriculture Organisation (FAO) of the UN, Eskom, Agrihub data, and the Intergovernmental Panel on Climate Change (IPCC).

An important factor that influenced the overall research project was the sensitivity of the collected data and assessment results. The collected primary data from industry collaborators were highly sensitive and were therefore treated as such to minimise the potential of traceability. All data and results were anonymised to ensure that collaborators' identities remained undisclosed. Utmost care was taken when storing, sharing, and handling this confidential data with stakeholders.

9.2.2.2 Assessment methods

In terms of the *assessment methods* used in the research, Chapters 2 through 8 show and confirm the significant difference in the methods used to assess data. This difference in assessment methods is due to the type of data collected, the differences in data collection methods, and the research's expansive scope. So far as possible, all assessment methods used to analyse data builds on existing literature principles or methodologies. This warrants conformance to existing emission accounting principles and ensures that the best elements of existing literature are used to develop the framework.

9.2.2.3 Developing the framework

The developed carbon mapping framework used the research results and methodologies of Chapters 2 through 6 and the typical distribution scenarios stated in Chapter 8 to design and develop the framework. According to Section 7.2, the various equally important inputs integrated to develop the framework were:

- *Literature* – Building the framework on existing literature assessed throughout the project research is important for conformance to existing emission research. This also ensured that the most applicable elements of current literature were used in the framework.
- *Observations* – No literature or other source could provide the primary researcher with the same insight and understanding as first-hand experience. These observations were vital to ensure the framework is developed to reflect the real-world distribution process.
- *Emission intensity factors* – Prescribing a framework without the means to quantify emissions results in the framework being less useful and user-friendly since emission intensity factors must be retrieved from the literature. Furthermore, emission intensity factors specific to the industry potentially increase the framework's accuracy since the suggested factors reflect the real-world distribution process and logistical circumstances. The emission intensity factors developed in Chapters 5 and 6 are, therefore, an important part of the framework.
- *Distribution chain diagrams* – These diagrams provide a consistent scope or breadth of emission assessment in the framework. This ensures that independent carbon footprinting projects assess the same set of emission-generating activities in a distribution chain.
- *Semi-structured interviews* – SMEs in different research fields and the fruit export industry provided essential input for the framework. The various individuals' opinions, recommendations, and critiques were incorporated to improve the framework and its usability.
- *Collaboration with industry* – The continuous collaboration and consultation with industry stakeholders throughout the project allowed the primary researcher to understand the macro-logistical process of fruit exports. This also ensured that the researcher maintained a systems perspective and incorporated the small yet essential elements that affect emissions.
- *Typical validated distribution scenarios* – The final type of input used to develop the framework was the iterative application of preliminary versions of the framework to typical distribution scenarios. The entire framework was developed in parallel with estimating the emissions of typical distribution scenarios. These validated distribution scenarios ensure that the framework addresses all emission assessment aspects and potential anomalies. Applying draft versions of the framework to example case studies warrants that the framework covers all "gaps" that might potentially exist and ensures that the framework can achieve its goal.

Regarding the verification and validation of the carbon mapping framework (Section 7.4), the continuous verification (questioning, theorising, and investigation) of the framework and various steps ultimately ensures end-to-end validity and rigour. The project, therefore, emphasised the value of internal verification employing data triangulation. However, the framework and associated steps were also validated by several SMEs to ensure credibility.

9.3 Achievements

The primary aim of this study was to develop a carbon mapping framework and emission intensity factors for the international distribution (transportation, handling, and storage) of fresh fruit exported from South Africa. This primary aim was achieved through a well-defined research methodology, which enabled the realisation of the various ROs defined in Section 1.3. The developed framework enables any stakeholder with reasonable knowledge to calculate the carbon footprint (kg CO_2e/kg of fruit) and total emissions (kg CO_2e) from a packing facility up until the international port of discharge on a shipment level. This is confirmed by the application of the developed framework to seven in-depth distribution scenarios (Chapter 8), which proved that the framework could incorporate a high level of detail if required. The framework enables the South African fruit export industry to assess and benchmark the environmental sustainability of distributing its fruit.

