



## Understanding Victoria's Fruit and Vegetable Freight Movements

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## Glossary

**ABS** Australian Bureau of Statistics

**Art\_I** Articulated truck, local/regional

**Art\_B2** Articulated truck, B-double.

**Carbon footprint.** The total amount of carbon dioxide equivalents and other greenhouse gases emitted over the full life cycle of a product.

**CO<sub>2</sub>-e (Carbon dioxide equivalent).** The amount of CO<sub>2</sub> that would have the same relative warming effect as the basket of greenhouse gases actually emitted.

**CSIRO** Commonwealth Scientific and Industrial Research Organisation

**DC** Distribution Centre

**PROC** Processors

**DPI** Department of Primary Industries

**EWE** Extreme weather event.

**F&V, F+V** Fruit and vegetables

**Greenhouse Gases (GHGs).** Gases in the earth's atmosphere that absorb and re-emit infrared radiation. The Kyoto Protocol lists six major greenhouse gases: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), HFCs (hydrofluorocarbons), perfluorocarbons (PFCs, a by-product of aluminium smelting) and sulphur hexafluoride (SF<sub>6</sub>).

**HAL** Horticulture Australia Limited

**LCV** Light Commercial Vehicle

**Local** Where referring to food, 'local' in this report refers to Victorian production

**MSC** Major Supermarket Chain

**MM** Melbourne Markets

**NRM** Natural Resource Management –related to the location of growing regions.

**PROC** Processors

**VEIL** Victorian Eco-Innovation Lab, University of Melbourne

**Rig\_2x** Rigid truck, 2-axles

**Rig\_3x** Rigid truck, 3-axles

**SCDT** Supply Chain Database Tool

1M-kg = 1kT

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# 1. Executive Summary

## **Context**

This report outlines the methodology and results of Part 2 of a three-part project initiated by the Victorian Eco-Innovation Lab (VEIL), which aimed to shed light on greenhouse gas emissions and vulnerabilities in Victoria's food freight systems.

The operations of the food industry can transform agricultural raw materials into safe, convenient, good tasting and nutritious products for consumers. However, to continue profitably doing so, it is becoming increasingly important to be more environmentally sustainable (particularly in terms of GHG emissions) and resilient to a changing agricultural landscape, oil price fluctuations, markets and weather variability.

While the greenhouse emissions from agriculture (12.9% of Victoria's total emissions) are increasingly well understood, emissions generated throughout the supply chain are considerably less so. Post-farmgate activities include packaging, processing, transport, storage, retail etc. These supply chains are complex and variable. A summary of existing knowledge is contained within this report and that from Part 3 of the project.

The horticulture industry in Australia is valued at \$3.5 billion and in Victoria is worth \$1.3 billion per annum. An improved understanding of the factors affecting greenhouse emissions, fuel use and potential vulnerabilities in the supply chains of these products will be important to their ongoing viability.

The analysis outlined in this report is intended to contribute to an increased understanding of how fruit and vegetables are moved from production to consumers in Victoria and the greenhouse emissions implications of this operation. The analysis is focused only on the **transport** components of the supply chain, including refrigeration within transport where required, but it **does not** include energy use or emissions from production, processing, packaging etc. It should not be understood as a lifecycle analysis, it is intended only to increase understanding regarding the transport components of food (particularly fruit and vegetable) supply chains in Victoria.

## **Development of Methodologies**

The key elements required in this analysis were identified as:

- Mapping of fruit and vegetable supply chains in Victoria, identifying: sources and destinations; transport types and amounts; key features (e.g. bottle-necks)
- Analysing greenhouse gas emissions throughout these supply chains i.e.
  - What are the contributions of different components of the fruit and vegetable supply chains to greenhouse gas emissions;
  - Identifying how these supply chains vary throughout the year, according to seasons and conditions; and
  - Exploring relative contributions to greenhouse gas emissions of changes in these components.

Two complementary methodologies have been developed and used for exploration of different components.

The first, described in Part A, employed a deterministic approach to the analysis. This approach allowed the study to identify and assign suitable values (observed or estimated) for each set of variables representing the required components of the supply chain. It approximates and makes

assumptions as appropriate, to enable calculation of summary values and overall measures of efficiency in the system.

The second type of analysis, described in Part B, explored the sensitivity of total greenhouse gas emissions to changes in different variables i.e. the relative significance of different components in the supply chain. Although some initial sensitivity analysis was undertaken using the methodology developed in Part A, the high level of data uncertainty and the need to investigate a large number of iterations of variables to represent reasonable scenarios made further pursuit of this approach infeasible within the scope of this project.

To overcome the high levels of uncertainty, a second analysis tool based on 'stochastic modelling' (which can take account of the probabilities of different events), was developed, to enable evaluation of the sensitivity of greenhouse gas emissions to a wide range of variables.

These two methodologies are summarised below and outlined in more detail in the full report and appendices.

## **Part A: Deterministic Analysis**

To conduct the deterministic analysis, a large amount of data was gathered to map the Victorian supply chain of fruit and vegetables (F&V) and therefore assess likely transport requirements.

The food movements investigated in this project included:

- Movements of fresh and processed F&V produced and consumed in Victoria.
- Movements of fresh F&V produced external to Victoria and consumed in Victoria (interstate and international);
- Movements of fresh F&V produced in Victoria and consumed externally (not including international transport legs).

This required information on the locations and amount of produce:

- Produced and moved from different NRM regions in Victoria;
- Movement of produce between states and internationally;
- Major processing centres;
- Distribution centres and Melbourne Markets;
- Retail outlets – major supermarket chains, independents and grocery stores; and
- Census collection districts where the population of consumers are sourced.

Once the amounts of produce and estimated pathways had been determined, a range of other factors affecting greenhouse gas emissions were also taken into account. These include:

- Vehicle types: articulated, rigid and light commercial (LCV);
- Proportion of trips refrigerated;
- Forward and backhaul trips; and
- Payloads – amount of produce moved within trip.

There have been very limited studies that map out Australian food freight movements across the complex landscape between production and consumer, let alone with the purpose of evaluating GHG emissions. Data availability on aspects such as volumes traded between states, volumes traded through specific supermarket chains and Melbourne Markets, and consumption of fresh and processed F&V was by far the greatest limitation in this project. Data of this type was either not collected historically due to the large volumes of information, or it is highly confidential information not publicly available. This project must therefore be interpreted in the context of these data limitations.

To map out the F&V supply chains, raw data was gathered from multiple sources, including the Australian Bureau of Statistics (ABS), information from the Department of Primary Industries Victoria, Geographical Information Systems databases, market research published by IBISWorld

and several others. Where data gaps existed, various methods of inference were used to estimate these flows. These methods are described in the report.

To take account of all these variables, a MS Access-based model, hereafter known as the Supply Chain Database Tool (SCDT), was developed. This model consists of Access queries performed on Excel input tables to obtain estimates of emissions produced by the transport and distribution of F&V in Victoria. The development of this tool was crucial in detaching the modelling work from the uncertainties in the data collection effort, as it enables various combinations of parameters and input tables to define different scenarios.

Due to the uncertainties in data collection, the SCDT enables investigation of relative (rather than absolute) measures of emissions, indicating the emissions produced from a base scenario based on one set of average values (e.g. average payload, average emissions factors, average distance). The emissions estimates from the supply chain legs for this base scenario were then aggregated into a range of categories to enable comparison i.e. relative contributions of different system attributes (see 1.3.1).

Full details of the deterministic methodology and assumptions are contained in the report. Appendix A provides a technical description of the database tool and an overview of how to use the Supply Chain Database Tool.

Assumptions are noted throughout the report in cases where data has been a limitation. The analyses and models created from this project should be treated as living documents, which improve as further accurate information is incorporated.

## Part B: Sensitivity Analysis

The first part of the sensitivity analysis was conducted by varying input data in the SCDT to explore the impact of changing truck sizes on emissions. However, in light of the significant data uncertainties, fuller exploration of the wide range of variables and uncertainties would require a very large number of iterations, which could not be completed within the scope of this project (see [Research Extensions](#)).

A second analysis tool, based on stochastic modelling, was developed to enable sensitivity analysis to be conducted on a wide range of variables within the timeframe and budget of this project.

For the purposes of identifying the major factors affecting GHG emissions in Victorian F&V chains, major supermarket chains (MSC) and Melbourne Markets-greengrocer chains (MM) were considered to be largely representative of current marketing methods (they cumulatively account for 97% of the total F&V trade<sup>1</sup>). Further, only fresh F&V product entering the Victorian market (through state production, imports and interstate trade) was considered. Time and scope limitations meant that exports and F&V volumes leaving Victoria could not be considered within this analysis.

Table 1.1 summarises how the use of this different tool has enabled a range of values for each variable to be considered, by comparing the input data for a number of key emissions contributors.

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<sup>1</sup> The remaining trade is attributable to a wide variety of small grower-consumer channels, amply discussed by Estrada-Flores and Larsen (2010).

Table 1.1: Comparison of Assumptions in Deterministic and Stochastic Models

Assumption	Deterministic	Stochastic
Vehicle types per segment	Constant mix of vehicles (LCV, rigid trucks, articulated trucks)	Mix of vehicles (LCV, rigid 2 axles, rigid 3-axles, articulated long haul and articulated B-double)
Payload per vehicle type	One load capacity (average payload)	Different loading capacities between a minimum and the maximum capacity per vehicle
Fuel consumption	Constant – independent of load	Variable and dependent on loading capacity used.
Backload per segment	Constant	Variable
Emissions from ship (imported product)	Calculated as per road analysis, with constant emission factors	Multiple assumptions to calculate emissions.
Emissions from refrigeration	Weighting by fuel factor	Factor combining fuel and motion
Volumes of fruit and vegetables	Mass per product type is distinguished	No distinction between product types (lumped volumes of F&V)
Consumer transport (from shops to CD)	100% of trip emissions attributed to F&V for grocery stores, 7.25% for supermarkets (CHOICE basket used)	Healthy Food Basket used. 30% of trip emissions attributed to F&V for both grocery and supermarket trips.
	Fixed number of trips	Variable number of trips
Scale	Individual trips and ABS CCD's	Aggregated over all supermarkets and grocery store trips

The use of a stochastic model allowed the simulation of 37 variables that included distances and product volumes between supply chain nodes, vehicle factors such as type of vehicle, loading capacity, backhauling, refrigeration and, in the consumer side, the effect of car size and number of trips to major shopping points for F&V. Each of these variables was represented by a stochastic distribution selected to realistically represent the range of values typically observed in Australian food freight movements (described in the full report).

## Results

This project did not aim to comprehensively determine greenhouse gas emissions or vulnerabilities, but to investigate the territory, develop methodologies for analysis, provide preliminary indications of significant aspects of supply chain operations for greenhouse gas emissions, and suggest directions for further work.

As the two methodologies were developed and used to elucidate different components of the analysis, they contain a variety of different assumptions and their results are not directly comparable. Considered alongside each other however, some clear themes emerge. The results of the two analyses are discussed below, separately and in relation to each other.

## Deterministic Analysis

The results presented below are obtained when the Supply Chain Database Tool is applied on a base scenario i.e. with all assumptions as outlined in Part A of the report and Appendix A.

The analysis undertaken on this base scenario included:

- Summary statistics: estimated greenhouse gas emissions from transport of fruit and vegetables in Victoria; and

- Comparisons between relative emissions (from transport only), as impacted by: origin of produce (NRMs within Victoria, interstate and internationally); seasonal variation; and fresh versus processed F&V.

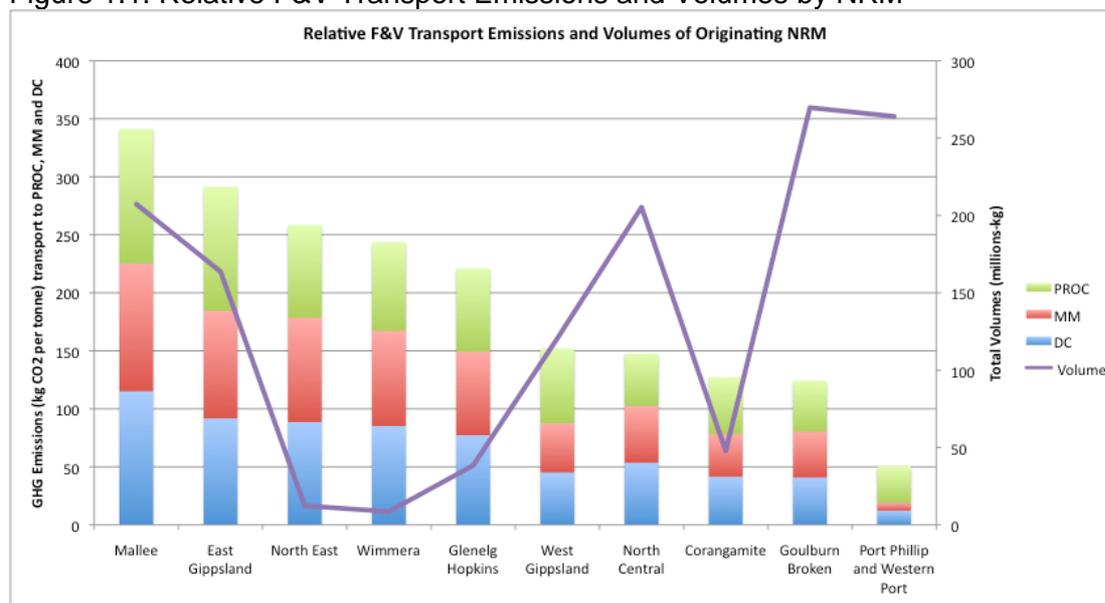
**Summary:** The overall performance of the supply chain resulted in around 133.8 kg of emissions produced for every tonne of fruit transported, and 134.5 kg of emissions for every tonne of vegetable transported. Overall, the supply chain was estimated to produce 134.3 kg of emissions per tonne of F&V moved.

**Processing:** The overall transport emissions for processed F&V were estimated at 190 kg CO<sub>2</sub>-e per tonne, and exceed that for unprocessed F&V (at 128 kg CO<sub>2</sub>-e) by about 60 kg CO<sub>2</sub>-e per tonne. This can be attributed to the additional transport legs to and from the processing centres. (NB. It does not account for increase or decrease in refrigeration requirements in transportation of processed F&V).

It should be noted that the extra legs of transport for processed F&V did not overly increase the overall F&V supply chain emissions because the F&V manufacturers based in Victoria (Table 5.1) are located either close to the F&V growing areas or are in Melbourne, near the supermarket DC's. This contribution could become more significant if processors were located at a further distance from growing regions.

**Origin of Produce:** The significance of distance was evident with the non-even spread of F&V's grown across each Victorian NRM region and the distance from the NRM region to Melbourne. There was a 660% difference in transport GHG emissions per tonne of F&V grown in NRM regions furthest from Melbourne versus the closest (as shown in Figure 1.1).

Figure 1.1: Relative F&V Transport Emissions and Volumes by NRM

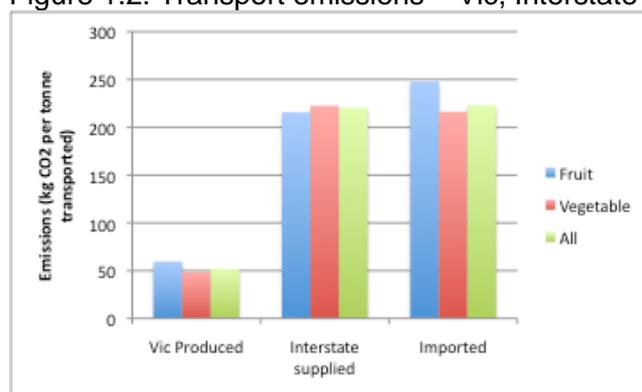


Since production of each fruit or vegetable tended to be concentrated in a subset of NRM regions, the GHG variation between F&V types was also significant with GHG emissions for a tonne of watermelons being 3.5 times that of mushrooms. Different fruits and vegetables had significantly different amounts of emissions per tonne transported, which is largely a factor of the differences in distances from the growing region and the Melbourne Markets or supermarket distribution centres. There is more than a fourfold difference between the items with the highest transport emissions per tonne (grapes, melons, watermelons and oranges) and those with the lowest (celery, beetroots, asian vegetables and parsnips). Transport emissions per \$1,000 value (at farm gate) varied slightly, with the lowest transport emissions per \$1,000 value coming from mushrooms, Asian vegetables, asparagus and cucumbers.

From the perspective of achieving F&V supply chains with lower transport GHG emissions, the analysis shows that there is a strong case for maintaining the production of F&V in areas closer to the main consumption region of Melbourne. Freight movements that go through processing versus DC's/MM had a much lower impact on GHG emissions compared to the growing region, particularly as the DC's/MM are already located around Melbourne. Unless the agronomic (production) GHG emissions per tonne differ substantially between growing regions, increasing the proportion of F&V grown close to Melbourne is an effective means of decarbonising food supply chains.

Taking a broader geographical view, the difference between Victorian grown and interstate grown products was substantial (see Figure 1.2). The analysis suggests that GHG emissions of transport for F&V grown interstate are four times greater than that of Victorian grown produce.

Figure 1.2: Transport emissions – Vic, Interstate and Imported

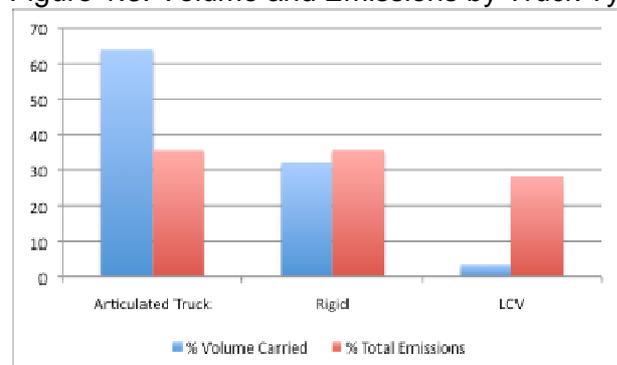


An interesting observation is that the international shipping leg had similar GHG emissions to the interstate road transport leg. However, this does not include ground transport in the foreign country they are imported from, which would likely make them significantly higher.

The deterministic analysis suggests that the household component of emissions is not a significant proportion of the overall emission from the supply chain. This is largely due to the attribution of only 7.25% (as per the CHOICE supermarket basket) of the emissions produced by the trip to the supermarket to fruit and vegetables.

Vehicle types and loads: Figure 1.3 shows the assumed proportion of the volume carried by different sized trucks and the proportion of emissions that this generates. This finding strongly suggests that significant emissions reductions could be achieved by moving to larger trucks. Although only a small percentage of F&V transport is attributed to LCVs (3.5% of total volume), a complete shift away from LCVs to articulated trucks could potentially reduce overall GHG by 26%. Similarly, a complete shift from rigid to articulated trucks could theoretically reduce overall GHG emissions by up to 18%.

Figure 1.3: Volume and Emissions by Truck Type



However, we would expect the improvements to be less than 26% or 18% in practice since LCV's will be more likely used on shorter trips and when it is impractical to use larger trucks. Attempting to move all F&V transport to articulated vehicles would be likely to also have implications for payloads and distances travelled. These results do not take into account congestion aspects, which may worsen (or improve) by these changes.

It is important to note that the relationship of emissions to distance in the base scenario does not allow for a different proportion of different vehicle types for different trip legs e.g. the proportion of articulate, rigid and light commercial vehicles is kept constant over intrastate and interstate trips.

Improved data or closer analysis of this factor would be required to improve understanding of the relationship between emissions and distance. The impact on emissions of changing truck sizes is further explored in Part B: Sensitivity Analysis.

**Seasonal Effects:** Seasonal variability of production & supply in Victoria had a significant impact on GHG emissions from two perspectives: the total volume varies each month due to total supply variation; and the proportion coming from each NRM region varied significantly due to harvest conditions of each F&V.

The highest emissions per tonne from Victorian produce (for Victorian consumption) are in October for fruits and November for vegetables. The period from June to November result in high emissions because only fruits like mandarins and oranges, which come from NRMs further from Melbourne, are available at this time. The low emission months for fruits belong to February to May, which coincides with the availability of strawberries, pears and apples, particularly from Goulburn-Broken region. Similarly, the period from November to January exhibit the highest emissions per tonne for vegetables because of the transport of high emission items like watermelons, melons, peas and butter beans, particularly from East Gippsland. The seasonal variability may be an underestimate since the harvest season will be shorter than the time window of availability and transport requirements may be variable within a harvest season.

An important observation was that the very low total emissions around October suggests that there is a much greater amount of F&V transported from other states during this period at four times the GHG emissions per tonne. Conversely, the large GHG emissions during March is likely due to supply exceeding demand in Victoria for which a large amount of F&V is transported to other states or internationally during this period. Unfortunately, the unavailability of data on the list and volume of items exported from Victoria (interstate and international) during this period prevents the study from calculating the associated volume of emissions.

NB. If lower Victorian production in October is offset by larger volumes of F&V imported from interstate, the total GHG emissions (local+interstate+imported) in the transport of F&V for the Victorian market would actually be higher in October than in any other month. This would be an important future analysis if supporting data were to become available.

### **Supply chain vulnerability**

**Extreme Weather Events:** Once established on the base scenario, the SCDT model was used to conduct preliminary testing on two features of potential supply chain vulnerability: extreme weather events and changes to oil price.

The impact of an extreme weather event was simulated by a 25% lost production in each NRM region, to explore whether this had a significant impact on supply chain emissions. The four NRMs with the highest volumes of production have the highest replacement requirements if 25% of production is lost i.e. Goulburn/Broken (76 M-kg), Port Philip/Westernport (70 M-kg), Mallee (58 M-kg) and North Central (54 M-kg). Consequently, these four NRMs produced the biggest impact on emissions from lost production.

The analysis suggested that a 25% loss of production in a NRM region only led to small gains in GHG emissions (mostly less than 4%). However, this finding is an average based on the simulated volume replacements from interstate sources for lost production from one affected NRM at a time, assuming the remaining NRMs are unaffected. Thus the gains in GHG is proportional to the lost volume; the NRMs with lost production volumes of 10 mil-kgs or less had GHG gains of less than 1%, while those with at least 40 mil-kgs of lost production produced gains of 1.5% or more.

**Oil Prices:** To explore potential implications of increasing oil prices, two scenarios of oil at \$2/litre and \$2.80/litre were simulated against current farmgate values for fruit and vegetables. These

scenarios only accounted for articulated vehicles (the largest and most efficient) and therefore underestimate the actual cost of fuel for F&V transport.

For F&V produced and consumed in Victoria, the scenario of \$2.80/litre led to fuel costs reaching 10% of current farmgate value for the most GHG / fuel intensive products e.g. watermelons and oranges (compared to 4% at \$1.20/litre). For produce with the lowest GHG / fuel use per \$1,000 (primarily those produced closest to Melbourne), the impact of the change in fuel price was much less significant to the overall value (i.e. for apples it changes from 0.5% of value to 1%). These scenarios, which may be conservative,<sup>2</sup> suggest that impact of increases in the cost of oil would be much more significant for produce being transported from NRMs located further from Melbourne.

From earlier analyses (above), the GHG emissions from interstate transport had been found to be four times that for F&V grown in Victoria (for F&V consumed in Victoria). Assuming fuel consumption is proportional to GHG emissions for long distance transport, one would expect fuel costs for each F&V type would be up to 40% of the product value under a fuel cost scenario of \$2.8/litre, if transported into Victoria from other states – and vice versa.

Where F&V with a high fuel cost to value ratio are transported between states under the high fuel price scenario, it would be likely to represent a significant increase in the retail price of these items. The actual impacts of this scenario on supply chain viability would depend on who bears the increased fuel costs (retailer, logistics company or producer) and current viability of these chain participants. Furthermore, the proportion of these costs passed onto consumers could have a significant impact on affordability of F&V products. Further vulnerability analysis is required to better understand the implications to each supply chain participant.

It is important to note that this sensitivity to fuel price does not reflect any fuel use except that in transport of the F&V produce i.e. it does not reflect impacts of on-farm fuel use or fertiliser cost. By Victoria's 'consumption', the demand by processors was included, as the inability to meet demand locally (or reliably) will impact on their costs of sourcing produce (at some oil / carbon price point, there could be a significant impact).

### Key Uncertainties

Emissions reduction in food supply chains is a complex analysis as there is a trade-off in costs of change, impact on the local economy, social/health value of the current availability of F&V, and estimated environment implications. While this analysis identified three major drivers (distance from growing region, seasonal variability, transport mode) that appear to provide significant opportunities for reducing GHG emissions, there are significant uncertainties that must be taken into account in considering these results.

Some of the gaps in data, and assumptions made to overcome these, are likely to have led to significant underestimates of the greenhouse gas emissions in some parts of the supply chain. For example, freight movements at micro level scale could not be identified in this analysis, as data on specific freight movements or companies were not available. This lack of data led to necessary simplifying assumptions, such as:

- Produce is moved directly to DCs using the shortest route, and then directly to stores (ie. there is no movements between DCs) again using the shortest route; and
- Victorian produce is allocated to Victorian consumption first and only sends surplus to other states. This is unlikely to be the case and therefore interstate emissions are probably underestimated.

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<sup>2</sup> Even \$2.80 could be a moderate fuel price increase – “However, if there is a near-term peak in international oil production resulting in declining future oil supplies, petrol prices could increase to between A\$2 and as much as A\$8 per litre by 2018.” (Future Fuels Forum, 2008)

Other assumptions are likely to have influenced the proportion of emissions allocated to different supply chain legs. For example, the constant allocation of vehicle types regardless of trip distance is likely to have overestimated emissions in long distance trips (i.e. interstate) and potentially underestimated those in shorter trips (where a higher proportion of LCVs may actually be used).

For other assumptions the potential impact is unknown. Some key areas where uncertainties resulting from a lack of data should be considered when interpreting results are summarised on Table 1.2.

### 1.2 Key Uncertainties in the Deterministic Analysis

Assumption	Likely Affect on Emissions
Produce takes most 'efficient' pathway from producer to consumer in terms of distance i.e. moves from production to closest processor, DCs, retailers etc to meet requirement.	Underestimate
F&V sourced for processing direct from production (not via MM) and proportional to production volumes for that region	Underestimate
Assuming that produce moves in the shortest road route in all cases.	Underestimate
F&V as a proportion of interstate transport / amount of F&V moved interstate	Unknown
Proportion of vehicle types kept constant in different stages of the supply chain	Unknown
Payloads not differentiated by F&V type i.e. tonne of potatoes requires same transport volume as tonne of lettuce	Unknown
Households would only travel to nearest supermarket and grovery store to purchase F&V	Underestimate
Attributing all consumer trip emissions to F&V for grocery stores, but only 7.25% to supermarkets	Likely bias towards supermarkets

## Sensitivity Analysis

The first component of sensitivity analysis was undertaken using the SCDT, to demonstrate how this capability could be used to explore different scenarios (and potential emissions reduction options). As vehicle types had been identified as a key driver of GHG emissions, despite nearly two thirds of F&V volumes already being assumed to travel in GHG efficient articulated diesel trucks, the effect of changing truck use patterns was further explored.

The analysis showed a decrease in emissions by 5.56% for every further 10% increase in the mode of share of articulated trucks from rigid trucks, while keeping the mode share of LCVs constant. The scope for significant GHG reductions through moving towards more efficient existing vehicles will be limited if it is difficult to shift from LCV's to rigid trucks or from rigid trucks to articulated trucks on some routes.

The stochastic model enabled two further, more detailed, sensitivity analyses to be undertaken:

- A complete farm-to-fork analysis (including consumer travel to shops); and
- A farm-to-store analysis that focused on results relevant to the commercial operations in the F&V supply chain.

In this section, the maximum GHG emissions, interpreted as *the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria*, was used to compare the relative importance of each link in the supply chains analysed. This maximum contribution is based on the potential values that all variables analysed can take, within realistic supply chain conditions. The main findings of these analyses are summarised below.

The stochastic modelling assumed specific patterns of vehicles used for each supply chain leg. Although there is no data available as to the mix of vehicles used to move F&V loads in commercial supply chains, the following educated assumptions were made:

- From the farm-to-pack house segment, it was assumed that all transport for this segment occurs in non-refrigerated rigid, 2 axle vehicles.
- For the pack house-DCs/MM segment and interstate to DCs/MM, it was assumed that the loads are moved through rigid (2 and 3 axles) and articulated trucks (long haul and B-doubles).
- For the Port of Melbourne-to-DCs/MM segment, a combination of LCVs (light and heavy), 2-axle and 3-axle rigid, semi-trailers and B-doubles was assumed.
- From MM to DCs and MM/DCs-to-stores segments, a combination of LCVs (light and heavy), 2-axle and 3-axle rigid and semi-trailers was assumed. B-doubles are restricted to certain routes and unable to travel through many urban areas. Therefore they mainly go to freight terminals (import, export and interstate focus) but are not used to move large loads between DCs and stores.
- From shops to consumers' households, a range of domestic vehicles need to be considered. This variation was reflected in the emissions factors used to calculate the GHG contribution of the consumer link.