To the best of the primary researcher's knowledge and the published journal article in Section 2.2, this framework is the first known standard for any type of commodity which provides industry-specific guidance and emission intensity factors to quantify distribution emissions. The framework presented in Chapter 7 is, therefore, an example for other types of commodities to follow in order to develop similar industry-specific standards.

9.4 Unique contributions

This research project focused on an important, however, overlooked source of emissions – the distribution of goods in SCs. Transportation, handling and storage of products will remain an essential part of all SCs in the foreseeable future due to globalisation, time and place discrepancies, and society's way of life. This dependency on logistics to move goods necessitates more comprehensive, accurate, and innovative ways to gauge how these logistical activities produce emissions. The research conducted and presented in this project, however, enables the assessing and benchmarking of emissions due to the distribution component in fresh fruit SCs.

In summary, the unique theoretical contributions as a result of the project are summarised as follows:

- Promotes and enables a fundamental shift in GHG emission accounting methodology from a corporate level to a product or transport service level;
- Develops a framework, which enables any stakeholder with reasonable knowledge to assess the carbon footprint (kg CO_2e/kg of fruit) and total emissions (kg CO_2e) of a shipment of fresh fruit;
- Develops and recommends a comprehensive set of industry-specific emission intensity factors needed to calculate emissions of all possible distribution activities by which fruit is exported from South Africa;
- Enables the comparison and benchmarking of different distributional scenarios to one another;
- Allows for a constructive discussion of the food miles debate and related topics.

The unique theoretical contribution of each part of the research is shown in Table 9.1 according to the various parts of the dissertation document structure defined in Table 1.3.

Table 9.1: The unique contributions of the research project

Part and chapter in the dissertation document	Unique contribution
Part II Chapter 2	• A peer-reviewed published journal article summarises valuable literature on carbon mapping frameworks for general freight and fresh fruit distribution.
Part III Chapter 3	• Five distribution chain diagrams in a peer-reviewed published journal article define the structure of fresh fruit exports from SA. These diagrams form the basis of seven important managerial actions, as discussed in the article in Section 3.3. • Identifies all potential emission-generating activities that should be included in the emission assessment of fresh fruit distribution chains. • Presents a critical and comprehensive review of the fruit export industry's logistics *status quo*.

Part and chapter in the dissertation document	Unique contribution

Part IV
Chapter 5
	• Develops and suggests novel emission intensity factors specific to South Africa for the following:
	  ○ Road transportation;
	  ○ Rail transportation of reefer containers;
	• Develops the first known emission intensity factor for reefer vessels;
	• Suggests a methodology and various formulae to accurately determine a road transport service's expected fuel use and emissions (refer to the journal article in Section 5.1.2);
	• Develops an emission intensity factor for a South African LSP that transports bulk liquids (refer to the accepted peer-reviewed journal article in Section 5.1.1);
	• Demonstrates how the emission intensity factors of various modes can be developed using different types of primary or secondary data;

Chapter 6	• Develops and recommends novel emission intensity factors for various types of logistical facilities that handle and store fresh fruit in South Africa. • Develops and suggests a new methodology to calculate the emission intensity factor for refrigerated facilities (refer to the peer-reviewed published journal article in Section 6.2.1). • Enables the fundamental shift in how refrigerated product emissions are accounted for and calculated by incorporating the time duration of storage.
Part V Chapter 7	• Suggests a carbon mapping framework and emission intensity factors which provides consistent and specific step-by-step guidance in determining GHG emissions. • The framework design serves as a blueprint for other types of commodities to develop similar industry-specific emission accounting standards.
Chapter 8	• Determines the emission intensity and total emissions of various distribution chains by which fresh fruit is exported. • Demonstrates the extent and use of the framework and associated emission intensity factors for future users of the framework.

9.5 Future work and recommendations

The carbon mapping of distribution chains and individual emission-generating activities is at an infant stage. The primary researcher recommends that the following list of items (in order of importance) be conducted as future work to improve the framework and increase its accuracy:

Fuel emission factors:

- Establish a credible emission factor for liquid fuels such as diesel and petrol in South Africa (and the Southern-African region) since the Well-to-Tank (WTT) emissions are potentially underestimated.

Methodological guidance to develop emission intensity factors:

- Significant future work is required to develop more detailed and credible guidance methodology when calculating emission intensity factors. This is essential to ensure that the future emission intensity factors for the various transportation modes and logistical facilities are derived from a sound methodology. Methodological aspects such as load factor, empty running, average dwell days, etc., significantly impact how emissions are allocated when establishing emission intensity factors.

- Simple yet comprehensive industry-specific guidance to determine emission intensity factors is important to ensure industry uptake and potential implementation by LSPs or facility operators.

<u>Emission intensity factors:</u>

Various opportunities exist for further research to narrow down the accuracy of emission intensity factors for the different modes of transport and the different types of logistical facilities. The most notable are:

- Accurate emission intensity factors for rail transportation in SA and international air transport for long-distance flights;
- Emission intensity factors for the handling of containers at different maritime container terminals;
- Further research is needed to establish more accurate average power consumption values of integral reefer containers;
- More detailed emission intensity factors for different sizes of vessels on different trade routes are required.

<u>Miscellaneous:</u>

- Establish an accurate industry-average volume loss percentage for the fruit export industry from packhouse to the port of import to determine the actual fruit volume loss percentage during distribution.
- Future research is required to assess the scale and emission impact of refrigerant leakage (fugitive emissions) from logistical facilities, transportation vehicles such as trucks, reefer vessels or transportation equipment such as integral reefer containers.
- The emission contribution of the longer-term storage of fruit in controlled atmosphere conditions is potentially enormous. Some cultivars of pome fruit (apples and pears) are stored for up to 12 months to enable a year-round supply of the fruit. The framework's scope should be expanded in future to include this long-term storage before the fruit is packed for distribution;
- Differentiate the framework for different temperatures of refrigeration.

9.6 Concluding remarks

The carbon mapping framework developed in this research not only sets a standard for the South African fruit export industry to estimate distribution emissions but also provides other commodity groups with guidance to develop a similar emission accounting standard. The practical research conducted in this dissertation is important for the long-term sustainability of any industry or business organisation since the environmental impact of a product or service is increasingly a parameter of value and interest. Apart from cost, emissions have become an important decision criterion to consider due to the increased global awareness of the environmental impact of GHG emissions. Further, ambitious carbon reduction targets (carbon neutral or net-zero) and decarbonisation strategies are becoming increasingly common without organisations having the ability or know-how to determine the scale of their distribution emissions. The developed framework and comprehensive set of emission intensity factors for each emission-generating activity solve this problem for the South African fruit export industry.

With the global freight volumes growing, it is now more important than ever to empower all stakeholders to understand the emission impact of their logistical decisions and actions. Operational factors such as empty running, load factor, the time duration of storage, and modal choice significantly impact distribution chains' efficiency and emissions. Therefore, decarbonisation efforts must begin by improving the efficiency of logistical activities since these are “low-hanging fruit”.

All stakeholders involved in an SC are equally responsible for the distribution emissions of a product such as fresh fruit. The emissions emitted during the distribution process should not only be the responsibility of LSPs, shipping lines, or logistical facility owners or operators who provide the transport service. All stakeholders, such as freight forwarders, exporters, retailers, and consumers, should have a shared responsibility for these emissions. Quantifying the GHG emissions of various distribution activities will potentially reduce emissions since polluters will commit to decarbonisation efforts once emissions have been assessed.