#### Farm-to-Fork:

- The calculated carbon footprint from farm-to-fork distribution of fresh F&V consumed in Victoria and sold through greengrocers and supermarkets is likely to fall within 82,214 and 318,976 tonnes CO<sub>2</sub>-e. These results reflect the large data uncertainty –discussed in the deterministic analyses– and the extent to which changes in the variables selected affected the resulting emissions. As the values of variables are refined through more accurate information on commercial distribution of F&V (i.e. the variability is decreased), the resulting GHG emissions would group closer to a mean value.
- In the major supermarket chains (MSC), the distribution segments that have the maximum contribution potential to GHG emissions were (in descending order of importance): transport of F&V from stores to consumers' households, transport from DCs to stores and interstate transport to DCs.
- In the Melbourne Markets (MM) chains, the segments that have the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of importance): transport of F&V from greengrocers to consumers' households, transport from MM to greengrocers and transport from pack houses to MM.

In the farm-to-fork analysis, the most significant factor in transport GHG emissions for fruit and vegetables was found to be consumer travel to purchase them. The significance of this factor is found to be greater than in the deterministic analysis, which is likely due to:

- a higher proportion of the consumer trip allocated to fresh fruit and vegetables (30% based on a healthy food basket, rather than 7.25% in the average); and
- refined allocations of truck types used in different supply chain legs. In particular, the assumption of LCVs used only for short trips led to a lower estimation of emissions for interstate segments.

Given the importance of the consumer segment, decreasing the uncertainty of variables that affect consumer travel would lead to more accurate carbon footprints. In particular, the number of consumer trips –which was assumed to be 1.7 weekly per household, but can be as high as 4 trips to supermarkets and greengrocers<sup>3</sup>– would have a significant influence. Other factors include shopping habits and basket share of fresh and processed fruit and vegetables in trips to supermarkets and greengrocers. Similarly, this analysis assumes that all consumer trips to

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<sup>3</sup> Freshlogic (2010). *Veginsights: the market-Q4 09. A vegetable market platform analysis plus a profile of the three-month period ending 31 Dec 2009*. Page 27.

supermarkets take place in cars. It does not account for those who shop on foot, cycle or public transport.

It is also important to note that the significance of the consumer trips is largely driven by the households located at distances over 5.5 km, despite the fact that these are a minority (less than 20% of the total Victorian households analysed). If the travel distance (or number of trips) of this minority of households were decreased, this would lead to a substantial decrease in the **total** F&V carbon footprint.

In the context of this analysis, which sought to uncover the most significant causes for GHG emissions in the transportation of fresh F&V, it would be incorrect to disregard the impact of distant households, which is the most significant factor. However, if the analysis was conducted excluding the percentage of households that are located beyond 5.5 km from the nearest supermarket/greengrocer, commercial operations such as interstate transport would be expected to be the most significant factor of GHG emissions. This is reflected in the farm-to-store analysis below. Further discussion on the impact of consumer travels is presented in Appendix E.

**Farm-to-Store:** While the farm-to-fork analysis presents results that may be of interest to policy makers and urban planners, a second analysis was conducted to pinpoint opportunities to decrease GHG emissions during commercial F&V chains. The following results can be highlighted:

- The calculated carbon footprint from farm-to-store distribution of fresh F&V consumed in Victoria and sold through greengrocers and supermarkets is likely to fall within 44,752 and 124,062 tonnes CO<sub>2</sub>-e. Again, these results reflect data uncertainty and the degree in which changes in the variables selected affected the resulting emissions. As the values of variables are refined (i.e. the variability is decreased), the resulting GHG emissions would group closer to a mean value.
- For MSC, the segments that had the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of importance): transport from DCs to stores, pack house-to-DCs and interstate transport to DCs. Differences between the GHG emissions of the 2nd and 3rd factors were marginal.
- In the MM chains, the segments that had the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of importance): transport from MM to greengrocers, transport from interstate to MM and transport from pack houses to MM. Again, between the GHG emissions of the 2nd and 3rd factors were marginal.
- Given the importance of the distance between DCs/MM to stores, decreasing the uncertainty of variables that affect this variable would lead to more accurate carbon footprints. Such variables include the specific channels used by greengrocers located in remote locations to source their products, the location of all Victorian greengrocers and the split of volumes from the DCs/MM to stores.

The greater significance of the distance from DCs / MM to stores is likely to result from the multiple trips to stores in distant locations and the low rate of backhauling assumed, compared to the packhouse-to-DC / MM trip. These findings could have implications for location and/or function of outlets and distribution centres, to decrease distances or increase backhauling opportunities.

## ***Conclusions and Recommendations***

These analyses, including mapping of current fruit and vegetable movements in Victoria from production to consumer, have improved understanding of the drivers that promote high GHG emissions in F&V transport in Victoria. The report establishes detailed methodologies, analyses, information, assumptions and some baseline numbers that can be used to inform assumptions

around transport in lifecycle analyses and other food supply chain projects. These are also aspects that can be improved upon.

When considering how the results of this report can be applied to emissions reduction, it is important to recognise that food distribution systems in Victoria have evolved in response to a wide range of economic, social, technical and political drivers. Reducing fuel use and emissions will be just two of the many factors that need to be taken into account in business and government decision-making relating to food supply chains.

The authors acknowledge that food transport systems designed to achieve the lowest GHG emissions would not necessarily result in the best outcome overall. For example, an optimised transport solution could result in the need of changing current production systems to others with a higher carbon footprint. However, the results of this report suggest that there are significant sources of transport emissions in F&V supply chains in Victoria that can be decreased, through management of both commercial operations and urban planning.

Comparisons of absolute GHG emissions predicted with each model are not possible, due to the differences in system boundaries and the different nature of the modelling approaches. For example, the stochastic approach detected non-linear correlations of GHG emissions with loading capacity of LCVs and distances from stores to consumers, which could not be easily identified through a deterministic approach only. As illustrated in the discussion of the impact of distant households on total emissions, non-linear behaviours can provide valuable information and greatly influence the results of comparisons between both models used.

Overall, key findings of this analysis are:

- a) The farm-to-fork transport of fruit and vegetables in Victoria generate significant greenhouse gas emissions.
- b) Distances between the different elements of the supply chain, including consumer markets, have a significant influence on the total GHG emissions generated, as do the type of vehicles used and the proportion of backhauling.
- c) Following the rationale of b) and from a transport emissions and fuel use perspective there are significant benefits in retaining F&V production in proximity to the major population centres. In this case, it is Melbourne's consumers.
- d) Most importantly, the proximity of retail outlets to consumers (or access without a car) is critical to decrease the consumer transport component in farm-to-fork supply chains.
- e) Seasonality has a large influence on the amount of fuel used / emissions generated from the transport of fruits and vegetables. Under current production patterns, Victoria has a large surplus in March and a likely deficit of produce in October.
- f) GHG emissions in these analysis act as a proxy for fuel use. Significant GHG emissions also represent vulnerabilities of both supply chain operators and consumers to increases in fuel price.

#### Methodologies Developed

- a) The evaluation of impacts of specific policies and strategies directing the selection of travel modes, vehicle types, and fuel types in transporting FFV will become an increasingly important area of analysis in the study of F&V supply chains.
- b) The creation of the SCDT has established an 'infrastructure' for evaluation of such policies through creation of scenarios that are then reflected through combinations of changes to the parameter tables. Improved data availability over time has the potential to increase the capability of this tool to provide 'absolute' emissions accounts of the transport components of food supply chains.

- c) Similarly, refinement of the stochastic modelling approach (with improved data sets) could allow for comparative assessments of different options and focus points.
- d) Through use of these tools, an improved understanding of how and where GHG emissions occur can help to identify where both incremental and transformational (including whole-of-chain) interventions could contribute. Such interventions may include changes in transport modes and vehicle types, sharing transport infrastructure, reduced sourcing from interstate at certain times of the year, and better linking production regions with consumers.
- e) The methodologies could be further developed and applied to investigation of other food supply chains, or more broadly.

### Research Extensions

Many of the things that could not be considered within this scope of research could be further investigated in later iterations. With improved data availability and development of more scenarios, the tools would enable more refined analysis. This report has also identified where further priority analyses are needed. We note these analysis and priority data acquisitions required to support them:

- a) Due to the severe lack of suitable data on interstate transport, many questions around the seasonal implications of GHG emissions remain unanswered. This includes better understanding the inefficiencies of interstate F&V GHG emissions at a more granular scale such as individual trip movements and companies. A more detailed analysis would help identify more tangible strategies to reduce GHG emissions.
- b) The scope of the international analysis needs to be expanded to incorporate airfreight and freight movements between the growing regions in the country of origin to the port of country of origin. This would provide a fairer comparison between local and international supply chains.
- c) Supply chains through processors require a more extensive analysis. In particular, data of F&V transported between states for processing is required. Also, GHG emissions of activities within the processor need to be considered to provide a balanced comparison with fresh F&V supply chains.
- d) Seasonal variability in the demand of transport vehicles will also have implications on the level of backloading. We suggest additional investigations be carried out to assess the GHG efficiencies of the road transport from the NRM regions, throughout the year. This would need to be assessed in terms of types of vehicles throughout the year, backloading, and implications of peak demand and excess capacity.
- e) An important analysis would be inclusion of GHG emissions for F&V consumed in food service outlets, and potential freight inefficiencies explored. This is a very complex set of supply chains and there are several thousand food outlets in Victoria. They vary in terms of small restaurants with local ownership, to large franchises (e.g. MacDonald's, KFC) with large complex supply chains.
- f) More data is needed on the proportions of different vehicle types used in different supply chain legs and the variables that affect the consumer trip.

The significance of the last mile in the stochastic analysis suggests that a more in-depth understanding of the 'last mile' effect on food distribution systems would be of interest. In particular, this could consider:

- Are the 'last mile' emissions as significant for other product types as the stochastic analysis suggests they are for fruit and vegetables?
- Given the significant contribution of rural households on the overall carbon footprint generated by consumers' travel to their nearest supermarket shop, what innovative food distribution systems can be more effective in decreasing the 'last mile' to rural households?
- What would be the impact of adding more food outlets to decrease consumers' travel intensity? The commercial realities of mass distribution may inhibit this solution, particularly in

rural areas. However, the transport of food by supermarkets to households, or increase in smaller outlets, could contribute (as discussed in Estrada-Flores and Larsen (2010)).

- If increasing the number of food outlets is an option to decrease the impact of the Victorian 'last mile', how these improvements compare with the increase in upstream distribution operations required to supply the extra stores.

## 2. Introduction

The Victorian Eco-Innovation Lab (VEIL) aims to identify and explore priority needs and opportunities for eco-innovation in Victoria. Freight transport, including that of food, is coming under increased pressure to become more environmentally sustainable (particularly GHG emissions) and resilient to a changing agricultural landscape, oil price fluctuations, markets and weather impacts.

In creating a more sustainable and resilient F&V distribution system, current value chains for F&V movements in Victoria need to be firstly mapped out from production to fork. It would not only better understand the value chain drivers that promote non-sustainable practices or high GHG emission, but will help to identify incremental and transformational (including whole-of-chain) intervention options. Such interventions may include changes in transport modes and vehicle types, sharing transport infrastructure, reduced sourcing from interstate at certain times of the year, and better linking production regions with consumers. It will also provide the capacity to explore the circumstances in Victoria where new systems of F&V distribution could achieve significant GHG reductions and reduced vulnerability to oil scarcity / price escalations.

**This report is Part 2** of a three-part food freight project that aims to shed light on Victoria's food freight system. It does not aim to comprehensively determine greenhouse gas emissions or vulnerabilities, but to investigate the territory and provide preliminary suggestions and directions for further work. The three parts of this project are briefly outlined below.

### Part 1: Summarise existing information relating to Victoria's food freight system.

- Description of Victorian food freight task
- Describe greenhouse gas emissions and vulnerabilities in Victorian food freight system (from available information)
- Outline potential impacts upon food security for Victorian communities

### Part 2: Increase understanding of how fruit and vegetables are moved from production to consumers in Victoria and the greenhouse emissions implications of this operation.

- Map fruit and vegetable supply chains in Victoria, identifying: sources and destinations; transport types and amounts; key features (e.g. bottle-necks)
- Identify how these supply chains vary throughout the year, according to seasons and conditions
- Identify and analyse greenhouse gas emissions throughout the supply chains
  - What components of the fruit and vegetable supply chains have significant greenhouse impacts
  - What factors influence these components e.g. distance, temperature

### Part 3: Assess "best practice" food distribution systems that can potentially achieve significant environmental improvements (i.e. reductions in GHG emissions).

- Identification, description and analysis of novel food distribution systems, including examples of urban, local and regional chains; government led and self-regulatory approaches; and supermarket-led initiatives.
- Analysis of the patterns, motivations and trends in the development and implementation of novel food distribution systems.
- Overview of the barriers and opportunities for the application of novel food distribution systems in Australia and Victoria.

## 2.1 Victorian Fruit and Vegetable Supply Chains

Agriculture is still a major contributor to Victoria's GHG emissions (Figure 2.1), with 9% of agriculture GHG emissions coming from cropping (Growcom 2008). GHG emissions from post farm gate activities ties in with transport and statutory power GHG emissions. In terms of Transport, 36% of GHG emissions road freight (urban and rural) (Victorian Department of Transport, 2008a). Of that 36%, about 3.6% and 5.8% were attributed to agriculture and food & beverages, respectively (Victorian Department of Transport, 2008b).

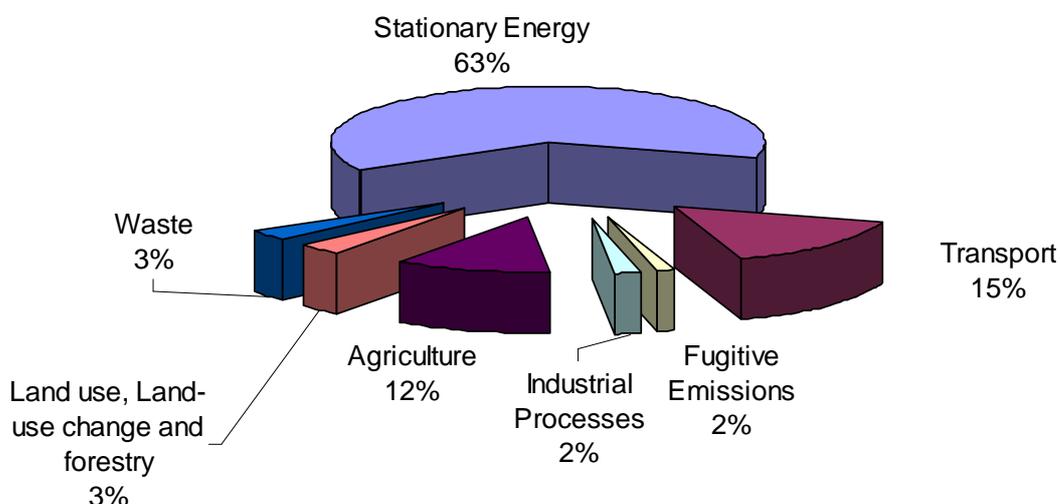


Figure 2.1. Victoria's net GHG emissions breakdown by sector. Source State & Territory Greenhouse Gas Inventories 2006, Australian Greenhouse Office, Department of the Environment and Water Resources, June 2008

The ABS estimates a total of 4,176 F&V growers in Victoria (Figure 2.2), which represent about 22% of the total number of growers in Australia. Figure 2.3 shows the partition between NRM regions. In 2007-08, the most important vegetable crops in terms of volume were potatoes, peas and tomatoes. For fruits, the most significant products were grapes, pome fruit, oranges, and stone fruit (Figure 2.4, 2.5).

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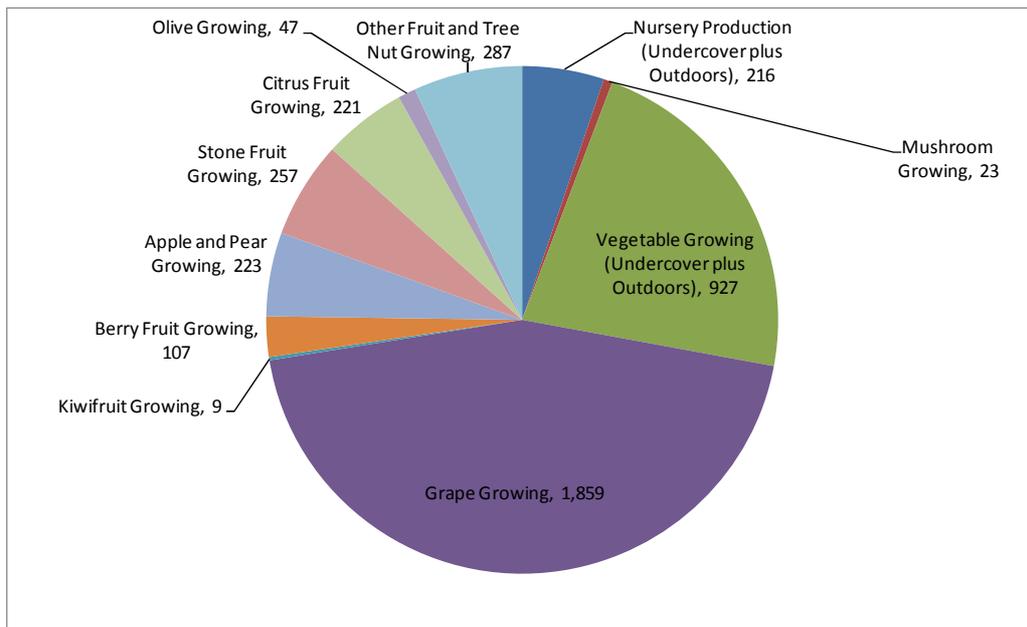


Figure 2.2. Number of businesses with agricultural activity in Victoria in 2008 (Australian Bureau of Statistics, 2008c)

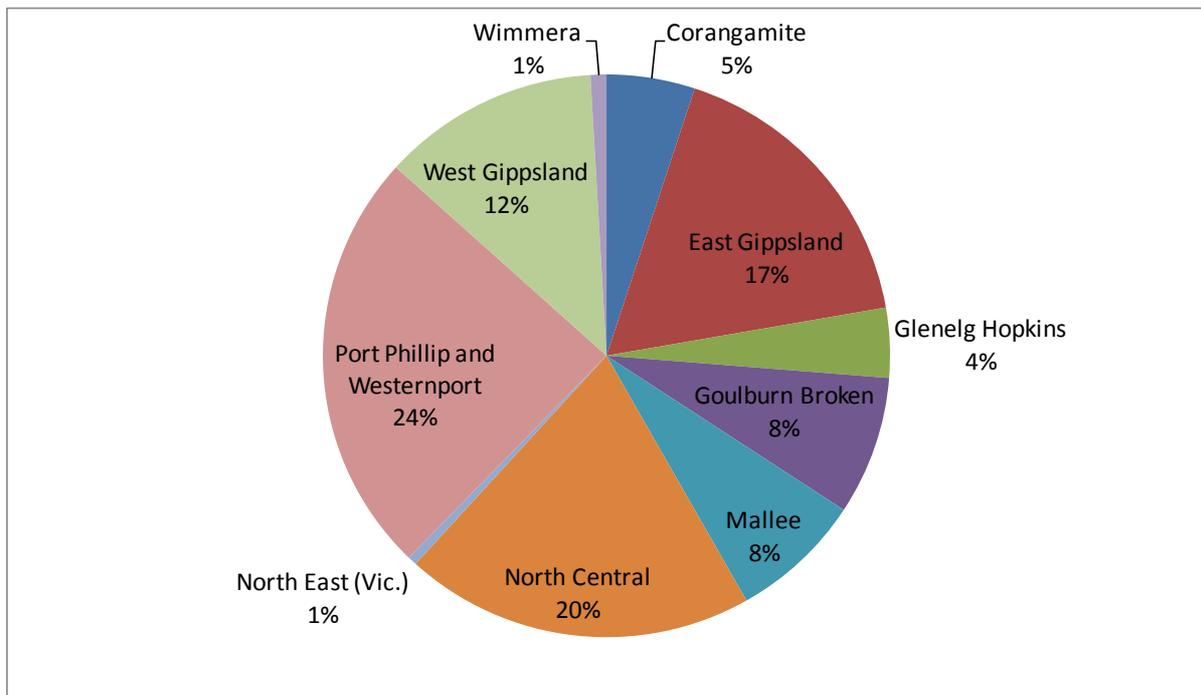


Figure 2.3. Percentage vegetable production in each Natural Resource Management (NRM) Region in Victoria during 2007-08 (Australian Bureau of Statistics, 2008c).

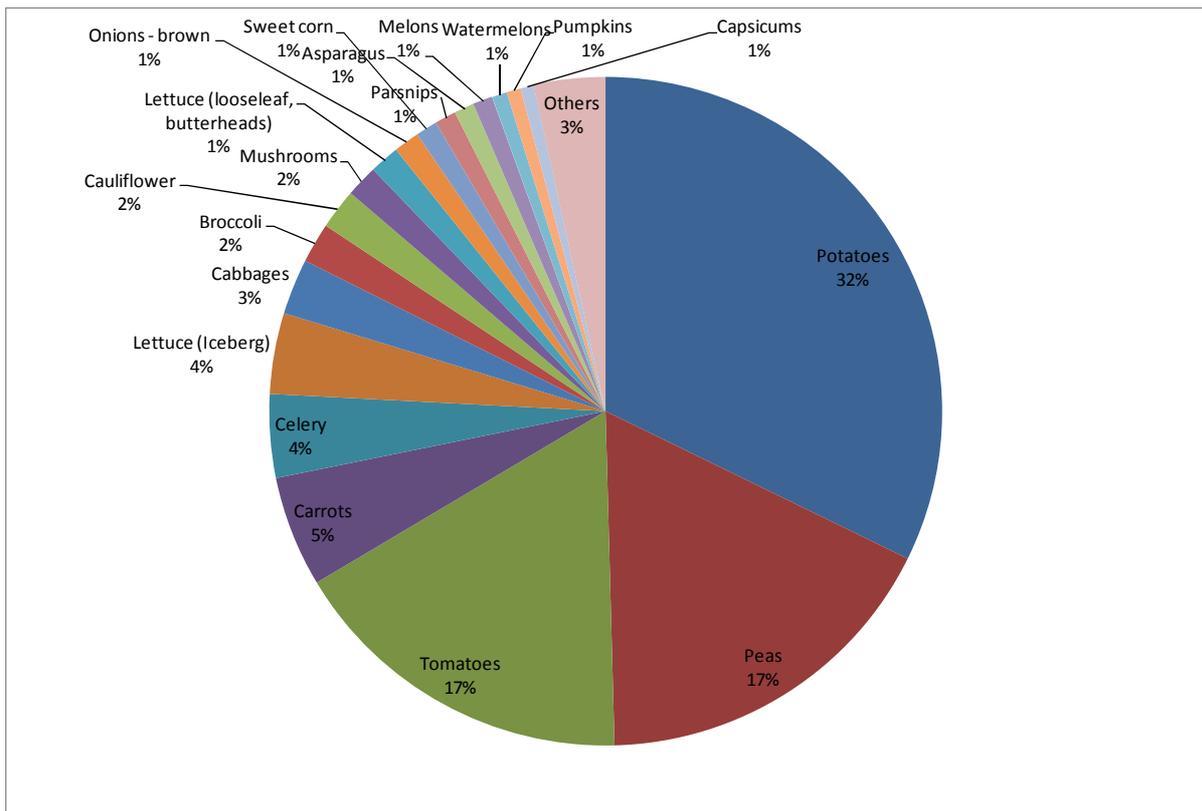


Figure 2.4. Percentage vegetable production as a portion of the total produced in Victoria during 2007-08 (Australian Bureau of Statistics, 2008c).

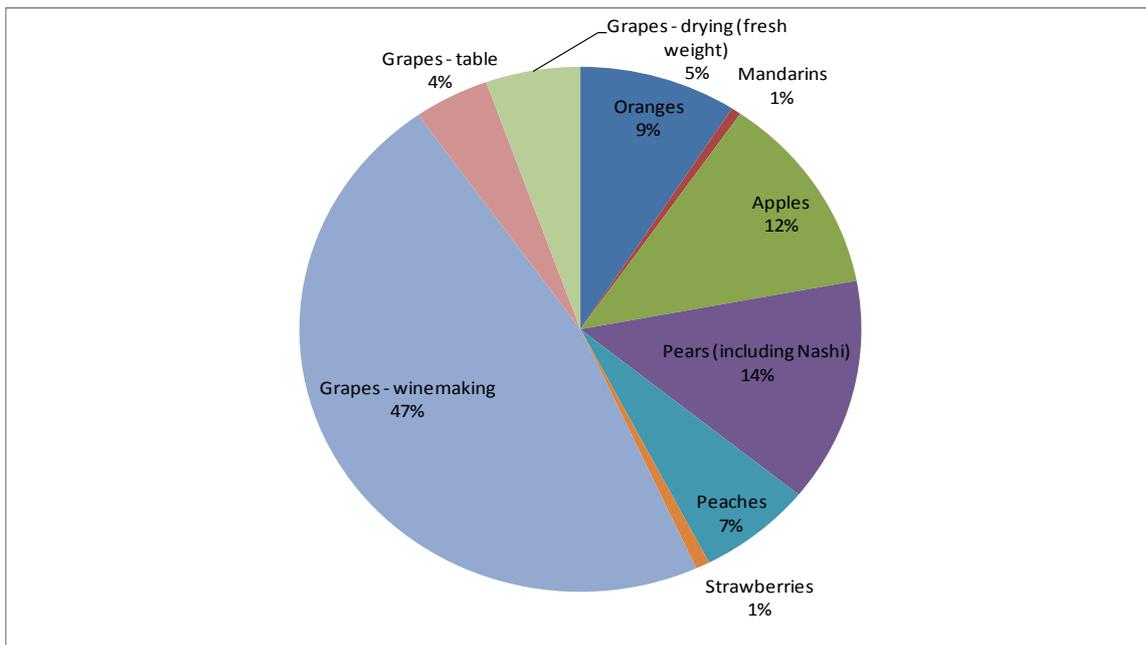


Figure 2.5. Percentage fruit production as a portion of the total produced in Victoria during 2007-08 (Australian Bureau of Statistics, 2008c).

Major growing regions are mostly located in the vicinity of irrigated water supplies. See Figure 2.6 for vegetables and Figure 2.7 for fruit.

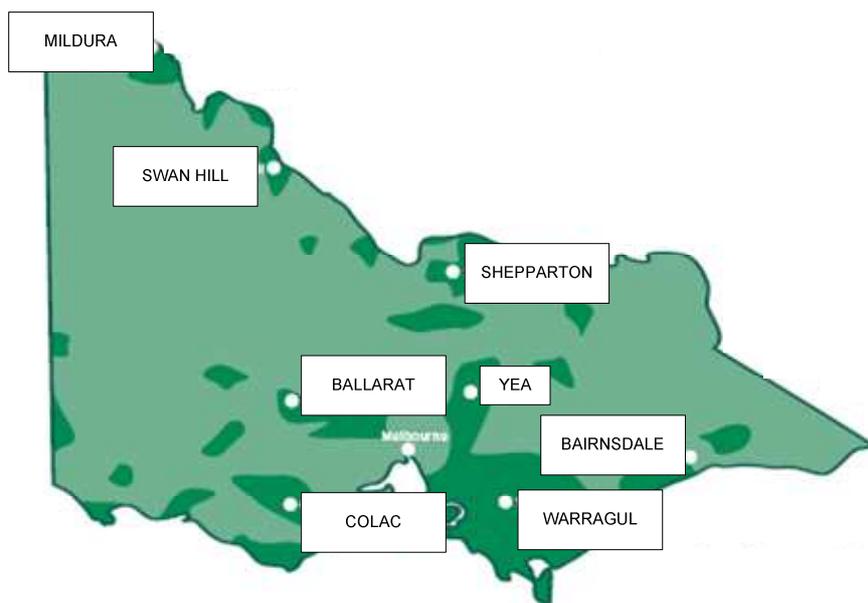


Figure 2.6. Major vegetable growing regions in Victoria. Adapted from DPI Victoria 2006.