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APPENDIX A – EMISSION INTENSITY FACTORS USED IN CHAPTER 8

Table A: Emission intensity factors used in the seven typical distribution scenarios

Description of distribution activity	Selected emission intensity factor
Avocado distribution scenario (Section 8.2.1)	
Transport via road transport (Tzaneen to Cape Town)	62 g CO_2e/t-km
Offloading, inland fruit facility, loading (cold store)	7.52 kg CO_2e pallet-day^{-1}
Transport via road transport (cold store to port)	112 g CO_2e/t-km
Offloading, port of export, Loading (maritime port)	60.2 kg CO_2e/container and 175 kg CO_2e day^{-1}
Transport via deep-sea transport (the Port of Cape Town to the Port of Rotterdam)	276.2 g CO_2e/TEU-km
Oranges distribution scenario (Section 8.2.2)	
Transport via road transport (Letsitele to Durban)	67 g CO_2e/t-km
Offloading, inland fruit facility, loading (cold store)	7.52 kg CO_2e pallet-day^{-1}
Transport via road transport (cold store to port)	112 g CO_2e/t-km
Offloading, port of export, loading (maritime port)	60.2 kg CO_2e/container and 175 kg CO_2e day^{-1}
Transport via deep-sea transport (Port of Durban to the Port of Rotterdam)	276.2 g CO_2e/TEU-km
Soft citrus distribution scenario (Section 8.2.3)	
Transport via road transport (Citrusdal to Cape Town)	105 g CO_2e/t-km
Offloading, inland fruit facility, loading (cold store)	7.52 kg CO_2e pallet-day^{-1}
Transport via road transport (cold store to port)	105 g CO_2e/t-km
Offloading, port of export, loading (maritime port)	Included in the reefer vessel emission intensity
Transport via deep-sea transport (Port of Cape Town to Port Philadelphia)	48.6 g CO_2e/t-km

Description of distribution activity	Selected emission intensity factor
Lemons distribution scenario (Section 8.2.4)	
Transport via road transport (Marble Hall to City Deep)	115 g CO_2e/t-km
Offloading, inland rail facility, loading (inland rail facility)	22.9 kg CO_2e/container and 175 kg CO_2e day^{-1}
Transport via rail transport (City Deep to Maputo)	31.5 g CO_2e/t-km
Offloading, port of export, loading (maritime port)	60.2 kg CO_2e/container and 175 kg CO_2e day^{-1}
Transport via deep-sea transport (Port of Maputo to the Port of Jebel Ali)	285.9 g CO_2e/TEU-km
Blueberry distribution scenario (Section 8.2.5)	
Transport via road transport (Packing facility to Paarl)	171 g CO_2e/t-km
Offloading, inland fruit facility, loading (cold store)	7.52 kg CO_2e pallet-day^{-1}
Transport via road transport (Paarl to Johannesburg)	91 g CO_2e/t-km
Offloading, port of export, loading (airport facility)	50.8 kg CO_2e pallet-day^{-1}
Transport via air transport (Johannesburg to Heathrow)	990 g CO_2e/t-km
Table grapes distribution scenario (Section 8.2.6)	
Transport via road transport (Packing Facility to Worcester)	107 g CO_2e/t-km
Offloading, Inland fruit facility, Loading (Cold store)	7.52 kg CO_2e pallet-day^{-1}
Transport via road transport (Worcester to Port of Cape Town)	115 g CO_2e/t-km
Offloading, Port of Export, Loading (Maritime Port)	60.2 kg CO_2e/container and 175 kg CO_2e day^{-1}
Transport via deep-sea transport (Port of Cape Town to Rotterdam)	276.2 g CO_2e/TEU-km
Pome fruit distribution scenario (Section 8.2.7)	
Transport via road transport (Ceres to Cape Town)	70 g CO_2e/t-km

Description of distribution activity	Selected emission intensity factor
Offloading, port of export, loading (maritime port)	30.1 kg CO_2e/container and 175 kg CO_2e day^{-1}
Transport via deep-sea transport (Port of Cape Town to the Port of Rotterdam)	155.4 g CO_2e/TEU-km

APPENDIX B – DECLARATION OF AUTHOR CONTRIBUTION

In line with the General Almanac of Stellenbosch University (paragraphs 6.9.5.2 - 6.9.5.4), journal-article-based dissertations must contain a formal declaration indicating the nature and extent of the contribution of co-authors. The declarations in this appendix are purposefully not signed (as per Stellenbosch University guidelines) to protect the signatures of the individuals and prevent unlawful reproduction thereof. However, the candidate and the primary supervisor, Prof Joubert van Eeden, are in possession of a signed declaration.

B1 Chapter 2 declaration

Declaration by the candidate:

With regards to the following published article:

Carbon mapping frameworks for the distribution of fresh fruit: A systematic review

included in Chapter 2 (page 31), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
Conceptualisation of research, methodology development, formal analysis and execution of research, data curation, writing – original draft preparation and finalisation, visualisation and general administration during the journal's peer-review process.	90%

The following co-authors contributed to the article presented in Chapter 2 (page 31):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Prof Joubert van Eeden	jveeden@sun.ac.za	Guidance and supervision, reviewing and editing, funding acquisition.	5%
Prof Leila Goedhals-Gerber	leila@sun.ac.za	Guidance and supervision, reviewing and editing.	5%

Date and signature of candidate: *Declaration with signature in possession of candidate and supervisor.*

Declaration by co-authors:

The undersigned hereby confirm that:

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to the article included in Chapter 2 (page 31),

2. no other authors contributed to the article included in Chapter 2 (page 31) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties, and that the necessary arrangements have been made to use the material in Chapter 2 (page 31) of this dissertation.

Name	Signature	Institutional affiliation	Date
Prof Joubert van Eeden	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	
Prof Leila Goedhals-Gerber	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	

B2 Chapter 3 declaration

Declaration by the candidate:

With regards to the following published article:

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

included in Chapter 3 (pages 37-53), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
Conceptualisation of research, methodology development, facility visits, formal analysis and execution of research, data curation, writing – original draft preparation and finalisation, visualisation, interviews, and general administration during the journal's peer-review process.	90%

The following co-authors contributed to the article presented in Chapter 3 (pages 37-53):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Prof Joubert van Eeden	jveeden@sun.ac.za	Guidance and supervision, reviewing and editing, funding acquisition.	5%
Prof Leila Goedhals-Gerber	leila@sun.ac.za	Guidance and supervision, reviewing and editing.	5%

Date and signature of candidate: *Declaration with signature in possession of candidate and supervisor.*

Declaration by co-authors: The undersigned hereby confirm that:

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to the article included in Chapter 3 (pages 37-53),
2. no other authors contributed to the article included in Chapter 2 (pages 37-53) besides those specified above, and
   potential conflicts of interest have been revealed to all interested parties, and that the necessary arrangements have been made to use the material in Chapter 3 (pages 37-53) of this dissertation.

Name	Signature	Institutional affiliation	Date
Prof Joubert van Eeden	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	
Prof Leila Goedhals-Gerber	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	

B3 Chapter 5 declaration

Declaration by the candidate:

With regards to the following accepted journal article:

DEVELOPMENT OF EMISSION INTENSITY FACTORS FOR A ROAD FREIGHT LOGISTIC SERVICE PROVIDER

included in Chapter 5 (pages 68-81), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
Conceptualisation, methodology development, facility visits to LSP, formal analysis, writing – original draft preparation and finalisation, general administration and assistance with the project.	50%

The following co-authors contributed to the article presented in Chapter 5 (pages 68-81):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Prof Joubert van Eeden	jveeden@sun.ac.za	Guidance and supervision, reviewing and editing, facility visits to LSP, funding acquisition.	10%
Megan Botha	mebotha5@gmail.com	Conceptualisation of research, formal analysis and execution of research, visualisation, facility visits to LSP, and data curation.	40%

Date and signature of candidate: *Declaration with signature in possession of candidate and supervisor.*

Declaration by co-authors:

The undersigned hereby confirm that:

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to the article included in Chapter 5 (pages 68-81),
2. no other authors contributed to the article included in Chapter 5 (pages 68-81) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties, and that the necessary arrangements have been made to use the material in Chapter 5 (pages 68-81) of this dissertation.