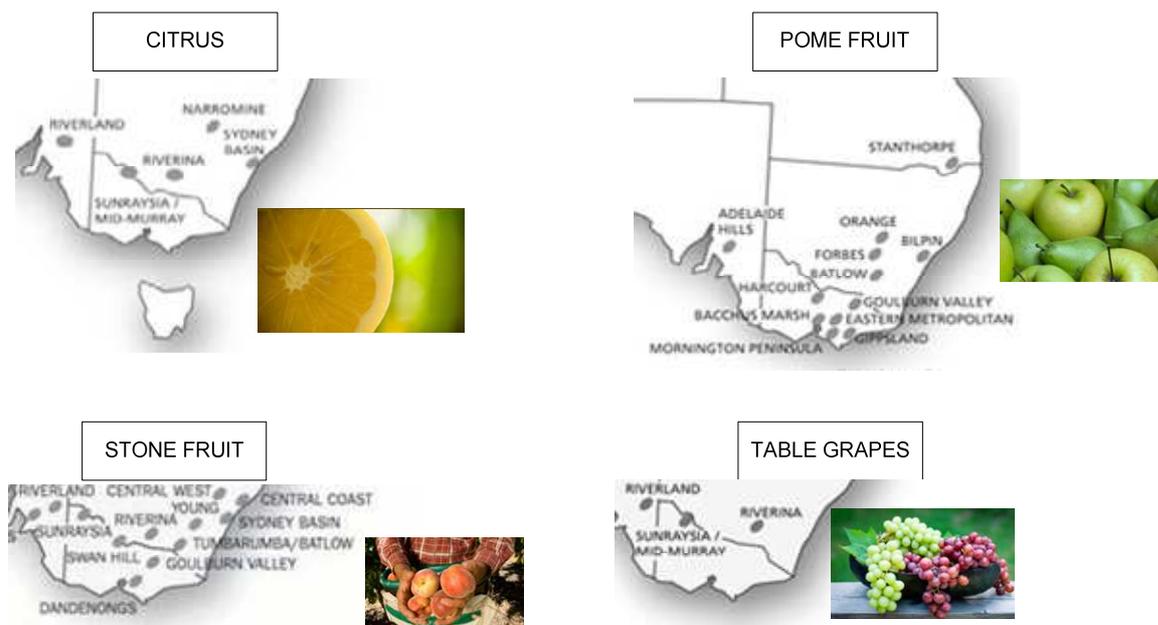


Figure 2.7. Major fruit growing regions in Victoria. Source: <http://www.australiafresh.com.au>

## 2.2 Food Freight Logistics

The aim of the food industry is to transform agricultural raw materials into safe, convenient, good tasting and nutritious products for consumers, in a profitable and sustainable manner. The horticulture industry in Australia is valued at \$3.6 billion (Australian Natural Resource Atlas, [www.anra.gov.au](http://www.anra.gov.au)) and in Victoria was worth \$1.3 billion in 1997-98 (Victoria DPI). Horticulture in Victoria supports 2236 enterprises employing 16,000 people full-time (1998-99).

Food value addition is generated by activities linked to farming, processing, packaging, distribution and retail, as illustrated in Figure 2.8. The boxes below each supply chain stage capture the processes that lead to the generation of GHG emissions. Processes highlighted in bold were in the scope of the F&V freight movements of this project, and encapsulate all of the

transport stages from farm to consumer. Operational aspects of transport were considered rather than embodied energy.

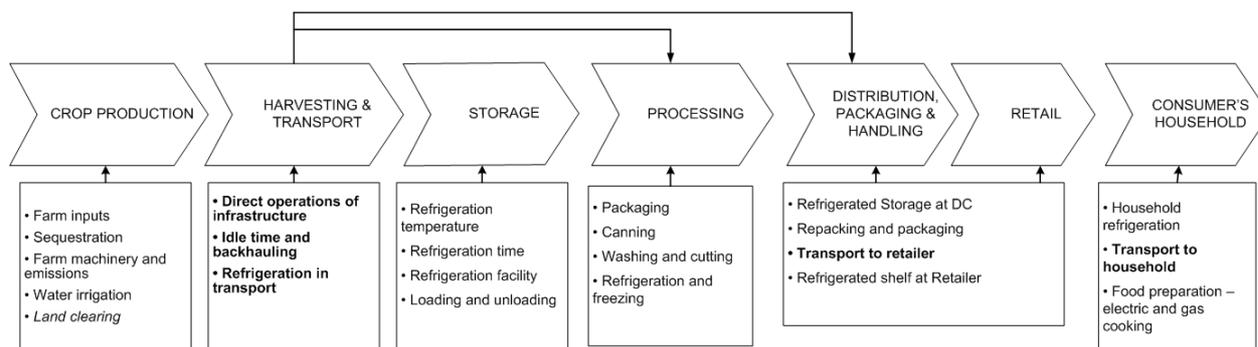


Figure 2.8. Features of the F&V supply chain stages that contribute to GHG emissions

F&V transport are complex spatial and dynamic networks in Australia, due to many factors, such as: multiple food products and supply chain paths; long supply chains with multiple stages of processing/distribution; specialised transport needs; multiple modes; mixture of domestic and export products; underpinning supply chain relationships; evolving production systems; and climate variability (Higgins et al 2007). Road transport paths between farms, markets, DC's and supermarkets are also a complex network for food freight (Victorian Department of Transport, 2008), which vary substantially with time.

## 3 Literature Review

### 3.1 Food freight

There have been limited studies in Australia aimed at analysing food freight logistics in a holistic sense. A State of Logistics study was carried out by CSIRO in 2006/2007 (Higgins et al. 2007) aimed to “Develop and test a methodology that estimates the costs of logistics in Australian food industries, and to apply this methodology to better understand the structure, drivers and challenges of these logistics.” Rather than considering all food categories, four different case studies were selected: fresh mango domestic chains, livestock represented by beef and lamb production, field crops including sugar and grain and wine. The project helped to better understand value chains operations such as transport, storage and packaging. The methodology developed can be extended to other food industries in Australia.

A study by Morgan (2009) assessed supply chains of F&V from the perspective of waste and consumption and their impacts on public health in Australia. As with the CSIRO study, case studies were used, primarily due to lack of available large data sets. Morgan considered GHG emissions across the food supply chains through reference to published reports for farming (Rab et al. 2008), distribution and processing and food preparations. The reports cited by Morgan (and Morgan's report itself) provide general statistics rather than a detailed supply chain analysis.

There have been various logistics studies conducted at an industry or sector level. For example, grains logistic costs were extensively addressed in the Royal Commission on Grains Handling, Storage and Transport (1988), though the findings are largely outdated. Internationally, there have been State-of-Logistics (SoL) studies aimed at defining R&D and infrastructure investment priorities, with CSIR (2005) providing a general analysis across the major industry sectors of manufacturing, mining and agriculture of South Africa. Scientists from CSIR also conducted a more detailed analysis on South African fruit logistics (van Dyk and Maspero, 2004) with a focus

on providing recommendations for priority investments in infrastructure. In light of the high-level analysis and recommendations from the South African studies, several “more-focused” logistics projects between CSIR and South African industries have been established. To date there has been no published whole of chain analysis assessing GHG emissions in food systems.

Analysis of F&V GHG emissions at farm scale is far more advanced than post farm gate. A project by HAL, Rab et al (2008) and O’Halloran et al (2008) extensively considered GHG emissions in the Australian vegetable industry by addressing: availability and applicability of emissions factors; limitations on data availability; and features of the production system that have the greatest contribution to GHG emissions. The authors state that their estimation of GHG emissions in the vegetable farming sector (1,047,008 t CO<sub>2</sub> / yr) was about one third of other estimates, highlighting the need to gather more relevant carbon footprint data. At the farm scale, the authors considered farm inputs and their land impact, as well as farm operations (e.g. irrigation, use of machinery). The Australian Farm Institute has released a GHG emissions calculator for farmers, FarmGAS<sup>4</sup>, for use in scenario planning to reduce GHG emissions on their farm. The Victorian DPI website also contains GHG accounting tools for other forms of agriculture<sup>5</sup>.

### **3.2 Food supply chains**

Estrada-Flores and Larsen (2010) presented an overview of the contribution of food supply chains to GHG emissions. Among the points highlighted in this overview the authors stated the following:

- 1) The activities required to feed the world’s population were estimated to account for 20% of GHG emissions annually. In Australia, food production, distribution and consumption contributes with 16% of the per capita GHG footprint (Hertwich and Peters, 2009).
- 2) The global footprint of logistics and transport is 2,800 Mt CO<sub>2</sub>-e per year, or 5.5% of the total annual GHG emissions generated by human activity. Road freight contributes around 57% of the total, followed by ocean freight (17%) (World Economic Forum, 2009).
- 3) It is now clear that “food miles” cannot be used as a sole indicator of the environmental impact of food supply chains (Smith, 2005). As well as distance, consideration must be given to:
  - Combinations of road vehicles used;
  - Effect of logistics technologies and fuel types;
  - Transport mode, efficiency and loading capacity
  - Differences in production systems
  - Distribution strategies: full and partial loads; backhauling and load matching; cooperative and competitive transport approaches.
- 4) The comparison of food carbon footprints between Europe and Australia are difficult for several reasons, including:
  - Differences in international trade. For example, about half of all vegetables and 95% of all fruit consumed in the UK are imported. In Australia, imports represent 30% and 4.2% of all processed and fresh fruit and vegetables consumed, respectively<sup>6</sup>.
  - Differences between production systems. For example, while the UK and Australia use almost the same area for protected vegetable cropping, the former produces 4 times more vegetables under this system than Australia, while the latter is 1.3 times more productive in field vegetable cropping (Estrada-Flores and Larsen, 2010).

<sup>4</sup> <http://farmgas.farminstitute.org.au/publicpages/AFIPublic.aspx?ReturnUrl=/default.aspx>

<sup>5</sup> <http://www.dpi.vic.gov.au/DPI/nrenfa.nsf/childdocs/-7945C583A915FBBDC25762B001D69A1?open>

<sup>6</sup> <http://www.ibisworld.com.au/pressrelease/pressrelease.aspx?prid=227>

- 5) For field-grown, non-processed or minimally processed fruit and vegetables, absolute differences between the emissions from primary production and transport are smaller than for meat and dairy products. For meat and dairy products, the carbon footprint is dominated by primary production (Cleland, 2010, Williams, 2009).
- 6) The carbon footprint of Australian vegetables production and marketing ranges from 7.4 and 8.5 Mt CO<sub>2</sub>-e. Transport (including refrigerated and non-refrigerated) represents 15-17% of this figure (Estrada-Flores, 2009).
- 7) In the calculation of carbon footprints, the excessive simplification of distribution activities can underestimate logistics emissions by about 30% (Blanco and Craig, 2009).

## 4. Project Scope and Limitations

This report explains the methodology and results of Part 2 of this project and is focused on a case study of the Victorian fruit and vegetable food chain. There are several benefits of analysing F&V, as follows:

- Appropriate and affordable access to F&V is critical to food security and fundamental to healthy diets;
- The value chains of fresh F&V are complex and more vulnerable than other product sectors, as F&V are perishable, easily damaged and have a limited shelf-life (or are processed). A methodology that is developed and tested on complex fruit and vegetable chains can be transferable to other sectors (e.g. meat, grains);
- F&V value chains change substantially throughout the year and according to seasonal conditions. This project provided some insight into the effect of seasonal factors on GHG emissions intensity and resilience of food supplies; and
- Australian F&V producers are under ever-increasing pressure from residential development; access to (and price of) water, nutrients and fuel; and cheaper imported produce. A price on GHG emissions is likely to affect F&V value chains, increasing downwards price pressure on fruit and vegetable producers. Improved understanding of value chain emissions and vulnerabilities, and options to reduce or avoid them, would have economic benefits for both producers and consumers.

Given the diversity and complexity of value chain activities for F&V's, as highlighted above, the methodology developed in this project could be transferable to the remainder of the Victorian food sector.

If ideal data were available, the full scope of analysing food freight movements would be: 1) F&V produced and consumed in Victoria; 2) F&V produced in Victoria and transported interstate or exported; 3) F&V imported into Victoria and transported from other states. These are best described by the supply chain diagrams in Figures 4.1 to 4.3 respectively. Arrows in the figures show the major supply chain paths. This project also considers the transport links from consumer to retail outlet. These are not shown.

Fruit & Vegetables Produced and Consumed in Victoria

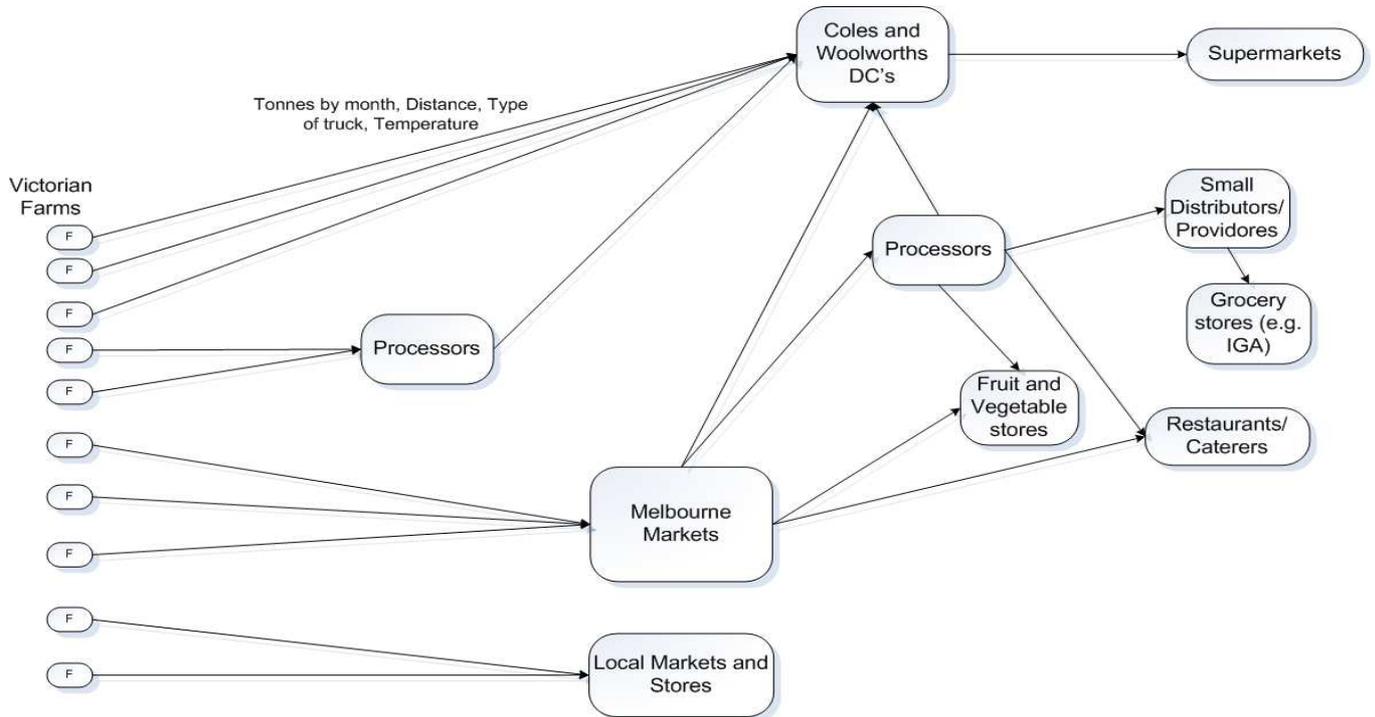


Figure 4.1. Supply chains of F&V produced and consumed in Victoria

Fruit & Vegetables imported into Victoria

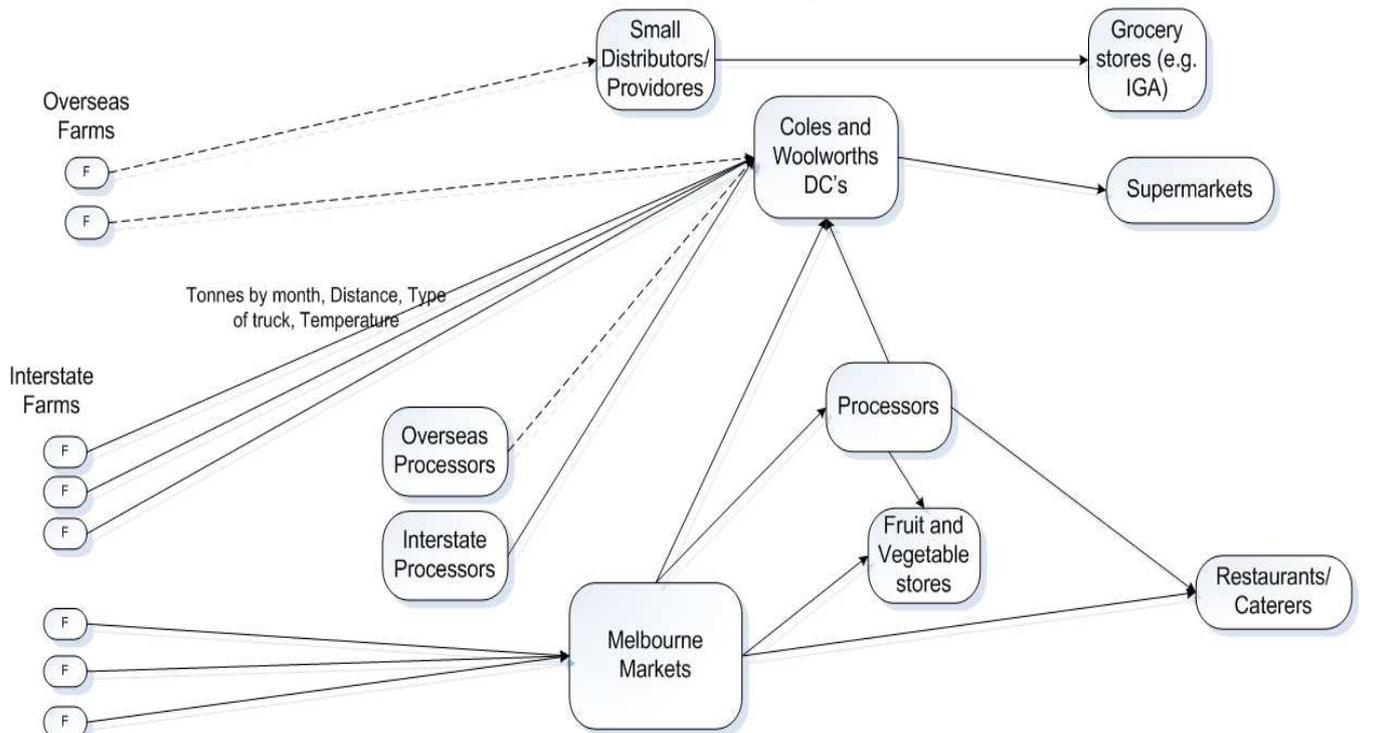


Figure 4.2. F&V transported into Victoria from interstate and overseas

### Fruit & Vegetables Produced in Victoria and Exported

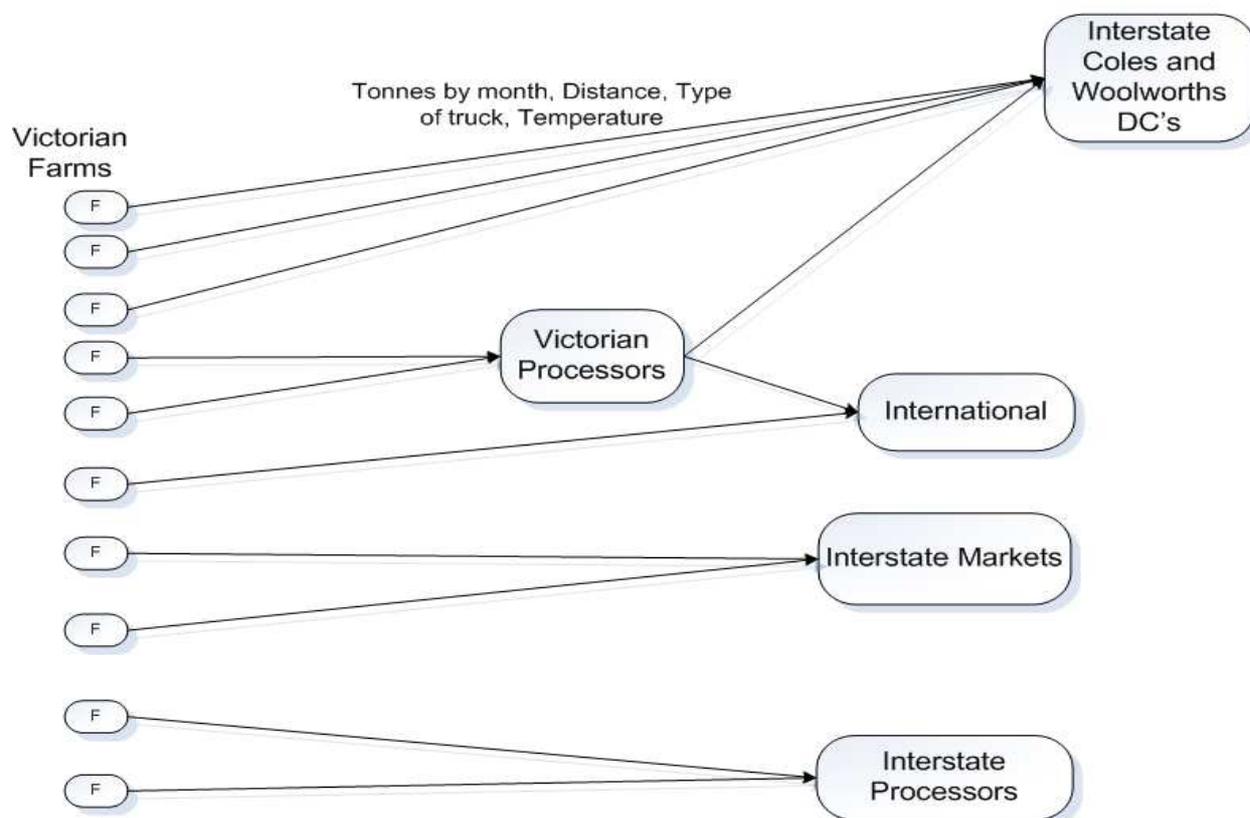


Figure 4.3. F&V produced in Victoria and transported

Due to the data and resource limitations, some of the supply chain paths in Figures 4.1 to 4.3 were not considered in this current project, in particular:

- Food service – restaurants, caterers. This is a very complex set of supply chains and there are several thousand food outlets in Victoria. They vary in terms of small restaurants with local ownership, to large franchises (e.g. MacDonal’d’s, KFC) with large complex supply chains. Sourcing of F&V for each restaurant will be hard to determine due to the large number of ownerships and large variety of Victorian versus interstate suppliers. A GHG analysis of the food service industry could be considered as part of further research.
- Processing. GHG emissions of transport to and from the processor were considered. However, GHG emissions of activities within the processor were not. F&V from interstate or overseas for processing is not considered, due to the difficulty of obtaining such information. Transport from interstate processors into DCs is considered.
- Farmers’ Markets and direct channels between growers-consumers have not been included or analysed.

Full data sets of volumes and locations of each outlet would be needed to represent transport along each of the supply chain links in Figures 4.1 to 4.3. Unfortunately some of the data is either not available altogether or not obtainable due to organisational confidentiality. This was a

similar challenge to that of the consumption and waste project by Morgan (2009). The main limitations in the scope of the current project were:

- Supply chains through Coles/Woolworths; processors to retailers; F&V transported out of Victoria. Where necessary, we have used proxy data, inference and simulation to accommodate information gaps, as shown in the next section.
- Uncertainty of analysis along a single supply chain path (e.g. individual farm to retailer) will be high. However, once the results of the supply chain paths were aggregated, the effect of the uncertainty diminished for the deterministic analysis.

In light of the data limitations encountered in this project, the supply chain paths of Figures 4.1 to 4.3 needed to be scaled down for the analysis. Figure 4.4 shows the scope of the supply chains used, with the dashed lines being outside the GHG analysis. The main consequence is that GHG emissions based on the supply chain in Figure 4.4 will be lower than if all the actual supply chain paths in Figures 4.1 to 4.3 were included.

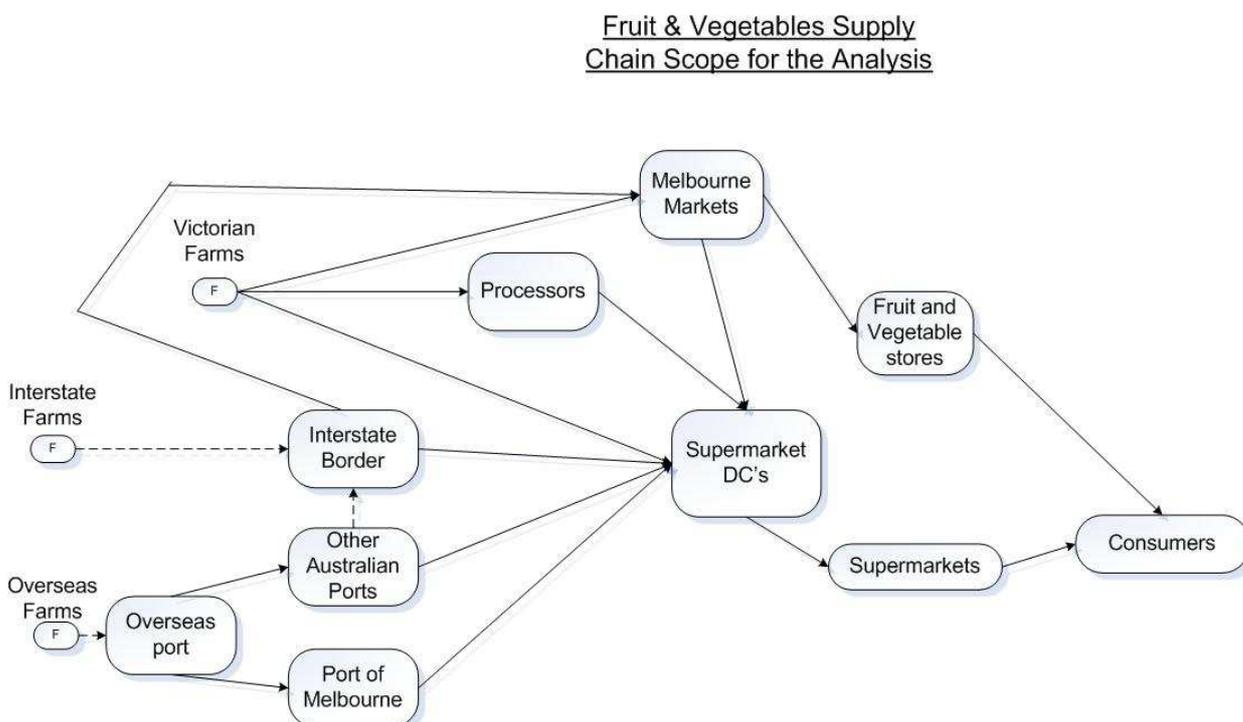


Figure 4.4. Summary of supply chain scope used for the analysis in this report

## PART A. DETERMINISTIC ANALYSIS

The methodology and results described in Chapters 5 to 7 are based on model inputs (e.g. payloads) where variability or uncertainty is represented by average values. A deterministic analysis is well suited to the GHG emissions results shown in Chapter 6, which aimed to identifying key average features across different components of the supply chain. Supply chain vulnerability simulations of Chapter 7 were based on the deterministic methodology. The simulations tested the consequences of different weather and economic events on the supply chain network. It is important to note that within the scope and constraints of this project simplifying assumptions needed to be made – these are explained throughout.

## 5. Information Gathering and Synthesis

For the case study, a base scenario of fruit and vegetable freight movements has been defined using 2007-2008 as the base year and involving 7 fruit items (apples, grapes, mandarins, oranges, peaches, pears, strawberries) and 28 vegetable items (artichokes, asian vegetables, asparagus, beetroot, broccoli, brussels sprouts, butter beans, cabbages, capsicums, carrots, cauliflower, celery, chillies, cucumbers, eggplant, fennel bulb, french and runner beans, garlic, herbs, leeks, lettuce, melons, mushrooms, onions, parsnips, peas, potatoes, pumpkins, radish, silver beet and spinach, snow peas, spring onions, swedes and turnips, sweet corn, tomatoes, watermelons, zucchini and button squash).

The project covers food transport between the National Resource Management (NRM) regions and export points, distribution centres (DCs) for the four major supermarket chains (Coles, Woolworth, IGA/Foodworks, Aldi), major food processing centres (Simplot, McCain, National Foods, SPC), Melbourne Market Authority (MMA) and listed grocery stores. It also covers imported produce from overseas and the customers' trip to collect food (also known as 'the last mile').

## **5.1 Locations**

### **5.1.1 Production**

Primary production data was obtained from ABS, which provided production data for 2004 to 2008. The data, which is partitioned by Natural Resource Management (NRM) region, contained the tonnes of each F&V produced. Figure 5.1 shows the boundaries of the Victorian NRMs. From the list of F&V's covered, the 7 fruits and 38 vegetable varieties in the data set were used to illustrate the freight flows. Some of the entries are broken down via fresh consumption and processing.

The ABS data does not specify the exact locations within each NRM region where major production takes place, so assumptions were made as to the coordinates of the origin points. Two options were available: 1) assuming that production occurs at the geographical centroid of the NRM region; or 2) assuming a centre on the major production areas as described in Figures 2.6 and 2.7.

For this version of the freight flow model, the geographical NRM centroids were chosen as the origin points, because they were a convenient and fixed point of origin. Further, statistics of production per NRM were available, while statistics for production from major growing areas were not. While alternative 2) may be accurate, there were a number of difficulties with this option in the deterministic approach:

- Absence of data on the actual farm areas; and
- Could result in different origin points for different fruit and vegetable items within the same NRM, or the growing region for one item may straddle several NRMs.

It was expected that the results of using option 1) would lead to a mixture of over and underestimating distances, where these will mostly cancel one another out. Therefore, the bias was deemed as small. On the other hand, an arbitrary selection of a single centroid, based on a perceived growing area for a single fruit or vegetable can lead to significant bias when there is no information on the concentration of volume or farm count in the growing area. Unless restricted by national parks, large bodies of water or extensive urban areas, Victorian farms are expected to be scattered widely within NRMs resulting in growing areas that are non-contiguous and that frequently cross NRM boundaries. With each NRM producing at least 9 of the 45 items of interest, it is highly unlikely that the centroids of all growing areas for the items produced (had these been known) would fall in exactly the same location. Thus, in the absence of any data other than NRM production and boundaries, the NRM centroid remains as the best single point estimate of the source of production.