Name	Signature	Institutional affiliation	Date
Prof Joubert van Eeden	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	
Megan Botha	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	

B4 Chapter 5 declaration

Declaration by the candidate:

With regards to the following unpublished journal article:

Calculating Fuel Usage and Emissions for Refrigerated Road Transport using Real-World Data

included in Chapter 5 (page 83), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
Conceptualisation of research, data collection and integration, data curation methodology development, formal analysis and execution of research, writing – original draft preparation and finalisation, visualisation and general administration during the journal's peer-review process.	85%

The following co-authors contributed to the article presented in Chapter 5 (page 83):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Jacques Else	jacques.else.1979@me.com	Data collection and integration, resources.	5%
Prof Joubert van Eeden	jveeden@sun.ac.za	Guidance and supervision, reviewing and editing.	5%
Prof Leila Goedhals-Gerber	leila@sun.ac.za	Reviewing and editing.	5%

Date and signature of candidate: *Declaration with signature in possession of candidate and supervisor.*

Declaration by co-authors:

The undersigned hereby confirm that:

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to the article included in Chapter 5 (page 83),
2. no other authors contributed to the article included in Chapter 5 (page 83) besides those specified above, and
3. potential conflicts of interest have been revealed to all interested parties, and that the necessary arrangements have been made to use the material in Chapter 5 (page 83) of this dissertation.

Name	Signature	Institutional affiliation	Date
Jacques Else	Declaration with signature in possession of candidate and primary supervisor.	Confidential	

Name	Signature	Institutional affiliation	Date
Prof Joubert van Eeden	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	
Prof Leila Goedhals-Gerber	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	

B5 Chapter 6 declaration

Declaration by the candidate:

With regards to the following published article:

The Carbon Footprint of Fruit Storage: A Case Study of the Energy and Emission Intensity of Cold Stores

included in Chapter 6 (pages 104-125), the nature and scope of my contribution were as follows:

Nature of contribution	Extent of contribution (%)
Conceptualisation of research, methodology development, data collection and curation, formal analysis and execution of research, validation, software, writing – original draft preparation and finalisation, visualisation and general administration during the journal's peer-review process.	90%

The following co-authors contributed to the article presented in Chapter 6 (pages 104-125):

Name	e-mail address	Nature of contribution	Extent of contribution (%)
Prof Joubert van Eeden	jveeden@sun.ac.za	Conceptualisation of research, methodology development, validation, guidance and supervision, reviewing and editing, and funding acquisition.	7%
Prof Leila Goedhals-Gerber	leila@sun.ac.za	Conceptualisation of research, resources, guidance and supervision, reviewing and editing.	3%

Date and signature of candidate: *Declaration with signature in possession of candidate and supervisor.*

Declaration by co-authors:

The undersigned hereby confirm that:

1. the declaration above accurately reflects the nature and extent of the contributions of the candidate and the co-authors to the article included in Chapter 6 (pages 104-125),
2. no other authors contributed to the article included in Chapter 6 (pages 104-125) besides those specified above, and
   potential conflicts of interest have been revealed to all interested parties, and that the necessary arrangements have been made to use the material in Chapter 6 (pages 104-125) of this dissertation.

Name	Signature	Institutional affiliation	Date
Prof Joubert van Eeden	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	

Name	Signature	Institutional affiliation	Date
Prof Leila Goedhals-Gerber	Declaration with signature in possession of candidate and primary supervisor.	Stellenbosch University	