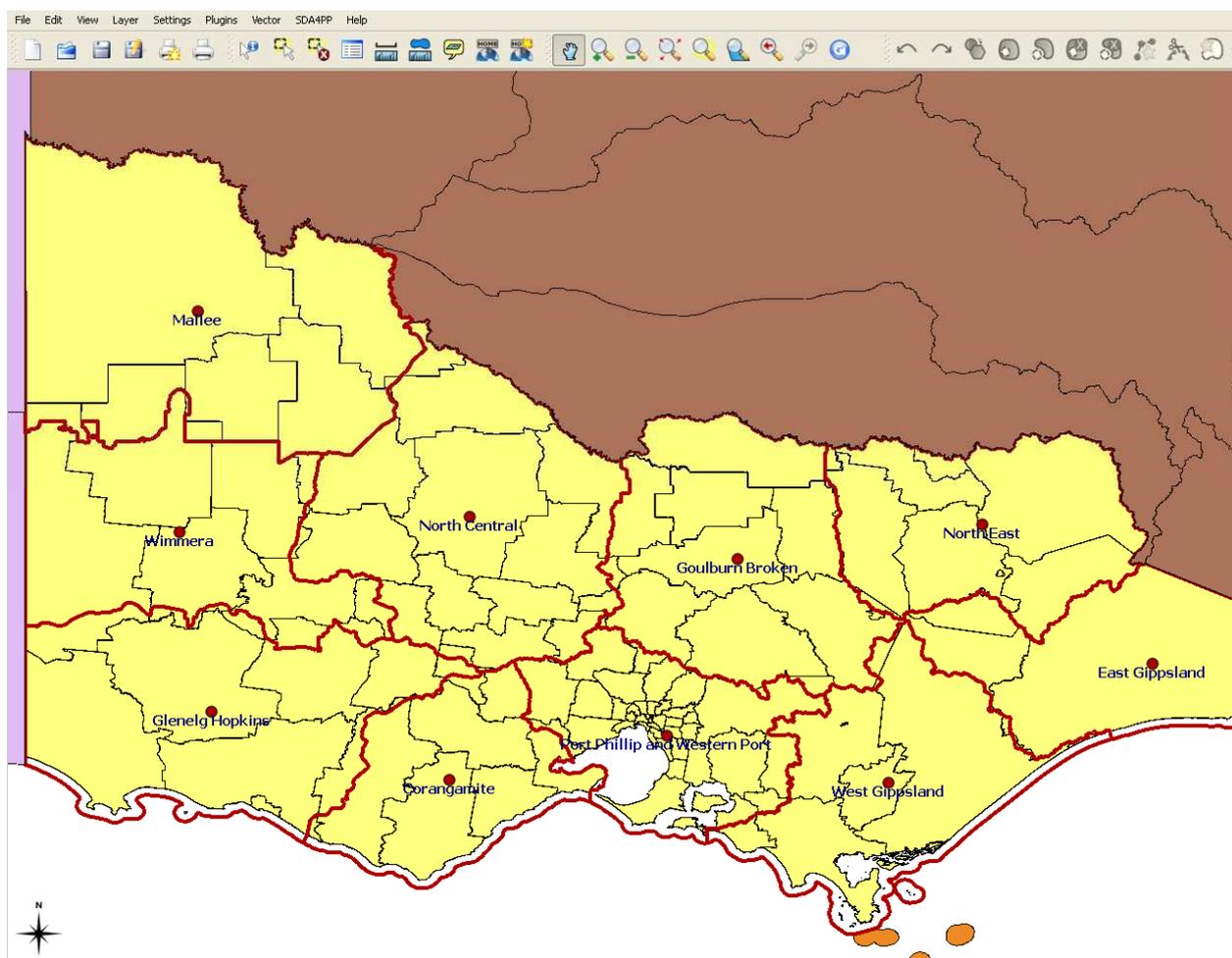


Figure 5.1. Outline of NRM regions used to differentiate the major growing areas in Victoria

### 5.1.2 International Imports and Exports

Imports and exports were analysed through the following data (Creese, 2010):

- Amount (T) and value of each F&V imported and exported by port for 2004 to 2008;
- Country of origin and destination;
- Interstate transfers via port.

A lot of care was exercised in using the data due to item code changes from one year to the next for some fruit (e.g. oranges) and vegetables. These code changes needed to be accommodated when comparing import/export totals with other sources (e.g. Citrus Australia).

Emissions from international imports were computed from two sources: 1) sea leg emissions from shipping the volumes from a foreign port to an Australian port, and 2) land leg emissions from transporting the volumes from Australian ports to Victorian DCs.

Representative sea distances between major Australian ports and the nearest port of entry for different countries were obtained using distance calculators available from various web sites such as Port World (<http://www.portworld.com/map/>). The distances obtained were based on typical shipping routes used between origin and destination points and do allow for passage through important portals such as the Panama Canal, Suez Canal and Bosphorus Strait. Figure 5.2 displays a map showing the route calculated by the PortWorld website for shipping between Melbourne and Helsinki (Finland). For this route the distance covered is 22,468 kms. Aside from

Melbourne, the other Australian ports used for international imports/exports are shown in Figure 5.3.



Figure 5.2. Voyage route and distance (22,468 kms) calculated by PortWorld website for shipping between Melbourne and Helsinki.

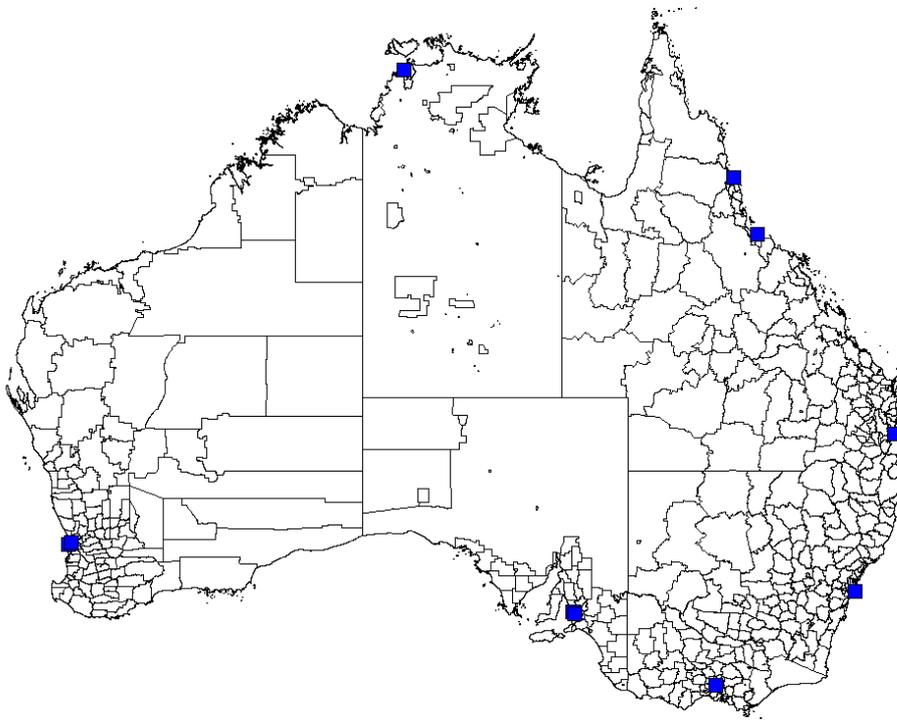


Figure 5.3. Points of entry or exit for export and import volumes

Land leg emissions were calculated for the export and import volumes (international and interstate) entering the Victorian supply network via a set of points as shown in Figure 5.3. This set consists of the state capitals (Sydney, Brisbane, Adelaide, Darwin, Perth) which were used to designate the source or destination of interstate freight, and possible ports of entry or exit

(Sydney, Brisbane, Cairns, Townsville, Port Adelaide, Melbourne, Launceston, Fremantle) for international imports and exports. Distances were then computed based on the road distance between these points and Victorian NRMs or DCs provided by Google Maps, as described in Section 5.1.7.

The methodology for calculating the sea leg emissions and the land leg emissions is discussed in Section 5.4.

### 5.1.3 Interstate transfers

We were not able to obtain data on fruit and vegetable volumes traded in interstate transfers, particularly at the detail of individual F&V's. The only indicative information was price signals for F&V transported to Melbourne Markets from other states. However, these price signals did not include volumes traded. Melbourne Markets Authority (MMA) does not collect volumes and information from MMA was not available.

Volumes of interstate freight were obtained from the 2001 ABS Freight Movements survey (Catalogue No. 9220.0), which detailed the tonnes moved by road between states and territories for the year ending 31 March 2001 (see Table 5.5). The volumes transported from Victoria to the other states, and the volumes delivered to Victoria from the other states, were then scaled up to reflect volumes for 2007. The scaling factor used was the ratio between the 2001 total volume of road freight and the total volume for 2007 obtained from Table 17 of the ABS SMVU (2008).

In the absence of more detailed information, we assumed that food and animals movements from Table 5.5 reflected interstate movements for F&V on a proportional (state by state) basis. We had no information available to validate the correctness of the assumption, which is based on the proportion of the nation's F&V grown in Victoria not being significantly different to the proportion of all of the nation's food produced in Victoria. For example, from Table 5.5, 2.8% of interstate transfers of all food & animals were from NSW to Victoria. If this 2.8% is not also representative of F&V only, the assumption will be incorrect. Results shown in this report will be aggregated across the states supplying to Victoria to reduce the bias introduced as much as possible.

### 5.1.4 Supermarkets and DC's

The addresses of around 800 supermarkets, their corresponding DCs and 540 grocery stores in Victoria were obtained from: (a) the Metcash supplier information webpage<sup>7</sup>; (b) the Woolworths vendors website<sup>8</sup>; (c) the Coles Supplier website<sup>9</sup>; (d) the GPS Data Team provider<sup>10</sup>; (e) the Foodworks store locator<sup>11</sup>. All sites of information were accessed in Jan 2010. The addresses obtained were plotted using Google Maps to obtain their coordinates in latitude and longitude. In addition, the coordinates of the processing centres, and Melbourne Market Authority were also plotted along with the boundaries for the NRMs and the collection districts in Victoria.

Figure 5.4 shows a map of the DCs and supermarkets in and around the Melbourne Metropolitan area.

<sup>7</sup> [http://metcash.com/index.cfm?page\\_id=2137](http://metcash.com/index.cfm?page_id=2137)

<sup>8</sup> [www.wowlink.com](http://www.wowlink.com)

<sup>9</sup> <http://supplier.coles.com.au>

<sup>10</sup> <http://www.gps-data-team.info/poi/australia/shopping/>

<sup>11</sup> <http://www.foodworks.com.au/store-locator?region=5&postcode=>

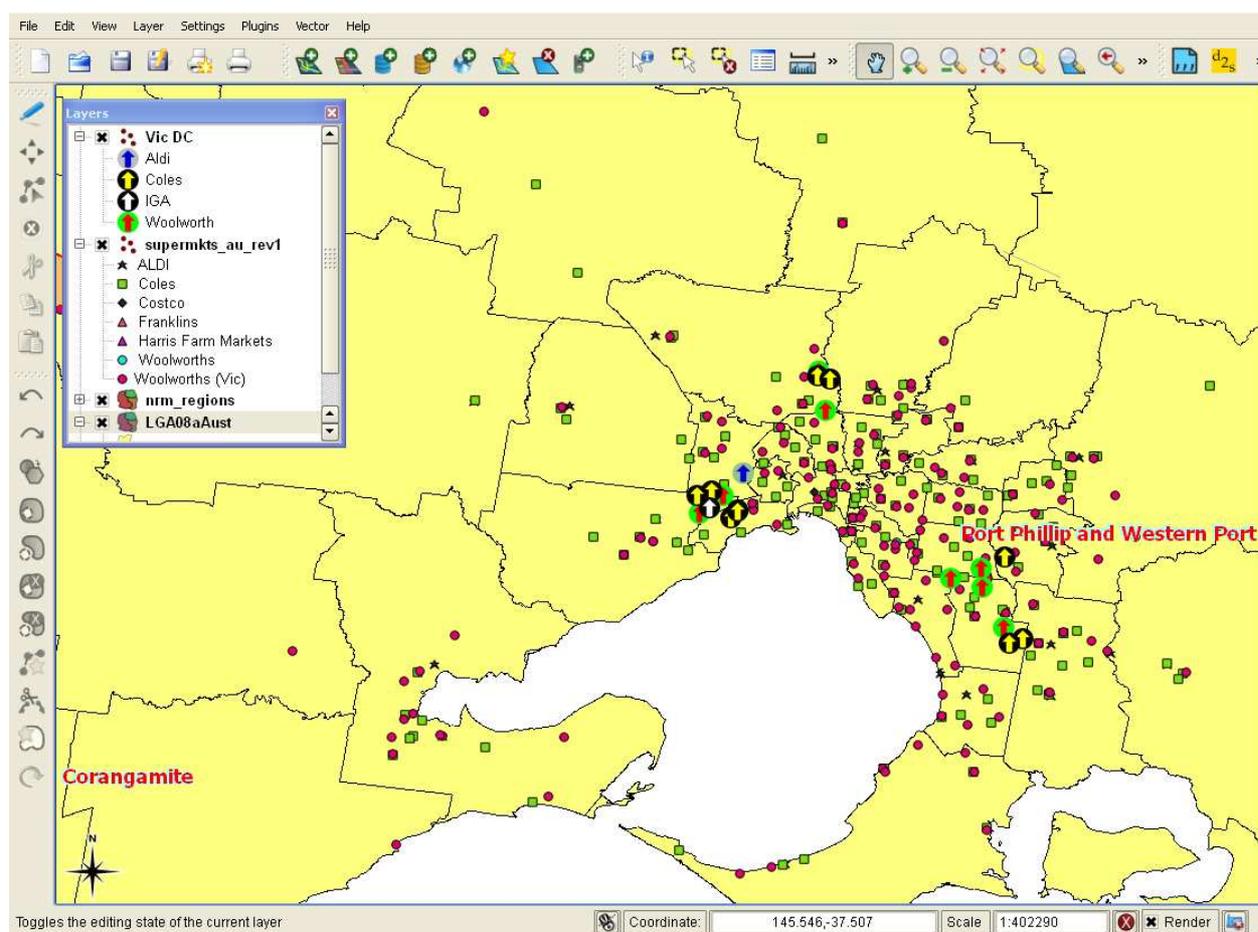


Figure 5.4. Locations of supermarkets and DC's around Melbourne

### 5.1.5 Processors

Whilst according to Business Victoria there are over 2,000 processors, the largest (shown in Table 5.3) account for a significant supply of processed F&V to supermarkets and consumers in Victoria. Each of these companies manufactures a range of products that source various F&V's from within Victoria. F&V that are sourced internationally or interstate were included in the analyses, although interstate imports cannot be disaggregated into individual items.

Several assumptions were made in the absence of data about processing. It should be noted that actual tonnages sourced by processors from each NRM region were not available due to confidentiality. Annual production for Victorian and interstate consumption was also not known. As 52% and 35% of total production is supplied to processing for fruit and vegetable respectively, we assumed that these were proportionally distributed among the companies in Table 5.1. We also assumed that F&V were sourced proportionally from each NRM region, according to the production volumes in that region. This simplification is likely to represent an underestimate of distances travelled. We do not expect this underestimation to be significant, unless the companies of Table 5.1 were a poor representation of distances of the broader 2,000 processors in Victoria.

Quantities sourced from each state for processing were not known, and it was difficult to put an upper error bound (i.e. how much the GHG emissions would be underestimated). It was also difficult to identify the farms in Victoria supplying F&V to each processor, and the contract arrangements between processors and farms often change. The exact quantities supplied via Melbourne Markets to processors were also unknown. For this report we assumed all F&V were supplied to processors directly from the farm.

The processor companies in Table 5.1 operate factories and processing plants. The locations of these factories have been geocoded and incorporated in the freight flow analyses.

Table 5.1. Major fruit and vegetable processing plants located in Victoria.

<b>COMPANY</b>	<b>Brands</b>	<b>Manufacturing locations in Victoria</b>	<b>Products</b>
<b>National Foods</b>	Berri, Pura, King Island Dairy, Yoplait	Morwell	Milk, fresh dairy foods, juice and speciality cheese.
<b>McCain Foods</b>	McCain	Ballarat	Frozen vegetables, french-fries and potato specialties.
<b>Golden Circle Ltd (now owned by H.J. Heinz Company Australia Ltd)</b>	Golden Circle, Original Juice Co, Popper, Excello, Adam's Ale	Mill Park	Fruit juice, oranges from Griffith area.
<b>Simplot</b>	Edgell-Birdseye, Herbert Adams, Four'n'Twenty, Nanna's, Leggos and Chiko.	Based in Melbourne, but with nine processing plants in most states.	Mostly frozen vegetables.
<b>SPC Ardmona (acquired by Coca Cola Amatil)</b>	Goulburn Valley, Frutopia, SPC, IXL, Ardmona, Taylor's.	Shepparton	Apples and pears
<b>Mildura Fruit Juices Australia Pty Ltd</b>	MFJA	Mildura	Single strength citrus juice.
<b>Wild About Fruit (formerly Ashwan Orchards)</b>	Wild About Fruit, Wild Child	Wandin	A range of apple-based juices.
<b>One Harvest</b>	Harvest FreshCuts, Vegco, The Harvest Company and Ooloo Farm Management.	Bairnsdale	Mostly minimally processed vegetables.
<b>Salad Fresh</b>	Salad Fresh, Private Label	Broadmeadows	Mostly minimally processed vegetables.
<b>Heinz Watties</b>	Heinz Baby Food, Heinz Tomato Sauces and Ketchup, Heinz Soups, Greenseas products, Weight Watchers meals and Hamper.	Echuca, Girgarre	Mostly tomato.

### 5.1.6 Consumers

Information on the spatial distribution of consumers was gathered via ABS census collection district (CD) data. The census CD is the smallest geographic area defined in the Australian Standard Geographical Classification (ASGC). It has been designed for use in the Census of Population and Housing as the smallest unit for collection, processing and output of data (except for some Work Destination Zones). CDs also serve as the basic building block in the ASGC and are used for the aggregation of statistics to larger census geographic areas.

Victoria had 9,298 collection districts in 2006, with an average of about 550 consumers in each. Figure 5.5 displays a thematic map showing the distribution of population for the collection districts in Victoria. The map shows the concentration of Victoria's population in the Melbourne Metropolitan region. In general, the farther the CD is from Melbourne, the larger the area of the CD, and the more sparse the population (e.g. north west Victoria). As there was a very large number of census CD's used, any bias of using a centroid would be balanced out across the 9,298 CD's.

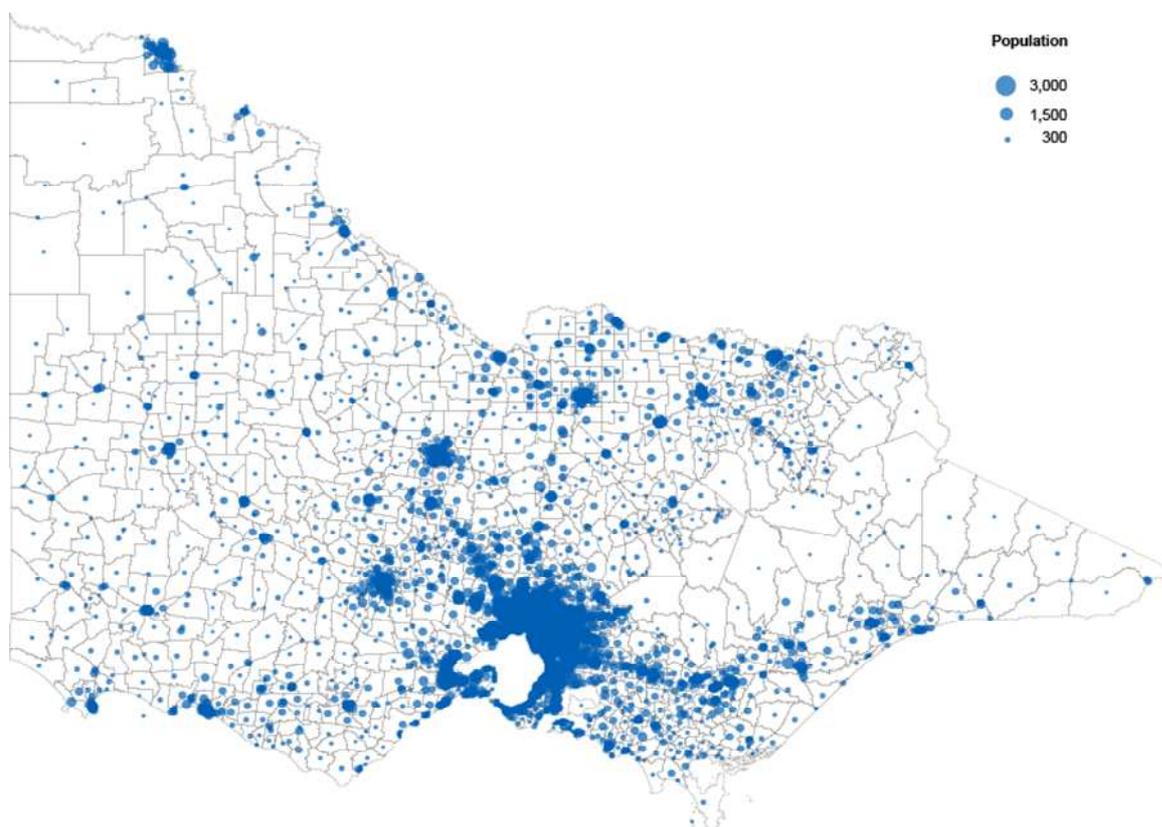


Figure 5.5. Location and boundaries of collection districts in Victoria. ABS Census of Population and Housing (2006).

Emissions from trips to the grocery store were attributed 100% to the purchase of F&V, trips, given that there are no specific studies that address the shopping habits of consumers during a greengrocer trips (e.g. purchase of other foods in those occasions). However, in supermarket trips, consumer purchases are not fully dedicated to F&V and a wide variety of food items are also bought. To determine the proportion of F&V in the consumer’s purchase, a grocery basket of 35 items as proposed by CHOICE (Choice, 2009) was used to determine the weight of F&V in proportion to the total weight of the basket.

Table 5.2 presents the contents of the CHOICE grocery basket and the corresponding packaged weights (in kilograms). This table shows that F&V items (bananas and fresh tomatoes) constitute a mere 7.25% (2/27.572) of the total weight of the basket. This percentage is then used to allocate to F&V the emissions produced from trips to the supermarket. Thus, in the deterministic approach trips to supermarkets add only 7.25% of the vehicle emissions while trips to grocery stores add all of the vehicle emissions.

A similar procedure was not performed for processed F&V because of the lack of information on the list and volumes of the F&V ingredients used in the individual processed grocery items. Without this information, the proportion in weight of F&V in a processed item would be difficult to estimate since the packaged weight of processed items includes significant contributions from non-F&V ingredients (water, sugar, preservatives, coloring, etc) as well as the packaging itself.

Table 5.2. Contents of the CHOICE grocery basket

Item	Size	Packaged weight (kg)
canned tuna	425g	0.510
Pasta	500g	0.500
Rice	2kg	2.000
baked beans	425g	0.510
canned peaches	825g	0.990
pasta sauce	550g	0.935
canned tomatoes	400g	0.480

tea bags	100bags	0.255
strawberry spread	500g	0.850
Coffee	100g	0.330
chocolate drink	450g	0.540
rice crackers	100g	0.120
cookies	200g	0.240
chocolate bars	200g	0.240
bacon	250g	0.250
sour cream	300g	0.360
milk	2litre	2.125
cheese	24pk	0.525
yoghurt	2x200g	0.480
butter	250g	0.300
cheese spread	140mg	0.000
dog food	1.2kg	1.440
sanitary pads	14pk	0.095
toilet paper	6pack	0.495
bread	700g	0.700
peas	1kg	1.000
sugar	1kg	1.200
carbonated drinks	2litre	2.400
fruit juice	2litre	2.150
sport drink	4x250ml	1.135
Cereal	560g	0.672
Eggs	12pk	0.745
Bananas	Unit	1.000
fresh tomatoes	Unit	1.000
chicken breast fillet	Unit	1.000
Total weight of basket		27.572

### 5.1.7 Distances

With locations of growing regions, DC's, supermarkets, processors and consumers in place, the next step was to calculate the distances between each of these entities. Distances between entities were measured using the shortest routes created by Google Maps to travel between the selected origin and destination. Figure 5.6 shows a sample route and estimated distance created by Goggle Maps for a given pair of origin and destination points.

For the growing regions or NRMs, the centroids of these were used as reference for measuring distances to DCs, processing centres and Melbourne Market, and export/import points. Export/import points refer to points (e.g. state capitals, ports of entry) where export/import volumes of F&V are assumed to connect to the Victorian supply chain network.

We applied several simplifying assumptions to the supply chain by assuming that produce moves in the shortest road route in all cases. This is likely to result in an underestimation of distances travelled, as some smaller roads are less suitable for articulated trucks, and drivers may select longer routes with higher speed limits. Also, there may be detours for other purposes. This underestimation is not expected to exceed 10% of the total distance travelled, given the need to minimise time and fuels costs as a proportion of transport costs. As GHG emissions are proportional to distance, the underestimate will be up to 10%.

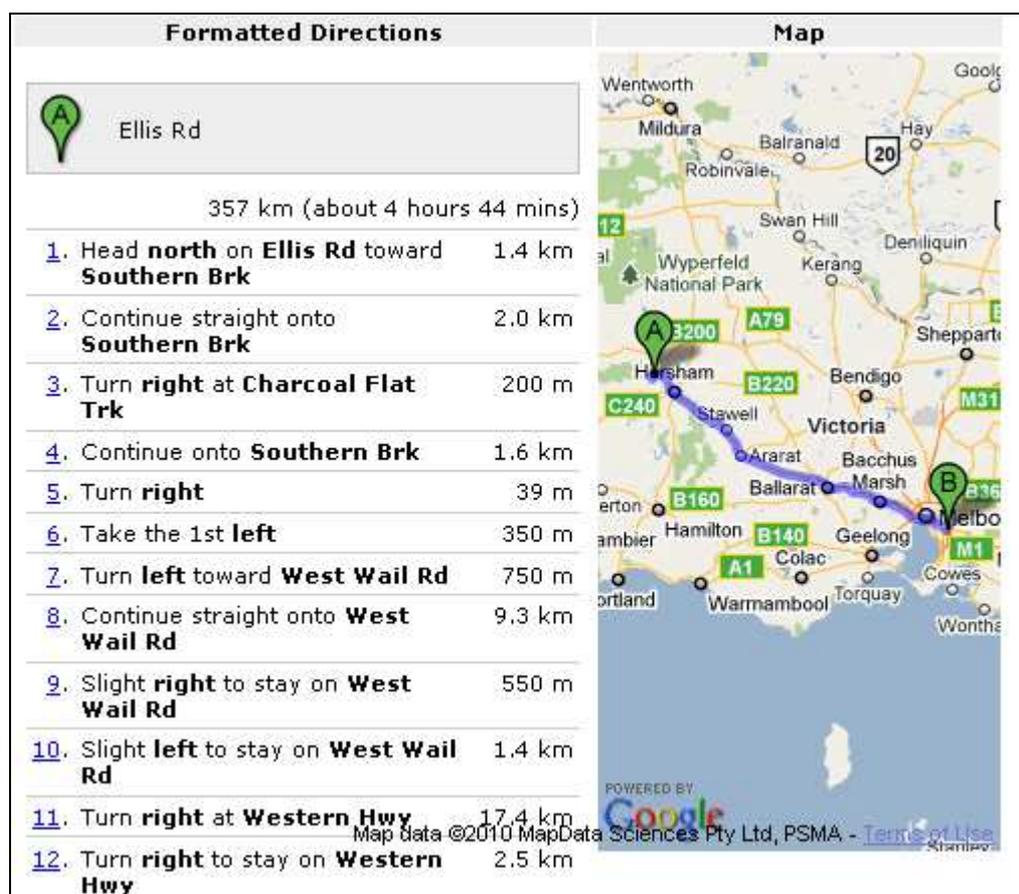


Figure 5.6. Sample route and distance created by Google Maps

Similarly to NRMs, collection districts (CDs) were also represented by their centroids in the calculation of distances to the nearest supermarket or grocery store. Google Maps was again used to provide the route distance from each CD centroid to the nearest supermarket and grocery store. A thematic map showing the distribution of distances from the CD centroid to the nearest supermarket is shown in Figure 5.7. Dark blue, red and purple colours indicate areas where consumers have to travel over 40 km to reach the nearest supermarket, whereas light shades indicate CDs where supermarkets are less than 40 km away. A detailed explanation of consumer travel distances to supermarkets can be found in Appendix E.

It was also assumed that households would only travel to the nearest supermarket and grocery store to purchase their fruits and vegetables. Surveys would be required to estimate the actual distances travelled by consumers to supermarkets/ grocery stores and the decision-making process of consumers to select their preferred supermarket for shopping. Assuming that less than 50% of consumers choose a supermarket other than their nearest and their preferred supermarket is at a distance of 1.5 times that of their nearest supermarket, then the underestimation of actual travel distance will be less than 25%.

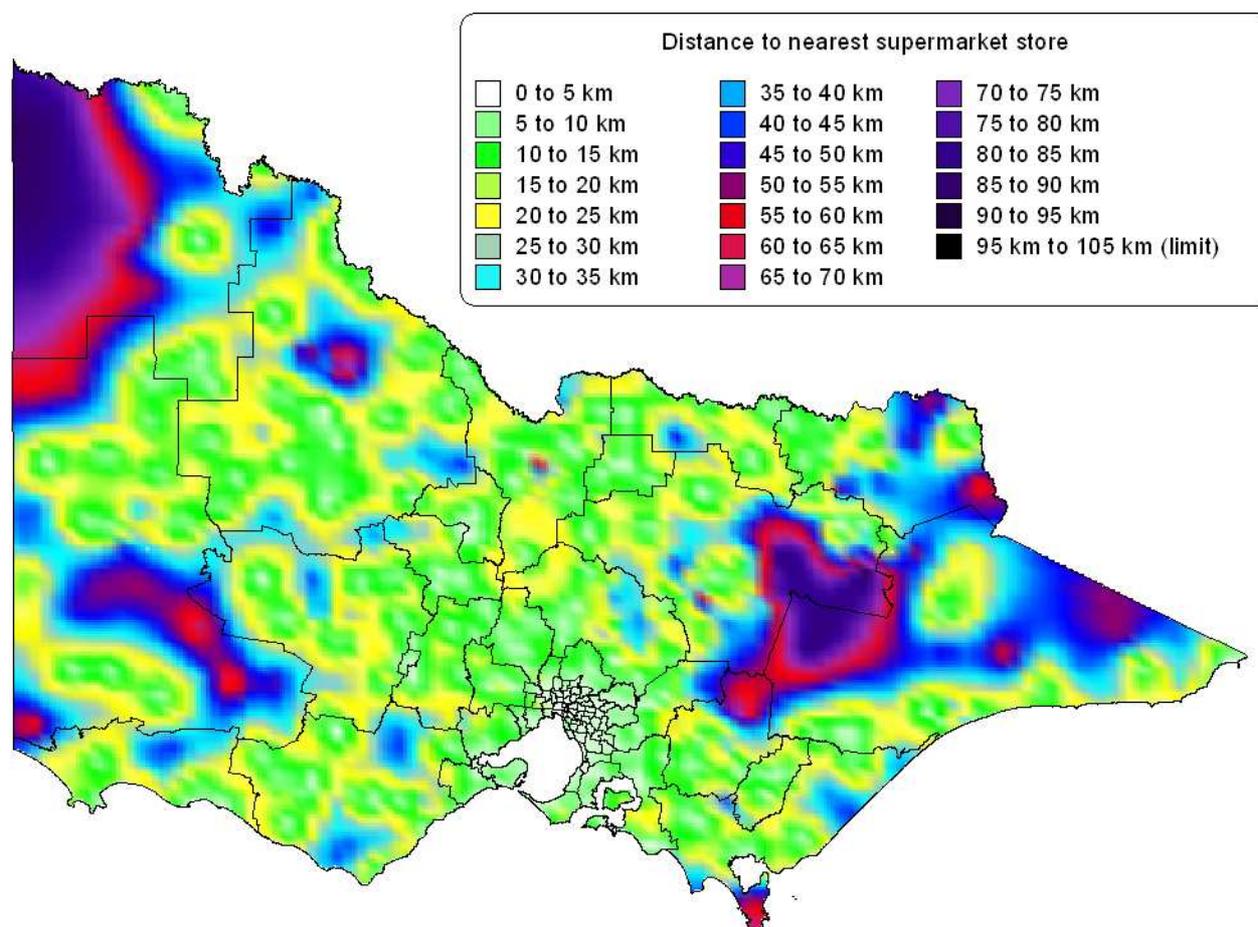
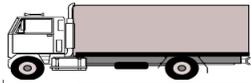


Figure 5.7. Distance from centre of CD to nearest supermarket, by road.

### 5.1.8 Transport vehicles and emissions

Modelling of the distribution of fresh fruit and vegetables requires knowledge of the type of vehicles relevant to Australian freight. The most common types are presented in Table 5.3.

Table 5.3. Types of vehicles used for commercial food transport in Australia (Hassall, 2003).

Type of vehicle	Gross vehicle weight	Diagram
Light Commercial Vehicles	1.0 – 2.5	
Medium 2-axle Rigid	11.9 – 13.0	
Heavy 2 & 3 -axle Rigid	15.0 – 23.0	
Local/Regional Articulated	39.0 - 43.0	

B-Double (see diagram)

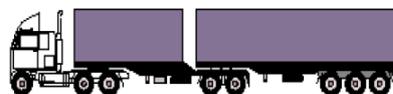
Usual Australian B-Double Configurations



**B-Double: 7 axle configuration**

Length 25m, Width 2.5m Height max 4.3m

Weight 55.5 tonnes GVM (57 Tonnes with mass management accreditation)



**B-Double: 8 axle configuration**

Length 25m, Width 2.5m Height max 4.3m

Weight 59 tonnes GVM (62.5 Tonnes with mass management accreditation)



**B-Double: 9 axle configuration**

Length 25m, Width 2.5m Height max 4.3m

Weight 62.5 tonnes GVM (68 Tonnes with mass management accreditation)



Figure 5.8. Understanding weight in trucks: Diagram showing the relationship between truckloads, pallets, cartons and items (Portland Group and SAHA, 2008).

Table 5.4 contains emission factors for vehicles that can transport F&V from production regions to DCs. Limited information is available on the transport mode, type and fuel used in transporting F&V at different stages of the supply chain. One estimate, from ABS (2008), states that 64.2% of freight volumes are carried by articulated trucks, 32.3% by rigid trucks and the remaining 3.5% by LCVs. It was assumed that this proportion of vehicles also applies to F&V movements. This is unlikely to be correct (Edhouse 2009), but without primary data collection improved information is not available. In the deterministic model, these proportions were used in all volumes\*km transported from NRMs and state border points to DCs, MM and PROCs, and finally to supermarkets and grocery stores.

The emission factors (in kg/km of CO<sub>2</sub> equiv) for the forward portion of the trip, as well as the refrigeration component (based on refrigerated transport at 0°C) and the backhaul (or return trip) component were calculated as follows: based on the approach used in the Ceres study (Gaballa and Abraham, 2008) the carriage of an average load in the forward trip leads to an emissions factor 50% higher than the emissions factor from moving the (assumed empty) truck in the backhaul trip. A comparison of forward and backhaul emissions of Table 5.4.

Emissions were also estimated for the refrigeration unit used in the delivery. Based on the proportion of F&V where refrigeration is essential for quality and safety maintenance, it was assumed that only 48% of the LCVs, articulated and rigid trucks carrying fruit have diesel-

powered refrigeration units while the proportion jumps to 60% for vehicles carrying vegetables<sup>12</sup>. We assumed that the proportion of trips refrigerated were consistent across all NRM regions and specific F&V types. Finally, emissions from backhaul (empty return) trips were added. It was assumed that for fruit deliveries, only 36.6% of the articulated and 37.9% of rigid trucks do the backhaul trip empty, while 36% of LCVs were also assumed to return empty. These proportions represent the ratio of “kms run empty” over “kms run loaded” for rigid and articulated vehicles obtained from the table “Loading of HGVs by vehicle type and weight (2006)” (Department of Transport 2008a). The same proportions apply for vegetable deliveries.

The emissions factors (in kg CO<sub>2</sub>-e/ km) for the forward portion (at full truckload), for the backhaul portion and for refrigeration components of the trip are presented in Table 5.4.

Maximum, minimum and average load capacities are presented in Table 5.5. The average load was used for the analyses of the determinist model. As per ABS information (2009), articulated trucks, rigid trucks and heavy LCVs were assumed to have an average payload of 22.5 tonnes, 6 and 0.4 tonnes respectively. We assumed that payloads were not differentiated by F&V type, though in practice the space to carry a tonne of mushrooms will be different to that used for a tonne of potatoes.

Table 5.6 presents the fuel, proportion of volume carried and emissions factors for consumer vehicles used during trips to the supermarket.

Table 5.4. Types of vehicles and emissions factors

Mode	Type	Fuel	Proportion of Volume Carried	Forward Emiss Factor (kg/km)	Refrigeration Emiss Factor (kg/km)	Backhaul Emiss Factor (kg/km)
LCV	Heavy	Diesel	3.50%	0.459	0.138	0.306
Trucks	Rigid	Diesel	32.30%	1.200	0.227	0.800
Trucks	Artics	Diesel	64.20%	2.240	0.520	1.493

Table 5.5 Payload used for each vehicle type

Mode	Type	Min tonnes	Max tonnes	Average tonnes
LCV	Light	0.10	2.00	0.38
LCV	Medium	0.10	2.50	0.38
LCV	Heavy	0.10	2.50	0.38
Trucks	Rigid	11.00	24.00	6.07
Trucks	Artics	20.00	117.00	22.60

Table 5.6. Types of vehicles for supermarket trips and emissions factors

Mode	Type	Fuel	Proportion of Volume Carried	Emiss Factor (kg/km)
Car	Heavy	Petrol	27.97%	0.329
Car	Medium	Petrol	27.97%	0.240
Car	Light	Petrol	27.97%	0.215
Car	All	Diesel	3.84%	0.175-0.268
Car	All	LPG	2.79%	0.195-0.298
LCV	All	All	10.00%	0.200-0.375

<sup>12</sup> Fruit where refrigerated transport is essential include oranges, mandarins, apples, pears (including Nashi), peaches, strawberries and table grapes. The vegetables list includes: artichokes, Asian vegetables, asparagus, beetroot, broccoli, brussels sprouts, butter beans, French and runner beans, cabbages, capsicums, chillies, cauliflower, celery, cucumbers, eggplant, fennel bulb (Finochio), herbs, leeks, lettuce (all varieties), melons (all varieties), mushrooms, parsnips, peas (all varieties), silver beet, spinach, spring onions, shallots, bunching onions, sweet corn, tomatoes, zucchini and button squash

## 5.2 Dividing the Volume of F&V Along Supply Chain Paths

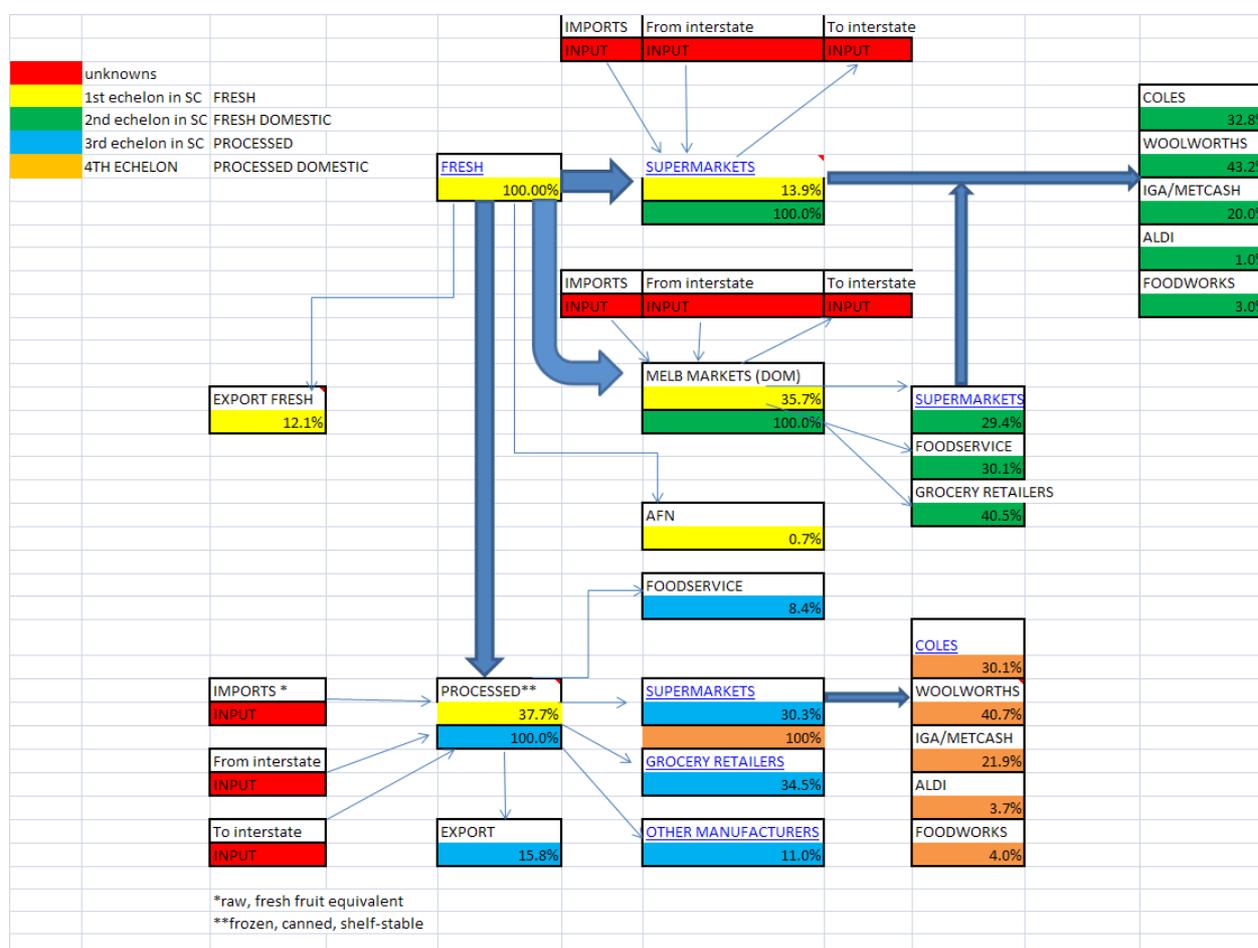
Once the locations and distances between the relevant entities are in place, the calculation of proportional amounts of produce that moved along each of the transport legs in each type of chain was required.

### 5.2.1 Producer to Retail

Two volume models were constructed to calculate the flows of fruit and vegetables entering and leaving each node of the chain<sup>13</sup>.

The FruitChain model calculates the split of product per chain type and segment, starting from the annual Victorian fruit production for 2008 (Australian Bureau of Statistics, 2008b). Percentages for each supply chain node (e.g. wholesale, supermarkets, specific retailers) were calculated through market share information from 11 IBISWorld reports (see References section) and information provided by retailers and fruit and vegetable growers and associations during the ACCC enquiry in grocery prices (Apple & Pear Australia Limited., 2008, Australian Competition and Consumer Commission, 2008, CDI Pinnacle Management, 2008, CFVIWA, 2008, Freshlogic., 2008, Fruit Growers Victoria Ltd., 2008, Metcash, 2008, The NSW Chamber of Fruit & Vegetable Industries Inc, 2008, Woolworths Limited, 2008).

The FruitChain model is illustrated in Figure 5.9.



<sup>13</sup> Models developed by Silvia Estrada-Flores, Food Chain Intelligence.

Figure 5.9. FruitChain model, showing the percentage split of fresh fruit entering the Victorian supply chain. Grapes for wine production have not been included in these percentages, as these do not enter the fresh and processed fruit chains.

In the FruitChain model (Figure 5.9), fruit production is distributed as follows: exports (12.1%), supermarket DCs (13.9%), Melbourne Markets (35.7%), Farmers’ Markets and other distribution systems (AFN, 0.7%). Supermarkets also receive 29.4% of the volume distributed by Melbourne Markets, and 30.3% of the volume distributed by F&V manufacturers. The model then assumed a split for each supermarket for fresh and processed product.

Similarly, a VegChain model was built using the same sources of information (Figure 5.10).

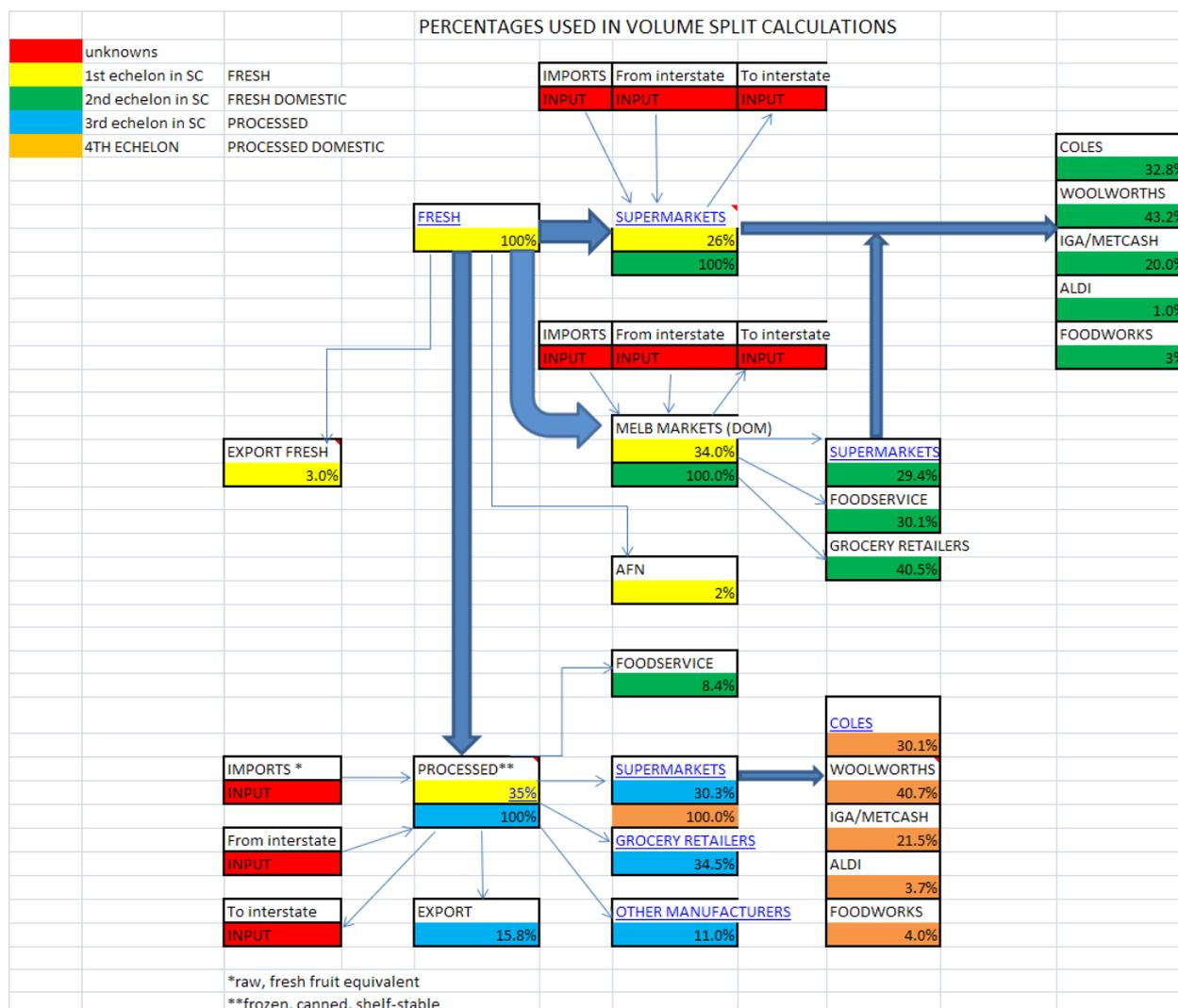


Figure 5.10. VegChain model, showing the percentage split of fresh vegetables entering the Victorian supply chain.

### 5.2.2 Retail to Home

These values (for each fruit/vegetable) were divided by the population of Australia, to obtain a gross consumption rate per capita, for which the consumption in Victoria was readily calculated. We factored for losses along the supply chain, which are about 11%, according to Estrada-Flores (2009).

Estimation of F&V consumed in Victoria (total and per capita) was achieved via a bottom up approach. Firstly, we subtracted the exports table (DPI data) from the ABS production levels for all NRMs. We then added the volumes imported from interstate and international sources. The total is then allocated to the various supermarkets and greengrocers via their corresponding DCs, processing centres and MM. We factored for losses along the supply chain, which are about 11%, according to Estrada-Flores (2009).

The remaining total is then divided by the population of Victoria to obtain a gross per capita consumption rate, which is then allocated to supermarkets and greengrocers based on the number of households residing in the supermarket's "catchment" area. The number of grocery trips is then calculated from each collection district to the nearest supermarket or green grocer using the household population in the collection district and a representative number of grocery trips made per year per household.

### 5.2.3 F&V Entering and Leaving Victoria

A significant challenge was estimating the amount of each F&V leaving or entering Victoria. A model of how these flows occur was built as shown in Figure 5.11. The rationale of this model follows the ABS methodology used in the report series "Apparent Consumption of Foodstuffs and Nutrients Calculations", reported between 1991 and 1999<sup>14</sup>.

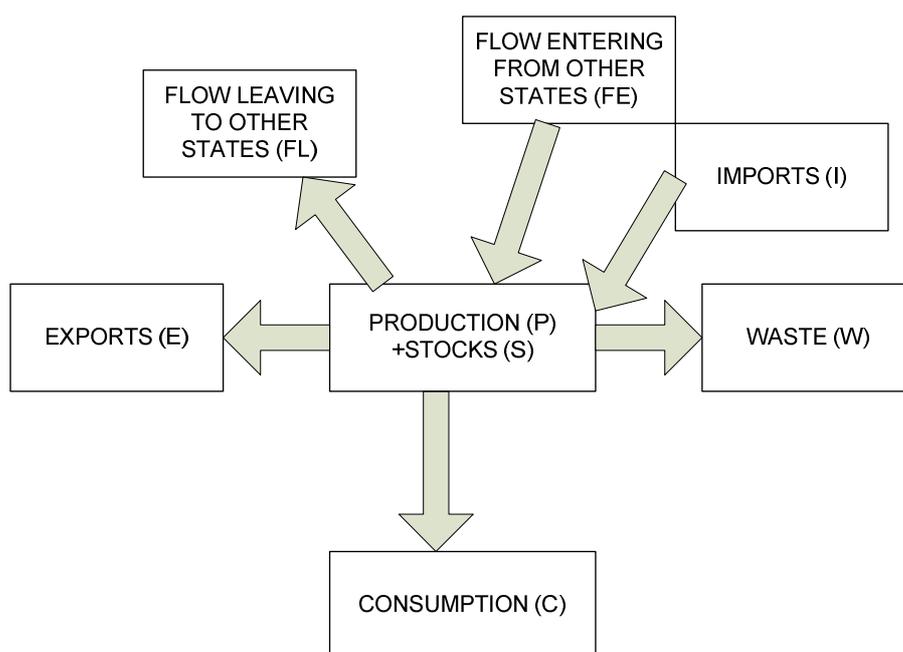


Figure 5.11. Balance of flows of F&G entering and exiting Victoria

The mass balance of Figure 5.11 is:

$$P+S+I+FE=C+W+E+FL$$

The known parameters are: P, I, W, C, E. The unknown parameters are: FE, FL, S. For this analysis, it was assumed that stocks (S) are similar from one year to the next, which means that stocks entering and consumed cancel each other out.

<sup>14</sup> <http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4306.0Main+Features11997-98%20and%201998-99?OpenDocument>

FE and FL were estimated at a coarse scale by using the ABS 2001 data for Laden Trips travelled between states by road. Turner (2010) used this data to formulate a matrix of interstate movements, which is shown in Table 5.7. Using these proportions along with ABS production levels by NRM region, the estimate amount of F&V transported in and out of Victoria by state were calculated. We recognise that the proportions will vary substantially by F&V product and by NRM region and by season. This aspect is later addressed in the stochastic modelling section.

Table 5.7. Total interstate movements (000's tonnes) of Food and Animals 2001

	DESTINATION								
ORIGIN	NSW	Vic.	Qld	SA	WA	Tas.	NT	ACT	Aust.
NSW	31,138	4,044	2,068	587	8		12	439	38,297
Vic.	2,206	32,532	515	1,015	-		-	6	36,273
Qld	1,790	494	29,738	125	39		55	-	32,241
SA	366	1,492	127	10,473	86		66	-	12,611
WA	30	15	19	74	18,018		22	-	18,178
Tas.						4,173			4,173
NT	5	8	17	45	21		714	-	810
ACT	134	2	-	-	-		-	83	220
Aust.	35,669	38,588	32,484	12,319	18,173	4,173	869	529	142,803

### 5.3 Database Tool

The previous sections highlighted the very large amount of information requirements and pre-processing needed to produce the results in this report. A spreadsheet model would not have provided the speed and flexibility for the analysis and would have been difficult to trace the volumes and GHG emissions across the supply chain segments.

A more powerful and adaptive framework was developed, using MS Access as the main modelling platform linked to Excel files that serve as the primary sources of data. Separating the modelling segment from the data segment was crucial in detaching the modelling work from the uncertainties in the data collection effort. This also allows various combinations of parameters and input tables to define different scenarios, which are then simulated and analysed using the same Access model.

The MS Access-based model, or the Supply Chain Database Tool (SCDT), provides simulations of flows along supply chain links and the associated emissions produced using a minimal set of input data based on average values (e.g. average payload, average emissions factors, average distance). Appendix A provides a technical description of the database tool and an overview of how to use the Supply Chain Database Tool.

### 5.4 Calculation of GHG emissions

The mathematical formulation of the calculation of GHG emissions for each supply chain leg (e.g. NRM region to DC, DC to supermarket, supermarket to consumer, foreign port to Australian port) for the SCDT was based on individual trips to transport fruit and vegetable items using specific vehicle types (LCVs, rigid trucks, container/ships).

#### 5.4.1 Emissions from road transport

To estimate emissions from road transport, we defined the indices used in the formulation as follows:

- Let  $j \in J$  be an individual supply chain link such as between a specific NRM centroid and DC or between a supermarket and a consumer CD (collection district) centroid. It can include interstate and international legs as well.
- Let  $v \in V$  be a road transport of a given type, mode and fuel category (e.g. articulated trucks using diesel fuel).
- Let  $i \in I$  be an individual fruit or vegetable item (e.g. potatoes, apples, oranges, etc).

If  $M_i^{v,j}$  is the total volume (in tonnes) of F&V item  $i \in I$  transported over supply chain link  $j \in J$  using vehicle  $v \in V$  in a given year, then the amount of corresponding emissions produced  $E_i^{v,j}$  (in kilograms) is given by:

$$E_i^{v,j} = (M_i^{v,j} / P^v) \times D^j \times (\lambda^v \times F^v + \alpha^v \times R^v + \beta^v \times B^v) \dots \dots \dots (1)$$

where

- $P^v$  is the average payload (in tonnes) of vehicle type  $v \in V$ ,
- $D^j$  is the distance travelled (in km) on supply chain link  $j \in J$ ,
- $\lambda^v$  is the multiplier used to account for the combined weight of the vehicle and load,
- $F^v$  is the emissions factor for the forward component of the trip (in kg/km) for vehicle type  $v \in V$ ,
- $\alpha^v$  is the proportion of trips made by vehicle type  $v \in V$  that are refrigerated,
- $R^v$  is the emissions factor for the refrigeration component of the trip (in kg/km) for vehicle type  $v \in V$ ,
- $\beta^v$  is the proportion of trips made by vehicle type  $v \in V$  that have backhaul, and
- $B^v$  is the emissions factor for the backhaul component of the trip (in kg/km) for vehicle type  $v \in V$ . This is usually the same value as  $F^v$ .

Note that  $(M_i^{v,j} / P^v)$  gives the number of trips required to transport the volume while  $(M_i^{v,j} / P^v) * D^j$  gives the vehicle-kilometres covered. The emissions formula merely multiplies the vehicle-kilometres covered with the emissions factors from the three components of the trip (forward-delivery, refrigeration and backhaul).

The database model provides the following input tables for the vehicle parameters:

- $P^v$  is given in column *Average* of table *Q\_VehPayload*.
- $\lambda^v$  is given in column *FullLoadMult* of table *P\_EmissFactors*. This is currently 1.50 which sets the average weight of the load as 50% of the weight of the vehicle.
- $F^v$  is given in column *EmissKGPerKm* of table *P\_EmissFactors*.
- $\alpha^v$  is given in column *FreqPropn* of table *Q\_VehFreqOfRefrigTrips*.
- $R^v$  is given in column *RefrigEmissFctr* of table *P\_EmissFactors*.
- $\beta^v$  is given in column *FreqPropn* of table *Q\_VehFreqOfBackhaulTrips*.
- $B^v$  is given in column *BHaulEmissFctr* of table *P\_EmissFactors*.

### 5.4.2 Emissions from shipping

Similarly, emissions from shipping are estimated by:

$$S_i^{x,y} = [ M_i^{x,y} * D^{x,y} * \sigma^C ] + [ (M_i^{x,y} / P^C) * D^{x,y} * ( \delta^C * \omega^C * \phi^C / \psi^C ) ] \dots \dots \dots (2)$$

Where:

- $S_i^{x,y}$  is the total emissions (in kg) from shipping F&V item  $i \in I$  between Australian port  $x \in X$  and partner country  $y \in Y$ ,
- $M_i^{x,y}$  is the total volume (in tonnes) of F&V item  $i \in I$  shipped between Australian port  $x \in X$  and partner country  $y \in Y$ ,
- $D^{x,y}$  is the voyage distance (in kilometres) between Australian port  $x \in X$  and partner country  $y \in Y$ ,
- $P^C$  is the average payload for 20-foot containers (currently 21 tonnes),
- $\sigma^C$  is the emissions factor for container (ship) movement (currently 0.014 kg CO2e per tonne-km),
- $\delta^C$  is the average fuel consumption of the refrigeration unit of the container (currently 300 g-MDO per kWh),
- $\omega^C$  is the emissions factor for the refrigeration unit of the container (currently .003206 kg CO2e per g-MDO. MDO stands for marine diesel oil, the fuel used by generators in refrigerated containers),
- $\phi^C$  is the average power consumption of the refrigeration unit of the container (currently 4 kW),
- $\psi^C$  is the average speed of the container/ship (currently 38 km per hour) .

In Eq. (2), the first term computes the emissions from the container/ship movement, while the second term calculates the emissions from the refrigeration component. The full formulation of these two components can be found in Appendix B.

### 5.4.3 OD distance tables

The route distances used for the different supply chain links are given in the following tables of the database model:

- Table *OD\_DC\_NRM* gives the distances between the NRM centroids and the DCs, MMA and processing centres.
- Column *Dist\_km* in table *OD\_MMA\_DC* gives the distances between the DCs and MMA (Melbourne Market Authority).
- Column *Dist\_km* in table *OD\_DC\_PROC* gives the distances between the DCs and processing centres.
- Column *Dist\_km* in table *OD\_DC\_Supa* gives the distances between the DCs and supermarkets.
- Column *Dist\_km* in table *OD\_MMA\_GG* gives the distances between the grocery stores and MMA (Melbourne Market Authority).
- Columns *Dist1* and *Dist2* in table *OD\_VIC\_CD\_Supa12* gives the distances between collection districts and the two nearest supermarkets.
- Column *Dist\_km* in table *OD\_VIC\_CD\_GG* gives the distances between the grocery stores and collection districts.
- Column *Dist\_km* in table *OD\_Exlm\_DC* gives the distances from selected Australian ports to NRM centroids, DCs, MMA and processing centres.
- Column *SeaDist\_km* in table *OD\_Exlm\_countries* gives the distances between the selected Australian ports and partner countries.

### 5.4.4 Aggregations

Using the above notation, we obtain the following basic aggregations:

1. Total emissions per year =  $\sum_{j \in J} \sum_{i \in I} \sum_{v \in V} E_i^{v,j}$
2. Total emissions on supply chain link  $j \in J$  for F&V item  $i \in I = \sum_{v \in V} E_i^{v,j}$
3. Total emissions on supply chain link  $j \in J = \sum_{i \in I} \sum_{v \in V} E_i^{v,j}$
4. Total emissions from vehicle type  $v \in V = \sum_{i \in I} \sum_{j \in J} E_i^{v,j}$
5. Total emissions per tonne transported =  $(\sum_{j \in J} \sum_{i \in I} \sum_{v \in V} E_i^{v,j}) / (\sum_{j \in J} \sum_{i \in I} \sum_{v \in V} M_i^{v,j})$

The component nature of the calculations allows more detailed aggregations to be made based on combinations of:

- supply chain links
- vehicle types
- item types
- specific fruits and vegetables
- processed and fresh produce
- Victorian production, interstate imports and international imports
- supermarkets and grocery stores
- household collection districts
- (export/import) partner countries

The above formulas can also be expanded to incorporate emissions per month in the case of seasonal effects in state production and interstate trade. Unfortunately, the seasonal data available for this report was limited to Victorian production only.

## 6. Analysis and Results

### 6.1 General GHG Statistics

This chapter presents and analyses some of the results obtained when the Supply Chain Database Tool is applied on a base scenario (ie. with all assumptions as outlined above).

Table 6.1 presents measures for overall performance of the supply chain for F&V volumes and emissions covering Victorian production, foreign imports and exports and domestic (interstate) imports and exports, as well as deliveries from DCs to supermarkets and deliveries from MMA to green grocers. The computation of emissions for domestic imports/exports involved the transport from the different state capitals to Victorian NRMs and DCs, so these were expected to be significantly higher than intrastate (Victorian) transport. As noted in Chapter 5, emissions for foreign imports included shipping transport emissions from foreign ports to the ports of entry (Melbourne, Sydney, Brisbane) in Australia, as well as land emissions from the travel of these export/import points to Victorian DCs. Emissions from the land transport portion of international imports and exports will be significantly higher than those from intrastate transport if the port of entry used is outside Victoria (Sydney, Brisbane) or significantly lower if the port of entry is Melbourne.

Emissions from supermarket deliveries involve links from DCs of specific supermarket chains (Coles, Woolworth, IGA, Foodworks, Aldi), while emissions from deliveries to green grocers involve links from Melbourne Market (MMA) only.

Succeeding sections will then disaggregate this overall measure into component values in order to highlight particular aspects of the supply chain. For example, Section 6.3 compares emissions between sources of deliveries to DCs (Victorian NRMs, interstate, and international) for F&V

consumed in Victoria, whereas Section 6.5 compares the emissions between fresh F&V and processed F&V delivered to DCs but sourced in Victoria, interstate or internationally.

As Table 6.1 shows, the overall performance of the supply chain resulted in around 133.8 kg of emissions produced for every tonne of fruit transported, and 134.5 kg of emissions for every tonne of vegetable transported. Overall, the supply chain was estimated to produce 134.3 kg of emissions per tonne of F&V moved. Although, the averages for fruits and vegetables appear identical, fruits had higher emissions for links originating from the NRMs, processing centres and international imports while vegetables had higher emissions for the links originating from interstate imports and exports.

The distribution of fresh F&V led to lower emissions than the distribution of processed F&V, with averages of 123.4 kg for fruit and 122.5 kg for vegetables in the former. Figure 6.1 shows a comparison of the emissions between all fresh and processed F&V and fresh F&V only. At a highly aggregate level such as Table 6.1 and Figure 6.1, there are minimal differences between F&V or between overall and fresh only. The minimal differences found between F&V were due to the even distribution volumes of F&V across NRM regions that are closer and further to Melbourne. This meant that the average distances were about the same for processed and fresh F&V.

The extra legs of transport for processed F&V did not overly increase the overall F&V supply chain emissions, as shown by the comparison of the last two columns of Table 6.1. This is because the F&V manufacturers based in Victoria (Table 5.1) are located either close to the F&V growing areas or are in Melbourne, near the supermarkets DC's. The results of Table 6.1 were dis-aggregated in the remainder of this Section to identify features of GHG emissions in the supply chains.

Table 6.1. Summary statistics of F&V volumes and GHG emissions for the transport of 45 items in Victoria (2008)

Type	Categories	% of Total Volume	% of Total Emissions	Emissions (kg) per tonne (Overall)	Emissions (kg) per tonne (Fresh F&V only)
Fruit	7	28.1%	28.0%	133.8	123.4
Vegetable	38	71.9%	72.0%	134.5	122.5
All	45	100.0%	100.0%	134.3	122.7

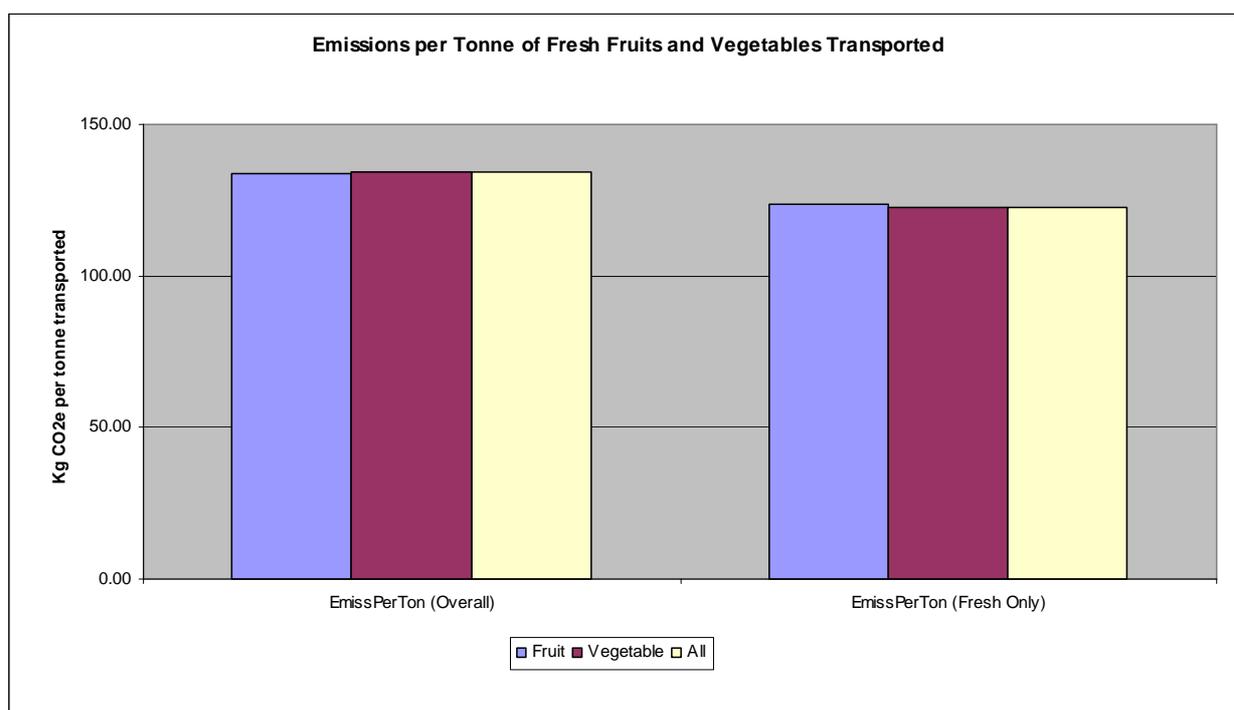


Figure 6.1. Emissions per tonne for F&V transported in Victoria for 2008.

Table 6.2 shows the average distance of an NRM to these interstate export/import points can be more than 10 times the average distance to the DCs, Melbourne Market and PROCs. For example, for Port Philip and Western Port, the average distance to DCs is only 48 kms, while the average distance to interstate export/import points is 2017 kms. East Gippsland on the other hand, is farthest from all export/import points, and second only to Mallee in average distance to DCs and MM. The average distance of Mallee from DCs and MM is more than ten times that of Port Philip.

Table 6.3 presents the intrastate transport emissions for 28 F&V items delivered to DCs. For the intrastate emissions obtained, the items are presented in descending order of emissions per \$1,000 value (at farm gate). The second column of Table 6.3 shows the GHG emissions per tonne of item transported. There is more than a four-fold difference between items with the highest (grapes, 97) and lowest (celery, 18) GHG emissions per tonne. Differences in distances between the growing region and MM/DC's were the main driver of the differences. For example, oranges, mandarins and grapes were amongst the highest as they are primarily grown in Mallee, the furthest NRM region from MM/DC's. By considering product value, the order changes a bit, as F&V with a lower dollar value will have a higher GHG emissions per dollar value ratio.

Table 6.2. Average distance of each NRM centroid from DCs, Melbourne Market, PROCs and export/import points.

NRM Region	Average distance (kms) to:			
	Distribution centres (DC)	Melb Market Authority (MM)	Processing centres (PROC)	Export/Import points (interstate)
Corangamite	171	149	226	2029
East Gippsland	371	377	381	2212
Glenelg Hopkins	317	293	330	1991
Goulburn Broken	170	163	205	1983
Mallee	474	455	464	1837
North Central	219	200	222	1925
North East	367	371	371	2065
Port Phillip and Western Port	48	28	126	2017
West Gippsland	180	173	201	2136
Wimmera	348	334	356	1905

The third column of Table 6.3 presents transport GHG emission per item, as influenced by the farm value per tonne in 2008. In this category, oranges, watermelons and grapes presented the highest emission per \$1,000 retail value, (ABS 2008d) by virtue of its high emissions-to-volume ratios. Carrots, potatoes, melons and tomatoes complete the top seven items with highest emissions-to-dollar value, as shown in Figure 6.2.

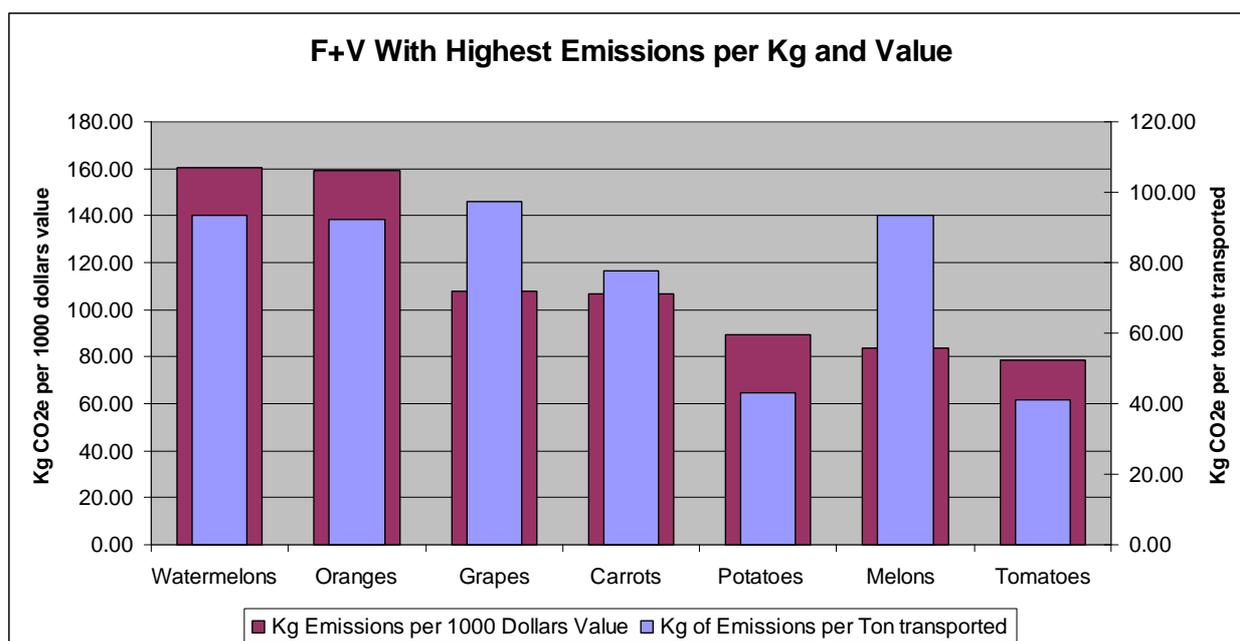


Figure 6.2. F&V with the most significant transport emissions per AUD\$1,000 value

Table 6.3. GHG emissions of 28 F&amp;V items as a function of volume transported within Victoria and farm gate value

Items	Emissions (kg) per tonne transported	Emissions (kg) per 1,000 Dollars Value
Watermelons	93.64	160.35
Oranges	92.38	159.27
Grapes	97.24	107.68
Carrots	77.86	106.81
Potatoes	43.03	89.64
Melons	93.63	83.75
Tomatoes	41.31	78.69
Sweet corn	67.20	67.88
Mandarins	97.38	59.74
Pears	38.68	56.88
Pumpkins	37.45	56.23
Onions	47.17	49.97
Beetroot	18.16	46.91
Cabbages	42.43	44.20
Peaches	42.71	35.01
Lettuce	32.11	34.97
Capsicums	72.40	32.18
Cauliflower	22.89	32.05
Zucchini and button squash	43.23	30.66
Parsnips	19.71	19.97
Apples	38.49	18.59
Celery	17.56	18.48
Broccoli	31.93	15.89
Cucumbers	21.96	8.38
Asparagus	22.04	4.87
Asian vegetables	19.02	4.20
Mushrooms	26.94	4.15

## 6.2 Contribution of Supply Chain Sectors

Table 6.4 presents the volumes (in millions of kg) for the 45 F&V items produced in Victoria and transported from the NRMs to distribution centres (DC), Melbourne Market and processing centres (PROC). Figure 6.2 illustrates the volumes transported from the origin NRM to the destination DC, PROC or MM. Goulburn-Broken and Port Philip/Western Port had the highest total volumes transported—around 270 million kg—destined mostly for processing centres (PROC) and Melbourne Markets (MM). North East and Wimmera occupied the opposite end of the list, with a combined 20 million kg transported to DC, MM and PROCs. As mentioned before, actual freight movements may not take the shortest path for the DC, MM or processor, and there may be movements between distribution centres. Therefore, these values should be used as comparative indicators of GHG emissions.

Table 6.5 presents the overall transport GHG emissions obtained for each NRM for Victorian produced F&V. The lowest emissions per tonne transported were calculated for Port Philip/Western Port (17.6 overall), Goulburn Broken (41.6) and Corangamite (42.5). This is illustrated in Figure 6.3 with the lowest bars representing Port Philip/Western Port and Goulburn-Broken, while at the same time having the highest levels of production volume. The highest overall emission levels, and highest bar charts, corresponded to Mallee (113.5) and East Gippsland (97.5) which can be largely attributed to the long distances required to transport the produce from these regions to the DCs, PROCs and MM.

Table 6.4. Volumes of F&V produced in Victoria transported from NRM to distribution centres (DC), Melbourne Market (MM) and processing centres (PROC).

NRM Region	F&V volumes (millions-kg) transported to:			
	DC	MM	PROC	TOTAL
Corangamite	13.1	17.1	17.6	47.8
East Gippsland	44.8	58.6	60.3	163.7
Glenelg Hopkins	10.5	13.8	14.2	38.4
Goulburn Broken	51.5	106.4	111.7	269.7
Mallee	41.2	81.1	85.0	207.3
North Central	54.4	74.3	76.6	205.3
North East	2.5	4.8	5.0	12.3
Port Phillip and Western Port	68.6	96.1	99.3	264.0
West Gippsland	32.7	43.3	44.6	120.5
Wimmera	2.3	3.1	3.2	8.6

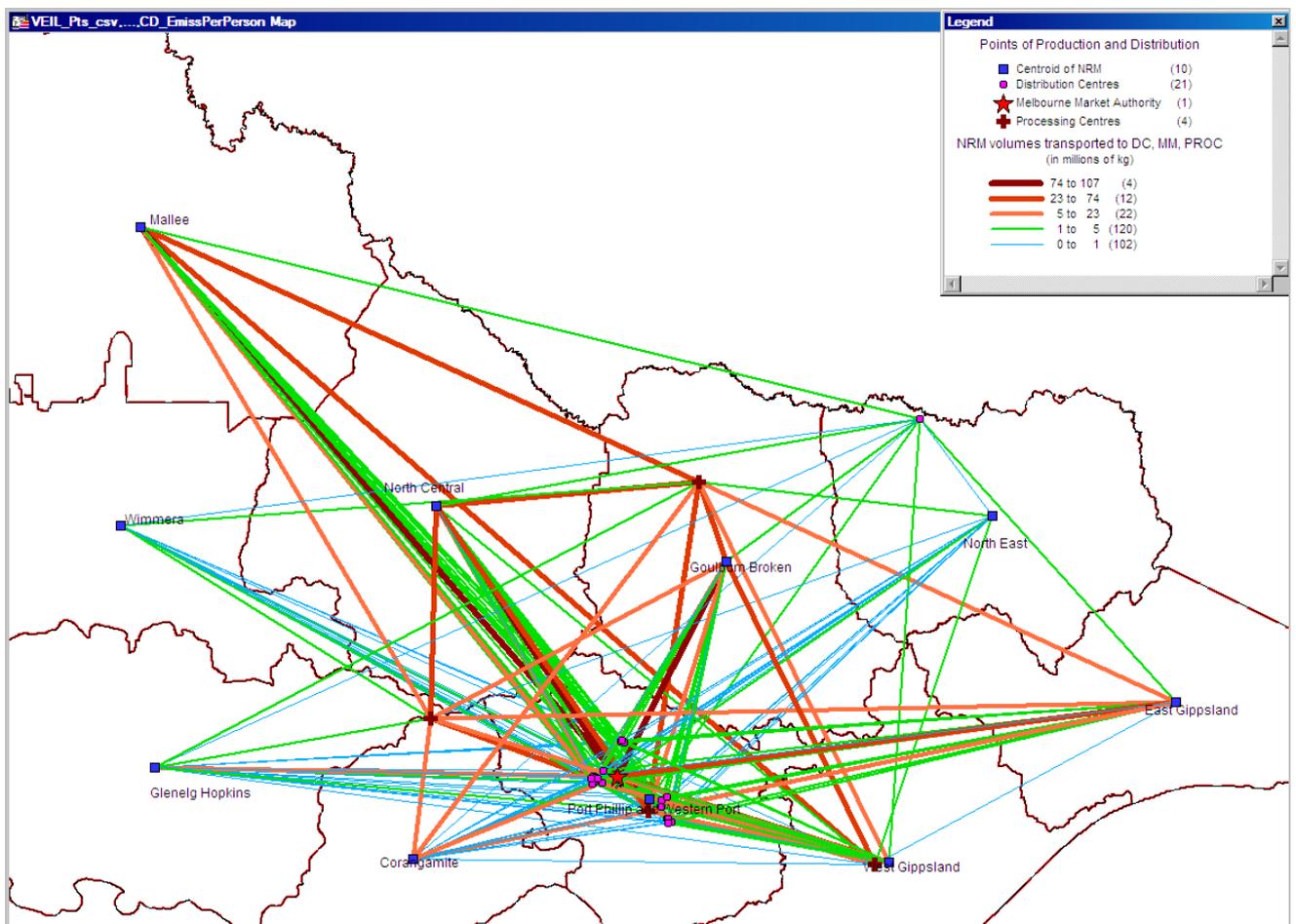


Figure 6.2. Volumes of production F&V transported from NRM to DCs, MM, and PROCs for 2008.

Table 6.5. GHG emissions per tonne transported from NRMs to distribution centres (DC), Melbourne Market and processing centres (PROC).

NRM Region	GHG Emissions (kg CO <sub>2</sub> -e per tonne) transported to:			
	DC	MM	PROC	OverAll
Corangamite	41.6	36.6	49.0	42.5
East Gippsland	91.8	92.7	107.1	97.8
Glenelg Hopkins	77.3	72.0	71.7	73.3
Goulburn Broken	40.9	39.5	43.8	41.6
Mallee	115.1	110.3	115.7	113.5
North Central	53.5	49.1	44.9	48.7
North East	88.6	90.0	79.6	85.5
Port Phillip and Western Port	12.3	6.9	31.5	17.6
West Gippsland	45.2	42.5	64.3	51.3
Wimmera	85.2	82.1	76.4	80.9

From the perspective of achieving F&V supply chains with lower transport GHG emissions, Table 6.5 shows that there is a strong case for maintaining the production of F&V in areas closer to the main consumption region of Melbourne. Freight movements that go through processing versus DC's/MM had a much lower impact on GHG emissions compared to the growing region, particularly as the DC's/MM are already located around Melbourne. Unless the agronomic (production) GHG emissions per tonne differ substantially between growing regions, increasing the proportion of F&V grown close to Melbourne is an effective means of decarbonising food supply chains.

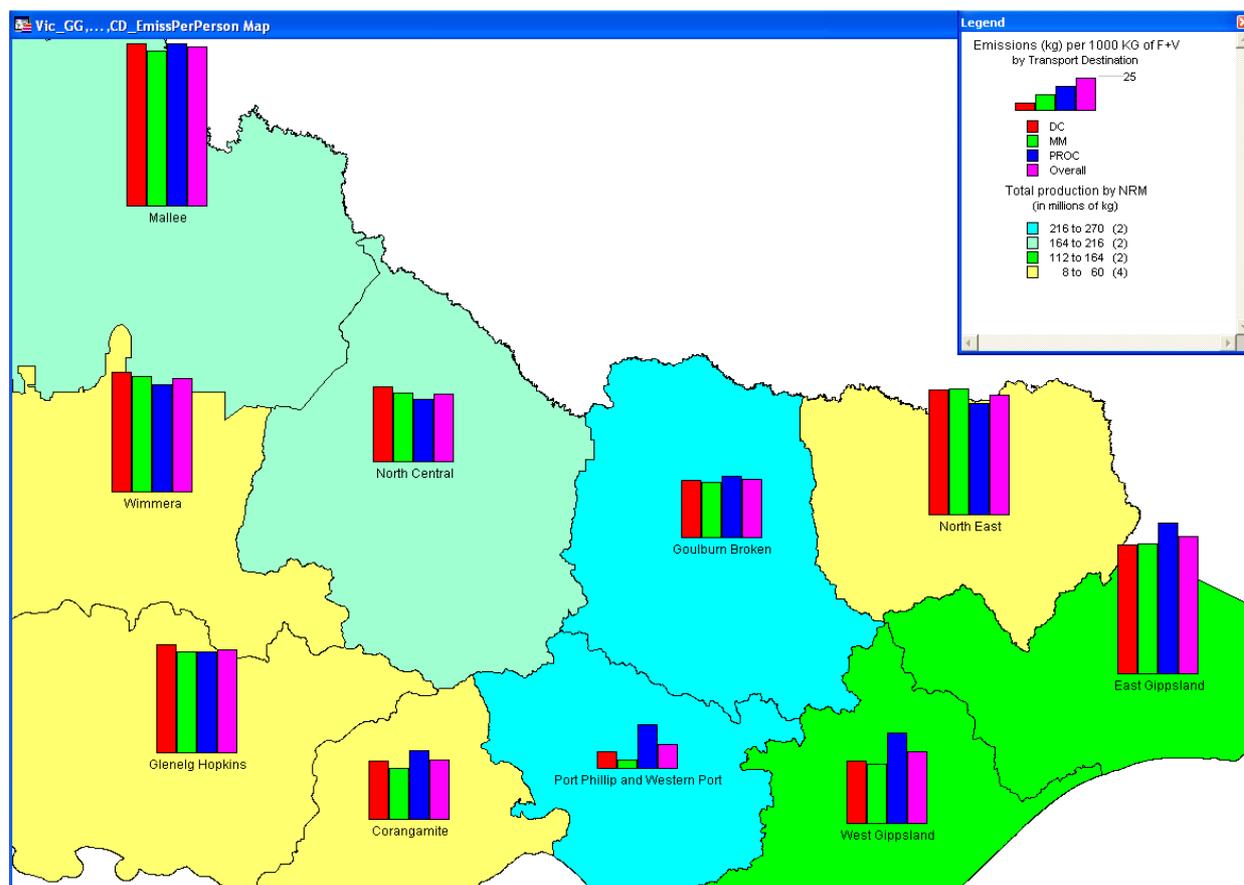


Figure 6.3. Comparison of volumes and emissions per F&V tonne transported from NRMs to DCs, MM, and PROCs for 2008

The impact of distance on the level of transport emissions produced carries over to the consumer side of the supply chain. Household trips to the nearest supermarkets and grocery store were estimated for each of Victoria's populated collection districts (CD), based on an average of 88.4 food shopping trips per year per household. Of these, 34.3% or 30.4 are assumed to be trips to supermarkets while 17.5% or 15.5 are trips to the grocery store. These trip averages are multiplied with the number of households in each CD, the travel distance to the nearest supermarket or grocery store, and the vehicle emission factors to obtain the total emissions for each CD. The resulting emissions per capita per CD produced by grocery trips are presented in the thematic map in Figure 6.4, based on the vehicle features of Table 5.4. The map also locates the +900 supermarkets and 540 grocery stores considered as grocery trip destinations.

The thematic map of Figure 6.4 shows that most of the high emission areas (*i.e.* blue and light-blue regions) occur outside Metropolitan Melbourne, where most of the supermarkets and grocery store outlets are concentrated (see Appendix E for further analysis). The inset shows a map of CDs in Inner Melbourne where most of the low emission areas (*i.e.* yellow and light-green regions) are found. The high emission areas contribute with at least 96 kg of GHG emissions per household per year, while the low emission areas only contribute a maximum of 46 kg per household per year. Even in high areas, the total GHG emissions from household trips represents only approximately 0.2% of total GHG emissions from the transport of F&V. This indicates that the household component of emissions is not a significant proportion of the overall emission from the supply chain, since it only accounts for 7.25% (as per the CHOICE supermarket basket) of the emissions produced by the trip to the supermarket.

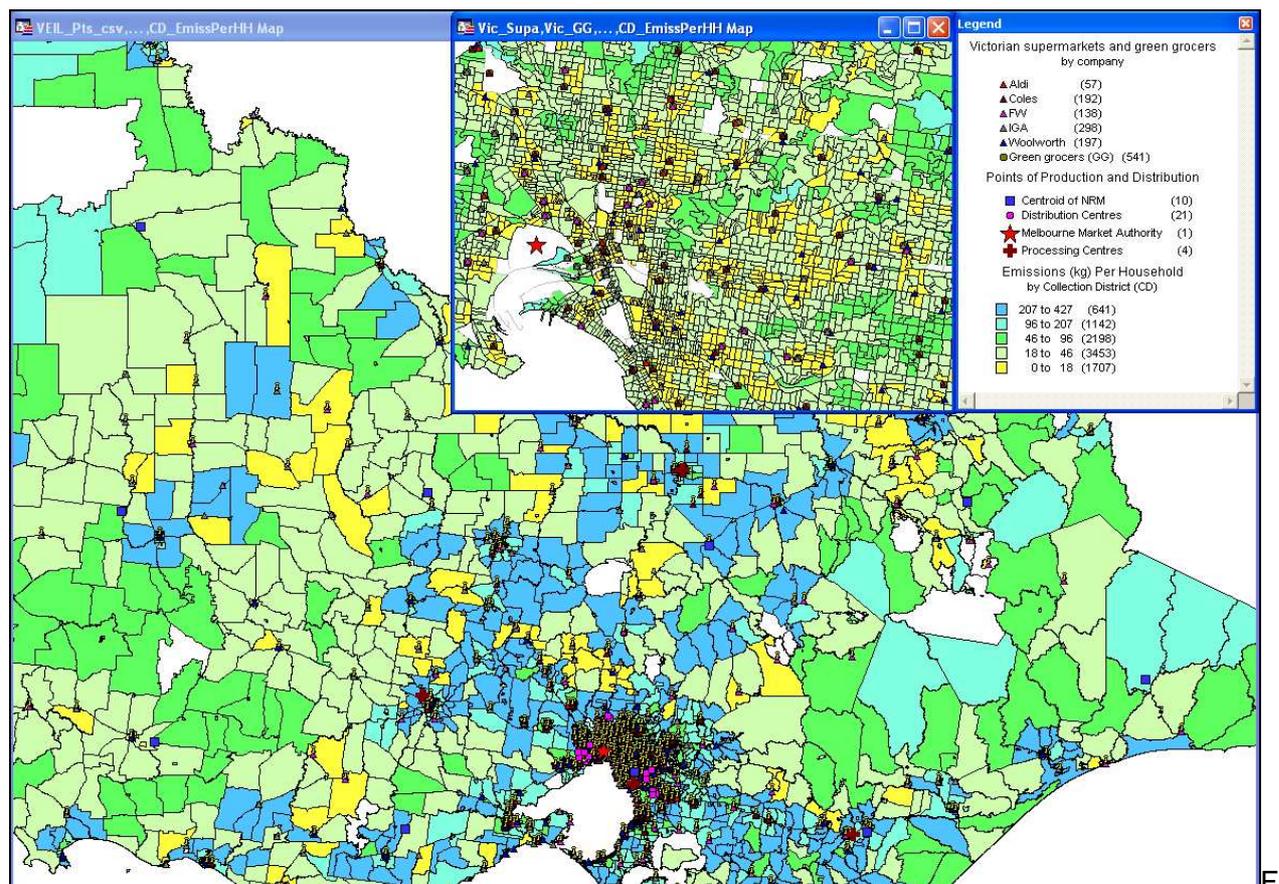


Figure 6.4. Distribution of emissions produced per household from grocery trips for FFV among Victorian collection districts for 2008. Inset shows map for Inner Melbourne.

### 6.3 Victorian, Interstate and Imported

Table 6.7 compares the average GHG emissions per tonne of Victorian-grown F&V consumed in Victoria compared to F&V sourced from interstate and imported from overseas. As Table 6.7 shows, imported fruits and vegetables showed the highest overall transport emission levels (248 and 216 kg CO<sub>2</sub>-e per tonne, respectively) while interstate supplies were not far behind with overall emissions of 221 kg CO<sub>2</sub>-e per tonne. Both international and interstate transport presented an emissions profile of almost four times the levels obtained for Victorian grown fruits and vegetables (60 and 49 kg CO<sub>2</sub>-e per tonne, respectively). These results can be attributed to the significantly longer distances required to connect foreign ports and state capitals to Victorian DCs compared to points within Victoria for Victorian grown fruits and vegetables, particularly the road segments.

Emissions from vegetables were highest for interstate transport while emissions from fruits were highest for international imports. An interesting observation is that the international shipping leg had similar GHG emissions to the interstate road transport leg.

Table 6.7. Comparison of GHG emissions of between Victorian and non-Victoria produced F&V

Product Type	Destination Type	Kg of Emissions per Tonne transported		
		Vic Produced	Imported	Interstate supplied
Fruit	Victoria DC	59.57	248.02	215.70
Vegetable	Victoria DC	48.73	216.22	222.45
All		51.94	222.89	220.62

Although international imports produced the highest emission levels of 248 kg per tonne of fruit imported, these emission levels only represent transport (including refrigeration) from the port of departure from the partner country to the port of entry in Australia and ultimately to Victorian DCs. Transport GHG emissions between the overseas growing region and the port of departure in the foreign country are not included. Therefore, these results are likely to underestimate the true values. As noted earlier, the land leg portion of international transport is considerably shorter than interstate transport since most foreign imports use the Port of Melbourne as the port of entry into Victoria, and Victoria DC's are already close to the Port of Melbourne.

Table 6.8 lists the top 30 countries in descending order of emissions per F&V tonne imported. The second column gives the average emissions per tonne of fresh F&V, the third column gives the average for processed F&V, while the fourth gives the overall average. The last column identifies the ports of entry used (Melbourne, Sydney or Brisbane) to calculate emissions for transport to Victorian DCs and NRMs. Many of the countries use Melbourne as the only port of entry for their products. Figure 6.5 shows a bar chart comparing the emissions from the top eight countries. Notice that most of the high emission sources come from Western and Eastern Europe where the sea distance covered is highest. As one would expect, GHG emissions are proportional to distance travelled.

Table 6.8. Comparison of transport-related GHG emissions from foreign imports by country of origin. The table assumes sea freight only.

Source Country (ranked in descending order)	Emissions (kg CO <sub>2</sub> -e) per tonne, fresh F&V	Emissions (kg CO <sub>2</sub> -e) per tonne, processed F&V	Emissions (kg CO <sub>2</sub> -e) per tonne overall	Entry ports
United Kingdom	439.0	558.7	558.70	Melbourne, Sydney
Finland		481.7	481.73	Melbourne
Belgium	446.0	471.7	471.60	Melbourne, Sydney
Poland	469.0	469.0	468.97	Melbourne
Netherlands	478.0	451.0	453.73	Melbourne, Sydney, Brisbane
Germany	453.7	453.7	453.71	Melbourne
Morocco		436.5	436.52	Melbourne
Brazil		431.5	431.48	Melbourne, Sydney, Adelaide
Portugal		424.3	424.34	Melbourne
Spain	400.2	421.9	418.73	Melbourne
Cuba		400.1	400.07	Melbourne
Argentina	278.2	419.3	391.76	Melbourne
Belize		390.1	390.13	Melbourne
France	384.7	384.7	384.65	Melbourne
Switzerland		380.7	380.67	Melbourne
Greece	383.2	377.1	377.18	Melbourne
Slovenia		376.8	376.79	Melbourne
Antigua & Barbuda	376.1		376.11	Melbourne
Czech Republic		375.8	375.81	Melbourne
Slovakia		375.8	375.81	Melbourne
Hungary		375.8	375.81	Melbourne
Croatia		375.4	375.37	Melbourne
Montserrat		375.2	375.21	Melbourne
Sierra Leone		373.9	373.93	Melbourne
Turkey	389.3	368.4	368.38	Melbourne
Italy	364.8	364.9	364.85	Melbourne
Bosnia & Herzegovina		364.5	364.48	Melbourne
Serbia and Montenegro		364.5	364.48	Melbourne
Netherlands Antilles		360.8	360.81	Melbourne
Bulgaria		357.8	357.78	Melbourne

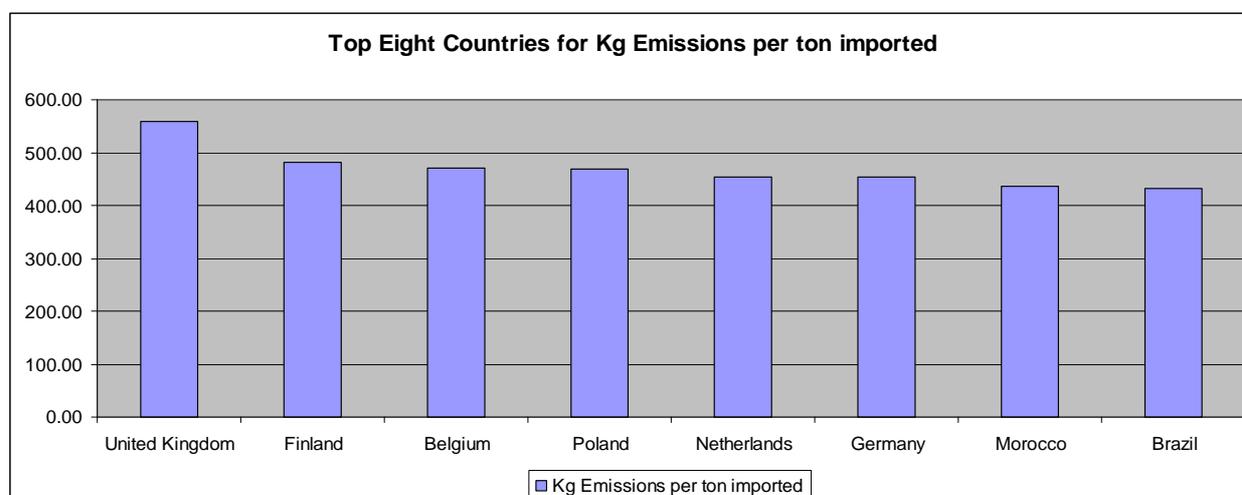


Figure 6.5. Eight partner countries with highest emissions per tonne of imported F&V.

## 6.4 Vehicle types and loads

Table 6.9 presents the proportion of the total volume carried, proportion of total emissions produced and emissions per tonne transported by transport mode, type and fuel. As per assumptions stated earlier, articulated diesel trucks carried 64% of the volume and accounted for 36% of the emissions. Rigid trucks carried 32% of the volume and produced 36% of the emissions while LCV carried 4% of the volume and accounted for 28% of the emissions. It is likely that LCV's will be used on shorter trips and when it is impractical to use larger trucks. Results in this report are in the absence of information of which supply chain links use LCV's.

Overall, the emissions attributed to LCVs were more than 14 times those of articulated trucks and about seven times those of rigid trucks (per tonne transported). The significant savings in emissions from deliveries by rigid and articulated trucks over LCVs is illustrated in the bar chart in Figure 6.6. Whilst the differences between LCV and trucks are substantial, the scope to reduce GHG emissions through selecting vehicles types are limited, given that the ABS statistics used in this report suggest that most food products (assumed here to also be the case for F&V) are already being transported by articulated trucks.

**We need to stress that these results are in the absence of information on supply chain links that use LCV's.** It should also be noted that the lack of data required the same allocation of vehicles to different legs in the chain, although in practice LCVs would rarely be used for long-haul interstate journeys (for example). This is likely to lead to a significant overestimate of the amount of emissions generated through use of LCVs (as in practice they are likely to travel much smaller distances).

While this base scenario attributes only a small percentage of F&V transport to LCVs, a complete shift away from LCVs to articulated trucks could potentially reduce overall GHG by 26%. We would expect the improvements to be less than 26% in practice since LCV's will be more likely used when impractical to use larger trucks. Similarly, a complete shift from rigid to articulated trucks could potentially reduce overall GHG emissions by up to 18%, although there would also be practical limitations to this move. Attempting to move all F&V transport to articulated vehicles would be likely to also have implications for payloads and distances travelled. These results do not take into account congestion aspects, which may worsen (or improve) by these changes.

Table 6.9. Comparison of GHG emissions by mode and fuel type for transport of F&V from NRMs and export/import points to supermarkets and grocery stores.

Mode	Type	Fuel	% of Total Volume carried	% of Total emissions produced	Emissions (kg CO <sub>2</sub> -e) per tonne transported
LCV	LCV	Diesel	1.2%	8.4%	906.4
LCV	LCV	LPG	0.2%	1.5%	1007.1
LCV	LCV	Petrol	2.1%	18.3%	1110.8
LCV	LCV	ALL	3.5%	28.1%	1035.7
Trucks	Artics	Diesel	62.7%	35.0%	72.0
Trucks	Artics	LPG	0.1%	0.0%	65.8
Trucks	Artics	Petrol	1.4%	0.9%	83.0
Trucks	Artics	ALL	64.2%	35.9%	72.2
Trucks	Rigid	Diesel	29.4%	32.3%	142.0
Trucks	Rigid	LPG	0.2%	0.2%	148.4
Trucks	Rigid	Petrol	2.7%	3.5%	163.8
Trucks	Rigid	ALL	32.3%	36.0%	143.9

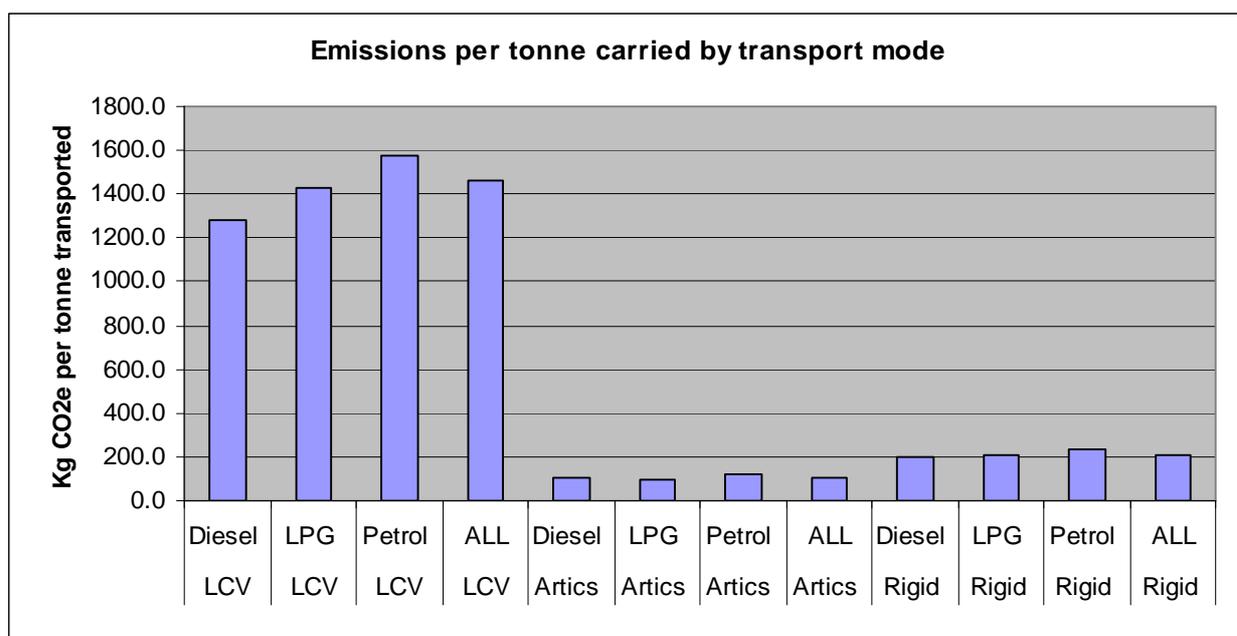


Figure 6.6. Comparison of emissions per tonne carried by transport modes and fuel type

The impacts of changing truck sizes are further explored in the Sensitivity Analysis (Part B).

### 6.5 Emissions from the transport of processed F&V

Table 6.10 compares the percentage of total volumes, percentage of total emissions and average emission levels associated with delivering processed and unprocessed (fresh) fruit and vegetables to DCs from Victorian (NRMs), interstate and international sources. Figure 6.7 presents a bar chart comparing the transport emissions (in kg CO2-e per tonne). Note these results are based on the estimated proportion of processed versus unprocessed F&V from Figure 5.8 and 5.9 and does not account for increase or decrease in refrigeration requirements for transportation of processed F&V.

Table 6.10. Comparison of GHG emissions from processed and unprocessed F&V

Type	% of Total Volume transported		% of Total Emissions produced		Emissions (kg CO2-e) per tonne transported	
	Processed	Unprocessed	Processed	Unprocessed	Processed	Unprocessed
Fruit	7.0%	20.9%	9.0%	18.5%	183.38	127.89
Vegetable	18.9%	53.1%	25.3%	47.2%	192.71	128.41
All	26.0%	74.0%	34.2%	65.8%	190.18	128.27

Although the total unprocessed volume moved accounts for 74% of total volume transported, the total emissions for unprocessed F&V only accounts for 66% of all emissions. Thus, the overall emissions for processed F&V are 190 kg CO2-e per tonne, and exceed that for unprocessed F&V (at 128 kg CO2-e) by about 60 kg CO2-e per tonne. This can be attributed to the additional transport legs to and from the processing centres.

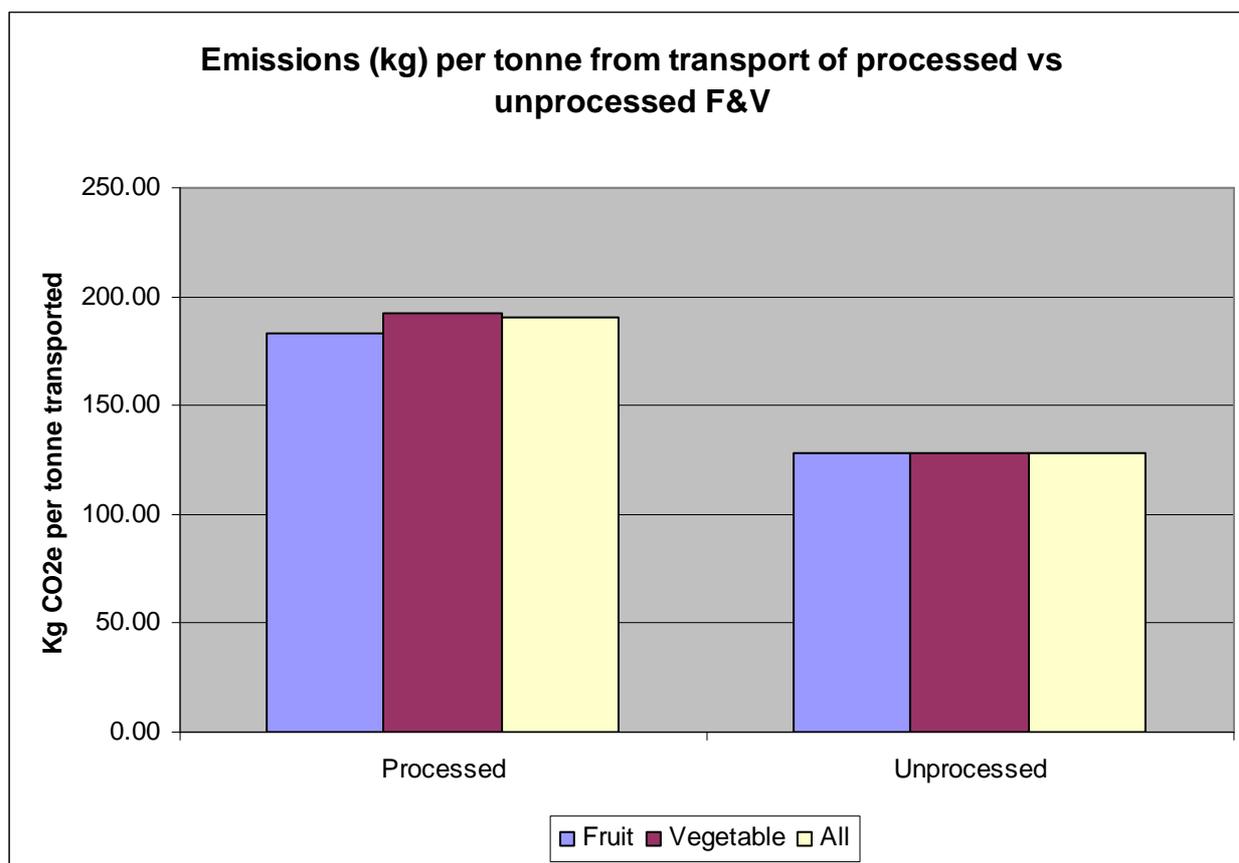


Figure 6.7. Comparison of GHG emissions (kg CO<sub>2</sub>-e per tonne) transported between processed and unprocessed F&V for 2008.

## 6.6 Seasonal effects

Figure 6.8 shows a line graph of the seasonally adjusted emissions per tonne of F&V transported from Victorian producers to DCs and MM, as well as a 100% bar chart of the percentage share of the total volumes between fruits and vegetables. The emissions are based on the same table used to compute the emissions per \$1,000 value for the 45 items considered in the study. The total annual emissions per item were then disaggregated into monthly totals based on the months for which the item is seasonally available. The months of availability were obtained from the Melbourne Market Authority ([marketfresh.com.au](http://marketfresh.com.au)). The months within the season of availability are then allocated an equal proportion of the volume transported and emissions produced. The seasonal variability may be an underestimate since the harvest season will be shorter than the time window of availability and transport requirements may be variable within a harvest season.

Figure 6.8 shows that the highest emissions per tonne from Victorian produce are in October for fruits, November for vegetables. The period from June to November result in high emissions because only high emissions fruits like mandarins and oranges are available at this time. The low emission months for fruits belong to February to May, which coincides with the availability of strawberries, pears and apples in Victoria, particularly from Goulburn-Broken region. Similarly, the period from November to January exhibit the highest emissions per tonne for vegetables because of the transport of high emission items like watermelons, melons, peas and butter beans, particularly from East Gippsland.

The line graph for overall (F&V) emissions lies close to the vegetables line, and far from the fruit line, for the months of June to December due to the large share of the total volume attributed to

vegetables. The fruit and vegetable volumes become more equal in the months of March, April and May.

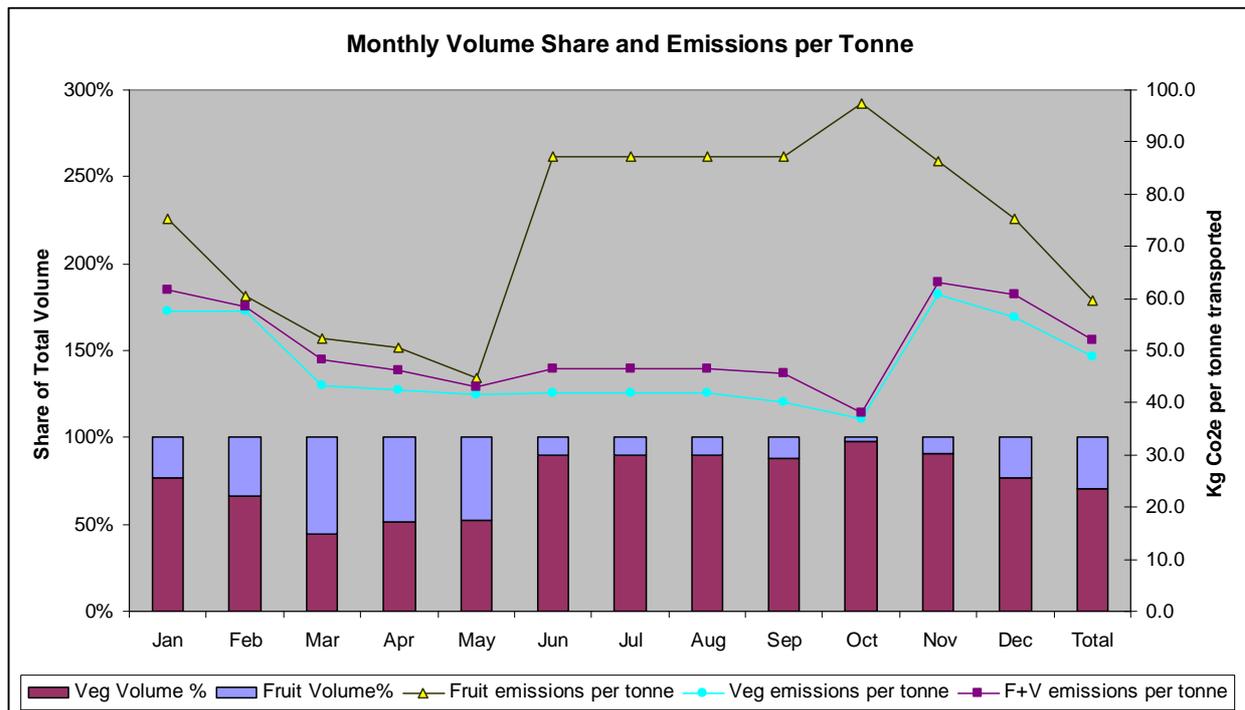


Figure 6.8. Comparison of monthly emissions per tonne transported for 2008

Figure 6.9 presents a stacked chart showing the monthly F&V production from each NRM in 2008. Read from top to bottom, the legend presents the NRMs in ascending order of total annual F&V production with Wimmera the lowest and Goulburn-Broken the highest. The highest total production levels were achieved in the summer months from December to March, while total production was lowest between June and November. Goulburn-Broken dominated production from March to May, while East Gippsland had the largest share from November to February. The period between June and October had Port Phillip-Westernport, North Central, Mallee and West Gippsland as the largest producers.

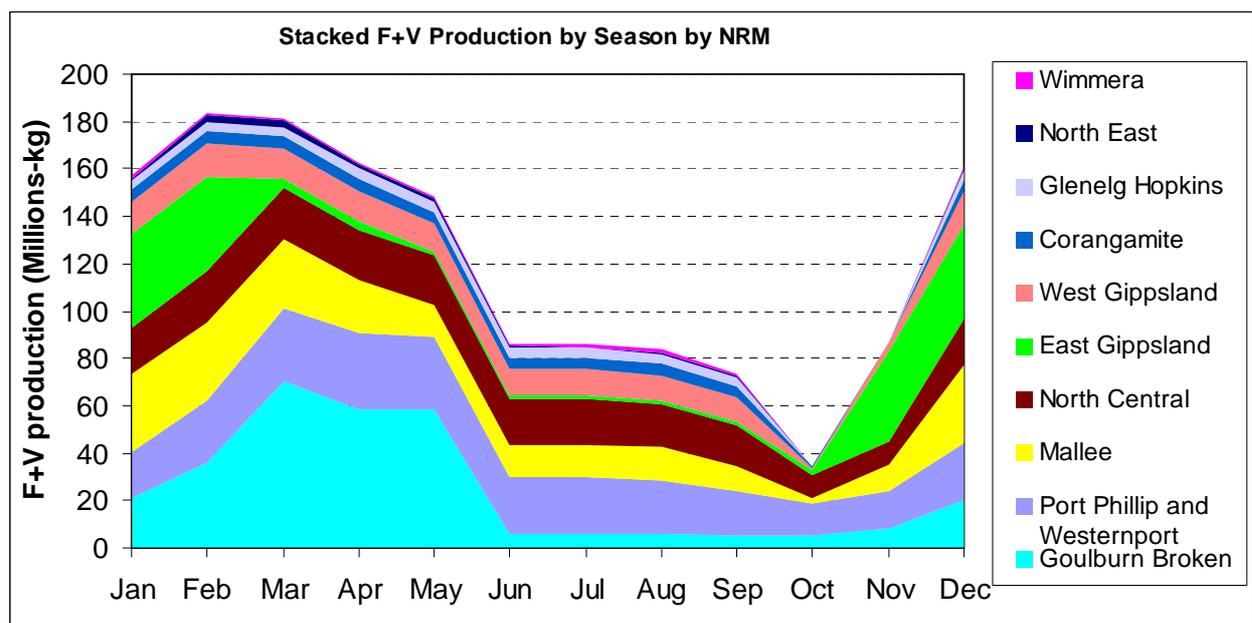


Figure 6.9. Comparison of monthly F&V production from each NRM for 2008

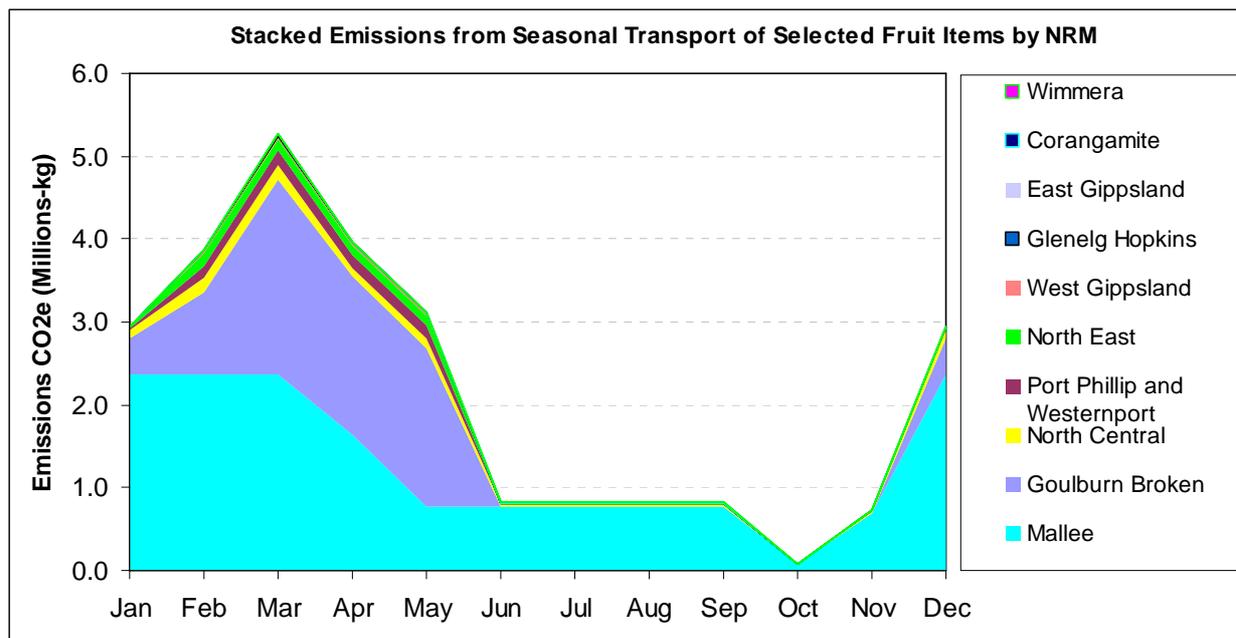


Figure 6.10. Comparison of monthly emissions per tonne of selected fruits transported from each NRM for 2008

Figures 6.10 and 6.11 present stacked charts comparing the seasonally adjusted transport emissions for fruits and vegetables, respectively, from each of the Victorian NRMs to Victoria’s DCs and MM. Again, the legend presents the NRMs in ascending order of total emissions from top to bottom. The shape of Figure 6.11 (vegetables) is closer to that of Figure 6.9 since vegetables comprised 71.9% of the total volume.

These two figures show that the contribution per NRM is highly dependent on the distance covered in each supply segment. In Table 6.2, the two highest average distances to DCs and processing centres corresponded to Mallee and East Gippsland. Figure 6.10 shows that Mallee is the major contributor to fruit transport GHG emissions all year round, with Goulburn-Broken adding significantly during the period November to June. With the exception of East Gippsland, transport usage and emissions tends to peak around March. Figure 6.11 shows that Mallee is also a major contributor to vegetable emissions, along with East Gippsland and North Central. Mallee has the highest average distance among all NRMs and is the 3<sup>rd</sup> highest in terms of total production, which contributes to make this NRM a top contributor for all months.

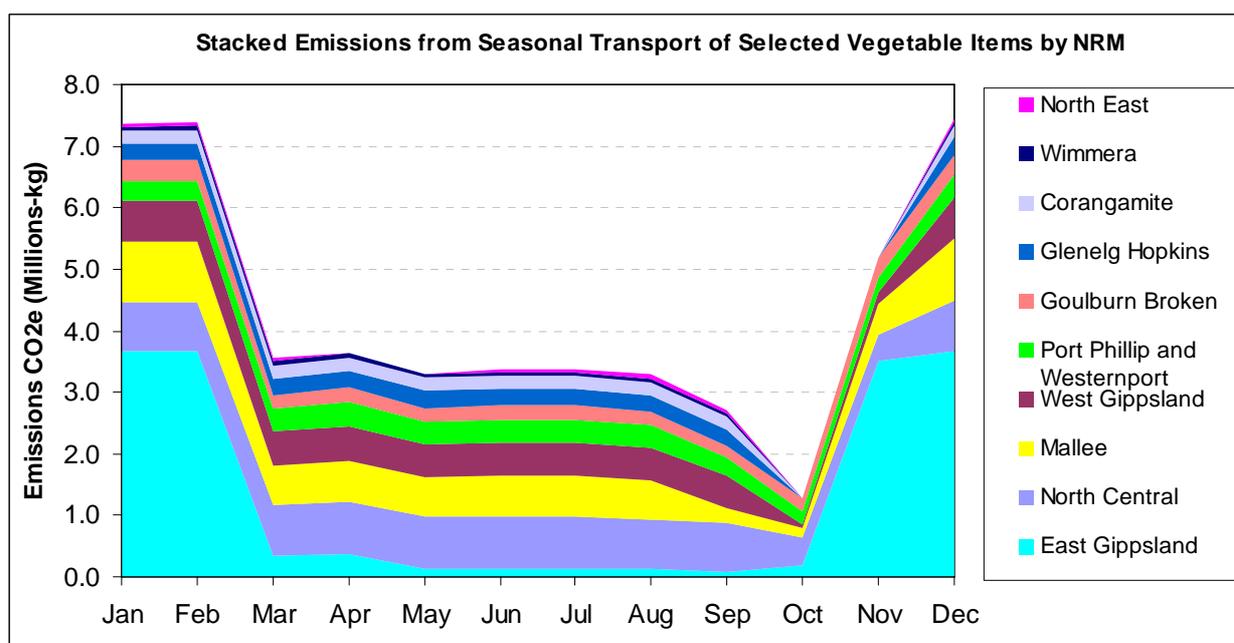


Figure 6.11. Comparison of monthly emissions per tonne of selected vegetables transported from each NRM for 2008

On the other hand, Goulburn-Broken, with the highest total volume of production, but second lowest average distance to DCs, only figures in the top two emissions contributors for the months of March to May. Finally, Port Philip-Westernport, which has the second highest volume of production, is a low contributor to emissions by virtue of it having the lowest average distance to the DCs.

The low transport emissions in October for F&V in Victoria (Figure 6.10 and 6.11) are due to the low production in this period. This would be offset by a large volume of F&V being transported into Victoria from other states, and/or that consumption of F&V decreases around this period. If the former is correct, the total GHG emissions (local+interstate+imported) F&V would actually be higher in October than in any other month. This would be an important future analysis if supporting data were to become available.

## 7. Supply Chain Vulnerability

Extreme weather events, fuel prices or potential shortages, rising operations and maintenance costs, uncertainty in relation to future fuel efficiency and emissions regulations continuously exert pressure on the transport industry to search for, and implement policies and practices that reduce fuel costs and greenhouse gas emissions. The evaluation of impacts of specific policies and strategies directing the selection of travel modes, vehicle types, and fuel types in transporting FFV is always an important area of analysis in the study of F&V supply chains. The database model allows the evaluation of such policies by creating scenarios based on combinations of changes to the parameter tables. For further discussion of vulnerabilities, see Part 1 report.

### 7.1 EWE on Production

In this section, we investigate the GHG impacts of lost production in Victoria's NRM regions caused by Extreme Weather Events (EWE). The analysis simulates losses in production due to bushfires, storm damage and droughts and estimates the increase in GHG levels resulting from the transport of replacement produce. Under normal circumstances, when production is lost in

one or more NRM regions, the shortfall in production to meet Victoria’s demand (consumption) requirements would be met through other NRM regions in Victoria (as distinct from international imports). Furthermore, when there is insufficient supply from other NRM regions, the shortfall would be compensated by interstate imports, where the GHG emissions are expected to increase due to lengthier freight movements and increased fuel use. In this sub-section, we focus on the use of interstate imports as the primary source of replacement for production losses. We believe a basic scenario where lost production from an NRM is replaced by interstate imports can provide important insight into the efficiency of alternative sources of supply during Extreme Weather Events. We also identify the NRM regions most vulnerable to increased GHG emissions resulting from EWE.

By Victoria’s ‘consumption’, the demand by processors was included, as the inability to meet demand locally (or reliably) will impact on their costs of sourcing produce (at some oil / carbon price point, there could be a significant impact).

A representative scenario was set to investigate the impact on emissions of switching the source F&V volumes from an NRM to interstate. The scenario simulates the condition where 25% of the annual production of an NRM is lost and the lost volume is replaced by corresponding additional supply from interstate, with each state given equal allocations. This condition may be produced by an extreme weather event causing damage to production areas in an NRM with recovery taking three months or more. The increased distance in transporting the replacement volumes between the interstate capitals and Victorian DC’s would result in increased emissions, with the total amount dependent on the actual volumes replaced.

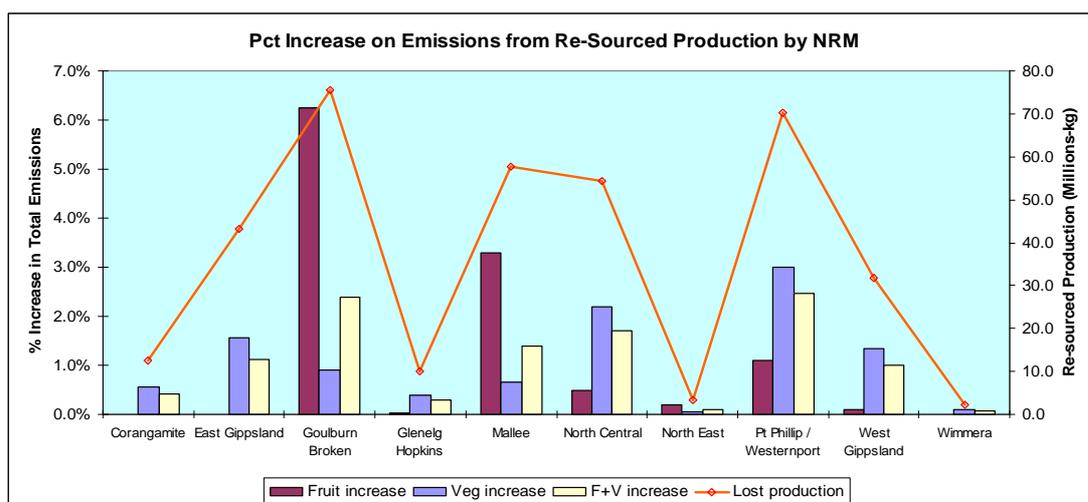


Figure 7.1.

Impact of lost production from NRM on total emissions from transport of F&V

Figure 7.1 presents a bar chart of the overall percentage increase in total emissions from the base scenario when the NRMs lose 25% of their production and the corresponding replacement volumes are sourced from interstate to the DC’s and MM. The line chart displays the volume of lost production re-sourced from interstate. The four NRMs with the highest volumes of production have the highest replacement requirements if 25% of production is lost i.e. Goulburn/Broken (76 M-kg), Port Philip/Westernport (70 M-kg), Mallee (58 M-kg) and North Central (54 M-kg). Consequently, these four NRMs produced the biggest impact on emissions from lost production.

The figure shows that the most significant increases on fruit emissions is produced by production losses from Goulburn/Broken (6.24%), followed by Mallee (3.29%) and Port Philip/Westernport (1.10%). For vegetable emissions, the highest increases came from Port Philip/Westernport (2.99%), North Central (2.20%), and East Gippsland (1.56%). In terms of overall emissions, Port Philip/Westernport (2.46%), Goulburn/Broken (2.38%) and North Central (1.72%) represent the NRMs with the biggest impact on Victoria’s fruit and vegetable supply chain. Overall, these do

not represent significant gains in GHG emissions (mostly less than 4%) given a significant loss of production of 25% in a region.

However, this finding is an average based on the simulated volume replacements from interstate sources for lost production from one affected NRM at a time, assuming the remaining NRMs are unaffected. Replacement volumes (equalling the volumes lost) will come from the other states (through their import/export point) in equal proportion. Thus the gain in GHG is proportional to the lost volume, and takes into account the (average) interstate distances travelled by replacement produce.

### 7.3 Oil Price Impact on Fruit and Vegetable Price

Here we consider the vulnerability of each F&V chain in terms of different fuel prices. We will consider the farmgate value of each F&V category and how the increase in oil price would affect additional costs. Table 7.2 shows the fuel costs versus the value of each F&V produced in Victoria (averages over regions of production) for three fuel price scenarios. It assumes only articulated vehicles (and is therefore an underestimate of fuel requirements). Under the extreme case of \$2.80/litre,<sup>15</sup> fuel costs reach up to 10% of product value for Victorian produced F&V supplied to Victorian consumers. Impact on supply chain viability depends on who the increased fuel costs are passed on to (retailer versus farmer) and current viability of these chain participants.

From Table 6.7 GHG emissions from interstate transport was about four times that for F&V grown in Victoria. Assuming fuel consumption is proportional to GHG emissions for long distance transport, one would expect fuels costs of Table 7.2 for each F&V type would be up to 40% of the farmgate value under a fuel cost scenario of \$2.8/litre, if transported into Victoria from other states. If F&V with a high fuel cost to value ratio were still transported between states under the high fuel price scenario, it would represent a significant increase in the retail price of these items.

Table 7.2. Impact of total fuel costs as a proportion of F&V value for three fuel price scenarios (based on articulated vehicles and Victorian produced and consumed F&V)

Item	Litres fuel / \$1,000 value	Cost fuel / \$1,000 value		
		\$1.20/ litre	\$2.00/ litre	\$2.80/litre
Watermelons	34.63	41.56	69.27	96.97
Oranges	34.40	41.28	68.80	96.32
Grapes	23.26	27.91	46.51	65.12
Carrots	23.07	27.68	46.14	64.59
Potatoes	19.36	23.23	38.72	54.21
Melons	18.09	21.71	36.18	50.65
Tomatoes	17.00	20.39	33.99	47.59
Sweet corn	14.66	17.59	29.32	41.05
Mandarins	12.90	15.48	25.81	36.13
Pears	12.29	14.74	24.57	34.40
Pumpkins	12.14	14.57	24.29	34.01
Onions	10.79	12.95	21.59	30.22
Beetroot	10.13	12.16	20.26	28.37
Cabbages	9.55	11.46	19.09	26.73
Peaches	7.56	9.07	15.12	21.17

<sup>15</sup> Even \$2.80 could be a moderate fuel price increase – “However, if there is a near-term peak in international oil production resulting in declining future oil supplies, petrol prices could increase to between A\$2 and as much as A\$8 per litre by 2018.” (Future Fuels Forum, 2008)

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Lettuce	7.55	9.06	15.11	21.15
Capsicums	6.95	8.34	13.90	19.46
Cauliflower	6.92	8.31	13.84	19.38
Zucchini and button squash	6.62	7.95	13.24	18.54
Parsnips	4.31	5.18	8.63	12.08
Apples	4.02	4.82	8.03	11.24
Celery	3.99	4.79	7.98	11.18
Broccoli	3.43	4.12	6.86	9.61
Cucumbers	1.81	2.17	3.62	5.07
Asparagus	1.05	1.26	2.10	2.95
Asian vegetables	0.91	1.09	1.81	2.54
Mushrooms	0.90	1.08	1.79	2.51

Table 7.3 shows the cost of fuel that would be required to transport a tonne of each fruit or vegetable type in articulated vehicles under each price scenario. This increased cost would be likely to be passed onto consumers, or present challenges to market access for some producers.

Item	T for \$1,000	Litres fuel / T	Cost of Fuel per Tonne		
			\$1.2/litre	\$2.00/litre	\$2.80/litre
Watermelons	1.71	59.30	71.16	118.60	166.04
Oranges	1.72	59.31	71.17	118.62	166.06
Grapes	1.11	25.76	30.91	51.51	72.12
Carrots	1.37	31.65	37.98	63.30	88.61
Potatoes	2.08	40.33	48.40	80.66	112.93
Melons	0.89	16.18	19.42	32.36	45.31
Tomatoes	1.90	32.38	38.86	64.77	90.67
Sweet corn	1.01	14.81	17.77	29.62	41.46
Mandarins	0.61	7.91	9.50	15.83	22.16
Pears	1.47	18.07	21.69	36.15	50.60
Pumpkins	1.50	18.23	21.87	36.46	51.04
Onions	1.06	11.43	13.72	22.86	32.01
Beetroot	2.58	26.17	31.40	52.33	73.27
Cabbages	1.04	9.95	11.94	19.90	27.86
Peaches	0.82	6.20	7.44	12.39	17.35
Lettuce	1.09	8.22	9.87	16.44	23.02
Capsicums	0.44	3.09	3.71	6.18	8.65
Cauliflower	1.40	9.69	11.63	19.38	27.13
Zucchini and button squash	0.71	4.70	5.63	9.39	13.15
Parsnips	1.01	4.37	5.24	8.73	12.23
Apples	0.48	1.94	2.33	3.88	5.44
Celery	1.05	4.20	5.04	8.40	11.76
Broccoli	0.50	1.71	2.05	3.41	4.78
Cucumbers	0.38	0.69	0.83	1.38	1.93
Asparagus	0.22	0.23	0.28	0.46	0.65
Asian vegetables	0.22	0.20	0.24	0.40	0.56
Mushrooms	0.15	0.14	0.17	0.28	0.39

## PART B. SENSITIVITY ANALYSIS

A key objective in this report was the identification of the parameters that most influence GHG emissions during the distribution of F&V. To answer this question, a sensitivity analysis is necessary to determine how “sensitive” the model is to changes in the value of the parameters of the model, and to changes in the structure of the model (Breierova and Choudhari, 2001).

A preliminary sensitivity analysis was conducted using the SCDT model to demonstrate the potential for further analysis to be undertaken using this methodology (as outlined below). The first part of the sensitivity analysis was conducted by varying input data in the SCDT to explore the impact of changing truck sizes on emissions.

However, in light of the significant data uncertainties, fuller exploration of the wide range of variables and uncertainties would require a very large number of iterations, which could not be completed within the scope of this project.

A second analysis tool, based on stochastic modelling, was developed to enable sensitivity analysis to be conducted on a wide range of variables within the timeframe and budget of this project (Sections 8 and 9).

### SCDT Sensitivity Analysis

Parameters related to the mode share and backhaul trips associated with rigid and articulated trucks were modified to examine the impact of transport modes used on the amount of emissions produced. Independent and separate changes were applied on the transport modes to examine four scenarios, namely:

1. Changing the mode share between rigid and articulated trucks, while keeping those made by LCVs constant, for trips made from NRMs to DCs and processing centres.
2. Changing the mode share between rigid and articulated trucks, while keeping those made by LCVs constant, for trips made from DCs to supermarkets and grocery stores.
3. Changing the percentage of backhaul (empty return) trips made by rigid trucks, and
4. Changing the percentage of backhaul (empty return) trips made by articulated trucks.

A summary of the implementation details and results for the four scenarios are presented in Table 7.1.

Table 7.1. Summary of results for transport mode scenarios

Scenario No.	Changes implemented on base scenario	Results over emissions from base scenario
1	In the table Q_VehPropnOfNRMtrips, increase (decrease) the “TypePropn” of rigid trucks and decrease (increase) corresponding value for articulated trucks	Emissions increased (decreased) by 5.56% for every 10% increase (decrease) in mode share of rigid trucks
2	In the table Q_VehPropnOfDCtrips, increase (decrease) the “TypePropn” of rigid trucks and decrease (increase) corresponding value for articulated trucks	Emissions increased (decreased) by 5.56% for every 10% increase (decrease) in mode share of rigid trucks
3	In the table Q_VehPropnOfBackhaulTrips, increase (decrease) the “FreqPropn” of backhaul trips for rigid trucks for both fruits and vegetables	Emissions increased (decreased) by 1.77% for every 10% increase (decrease) in backhaul pct of rigid trucks
4	In the table Q_VehPropnOfBackhaulTrips,	Emissions increased (decreased) by

increase (decrease) the “FreqPropn” of backhaul trips for articulated trucks for both fruits and vegetables	1.74% for every 10% increase (decrease) in backhaul pct of articulated trucks
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The first two scenarios examine the trade off in emissions between the use of rigid trucks versus articulated trucks in transporting F&V, while keeping the mode share of LCVs constant. The first scenario applies the trade off to trips from NRM to DCs, MMA and processing centres while the second applies the trade off to trips from DCs to supermarkets and grocery stores. The simulation results are the same for both scenarios. The results showed that each 1% switch in mode share from articulated trucks to rigid trucks increased the associated emissions from those trips by 0.556%. Thus, policies encouraging the use of articulated trucks can be expected to contribute to reduced transport emissions. This can be attributed to the fact that articulated trucks produce about half the emissions that rigid trucks produce per tonne-kilometre of FFV transported. However, emissions reduction is just one measure for assessment. Other issues relating to safety, congestion, noise pollution and access will have to be considered.

The third and fourth scenarios illustrate the importance of minimising the proportion of empty return trips made by rigid and articulated trucks in relation to forward delivery trips. The simulation results show that each 1% increase in the proportion of backhaul trips made by rigid and articulated trucks will produce a corresponding 0.17% increase in emissions from the associated trips. Consequently, reducing the proportion of empty trucks during the return leg will result in reduced emissions. This can be achieved by policies encouraging more efficient scheduling and routing of trips as well as more flexible packing and consolidation of cargoes.

## 8. Philosophy of Stochastic Modelling

Figure 8.1 illustrates the data needed to model each segment in a F&V supply chain scenario, in this case, the fresh F&V chain of a major supermarket (MSC). This figure suggests that at least 16 types of variables can affect GHG emissions in a given chain. Each of these variables can take a wide number of values and in some cases such as loading factors, the variables can have an infinite number of values between a maximum (capacity) and a minimum (capacity). The step increase required to identify the specific relation between each variable and the GHG emissions resulting from each step change makes the number of permutations required prohibitive, using a deterministic approach.

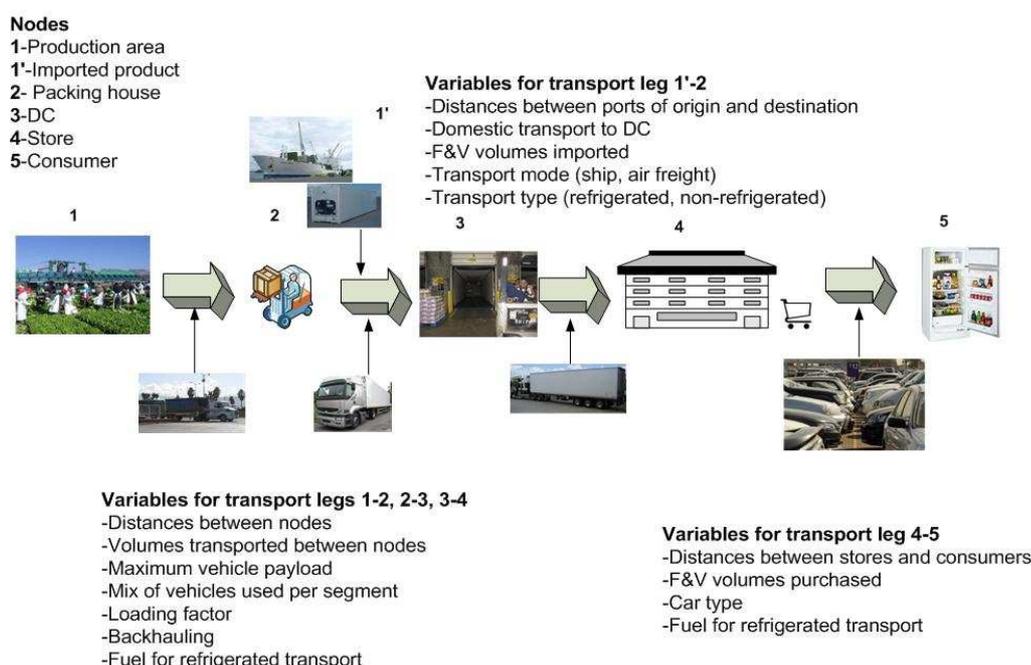


Figure 8.1. Variables affecting each segment of a MSC (fresh F&V).

On the other hand, stochastic (probabilistic) modelling allows the simulation of several variables, each one represented by a wide range of possible values. This is achieved by representing each variable as a probability distribution that realistically models the behaviour of each variable. In this way, the model accounts for every possible value that each variable could take and a weighing for each possible value is applied through the use of probabilities.

Therefore, the stochastic modelling approach was used to provide a wider picture of the key factors affecting GHG emissions for the two major supply chains (*i.e.* MSC and MM-greengrocer chains). This approach provided insights on general trends that would be difficult to generate through the use of single point (deterministic) modelling, where a single best estimate of each variable (*e.g.* fruit and vegetable volumes) is used to determine a single outcome (*e.g.* GHG emissions). The stochastic modelling has only been undertaken on the fresh F&V chains. Inclusion of processing could be a research extension.

As an example of the rationale used to develop the stochastic model, the effect of imported product going into the Victorian food chain in a particular distribution system is used in the next paragraphs.

According to DPI data (2009)<sup>16</sup>, Victoria, as the state of dispersal for imports of fresh fruit and vegetables, receives products from at least 60 countries. Further, these countries appear in the list of “country of origin” with different frequencies. Therefore, a given import could be imported from any of these 60 countries. The probabilities of shipments coming from each country listed also vary, because the number of shipments imported from each country per year is different.

To model the distance between countries of origin and the Port of Melbourne, the shipping frequency and distance between each country listed and any Australia port were converted into a discrete distribution, using ModelRisk<sup>17, TM</sup>. Similar approaches were used to model other input variables, as shown in Table 8.1.

Table 8.1. Stochastic modelling of input variables.

TYPE OF F&V CHAIN	TYPE OF VARIABLE	TRANSPORT NODE	STOCHASTIC DISTRIBUTION
MSC	Distance (km)	Farm →Packing house	D~N(15,5)
		Packing house →DCs	D~D(x <sub>i</sub> ,p <sub>i</sub> ) where x= distance from each growing region(i) and P= probability for each growing region (i)
		Country of origin→DCs	D~D(x <sub>i</sub> ,p <sub>i</sub> ) where x= distance from each import country (i) and P= probability for each country (i)
		MM→DCs	D~D(x <sub>i</sub> ) where x= distance from MM to each DC (i), with equal probabilities per DC.
		Interstate→DCs	D~D(x <sub>i</sub> ,P <sub>i</sub> ) where x= distance from interstate entry points to each DC (i and P= probability for each state (i)
		DCs→MSC stores	D~D(x <sub>i</sub> ) where x= distance from DCs to each store (i), with equal probabilities per store.
		MSC stores→consumers CDs	D~D(x <sub>i</sub> ,p <sub>i</sub> ) where x= distance from each store (i) and P= probability for each CD as per population(i)
MM		Packing house →MM	D~D(x <sub>i</sub> ,p <sub>i</sub> ) where x= distance from each growing region(i) and P= probability for each growing region (i)

<sup>16</sup> Data provided by J. Creese, DPI Strategic Market Analysis officer.

<sup>17</sup> Vose Software, Belgium. <http://www.vosesoftware.com/>

		Country of origin→MM	$D \sim D(x_i, p_i)$ where $x$ = distance from each import country (i) and $P$ = probability for each country (i)
		Interstate→MM	$D \sim D(x_i, P_i)$ where $x$ = distance from interstate entry points to MM (i and $P$ = probability for each state (i)
		MM→greengrocer stores	$D \sim D(x_i, )$ where $x$ = distance from MM to each store (i), with equal probabilities per store.
		GG stores→consumers CDs	$D \sim D(x_i, p_i)$ where $x$ = distance from each store (i) and $P$ = probability for each CD as per population(i)
Both	Loading capacity (tonnes)	DC/MM→supermarket/ greengrocer stores	LCV~PERT(0,0.4,2) Rig_2x~PERT(0,6,13) Rig_3x~PERT(0,11.5,23) Art_1~PERT(0,22.5,40) Art_B2~PERT(0,27.5,55)
	% backhauling	All	LCV~PERT(25,35,50) Rig_2x~PERT(33,50,66) Rig_3x~PERT(33,50,66) Art_1~PERT(33,50,66) Art_B2~PERT(33,50,66)
	Container power consumption for refrigeration (kW)	Country of origin→DCs	PERT(1,4,9)
	Fraction of refrigerated cargo	All	PERT(0,0.5,1)
	Emissions factor as a function of various car sizes (g CO <sub>2</sub> /km)	stores→consumers	PERT(180.9,213.9,295.8)
	Number of consumer trips	stores→consumers	PERT(44.2,88.4,176.8)
MSC	Volumes (tonnes)	Farm →Packing house	$V \sim \text{PERT}(V_s * 0.5, V_s, V_s * 1.5)$ where $V_s$ = production volume for the fresh supermarket channel in 2008
		Packing house →DCs	Varies as a function of the previous volume
		Country of origin→DCs	$V \sim \text{PERT}(V_i * 0.5, V_i, V_i * 1.5)$ where $V_i$ = imported volume of fresh F&V for supermarkets in 2008
		Intestate→DCs	$V \sim \text{PERT}(V_p * 0.5, V_p, V_p * 1.5)$ where $V_p$ = Victorian production volume of fresh F&V in 2008.
		DCs→MSC stores	Varied as a function of the previous volume
		MSC stores→consumers CDs	Varied as a function of the previous volume
MM	Volumes (tonnes)	Packing house →MM	$V \sim \text{PERT}(V_m * 0.5, V_m, V_m * 1.5)$ where $V_m$ = production volume for the fresh Melbourne Market channel in 2008
		Country of origin→MM	$V \sim \text{PERT}(V_i * 0.5, V_i, V_i * 1.5)$ where $V_i$ = imported volume of fresh F&V for MM in 2008
		Intestate→MM	$V \sim \text{PERT}(V_p * 0.5, V_p, V_p * 1.5)$ where $V_p$ = Victorian production volume of fresh F&V in 2008.
		MM→greengrocer stores	Varied as a function of the previous volume
		GG stores→consumers CDs	Varied as a function of the previous volume

As per Table 8.1, a total of 37 input variables were considered. Sixteen outputs were obtained for the model, consisting on the GHG emissions per segment of each chain –that is, seven segments for the MSC chain and six segments for the MM chain– the GHG emissions for the total of each chain and the GHG emissions as the sum of the MSC and MM chains. As discussed before, these chains are likely to be the most significant contributors to the emissions generated by F&V distribution.

On the basis of Table 8.1, a comparison of the SCDT model and the stochastic model is presented in Table 8.2. Essentially, all the distances used for the stochastic model were extracted from the SCDT. The stochastic representation of these distances and volumes, and some assumptions indicated in Table 8.2 are the key points of difference between the two approaches.

Table 8.2. Comparison of assumptions made for the deterministic model and the stochastic model

<b>Assumption</b>	<b>Deterministic</b>	<b>Stochastic</b>
Vehicle types per segment	Constant mix of vehicles (LCV, rigid trucks, articulated trucks)	Mix of vehicles (LCV, rigid 2 axles, rigid 3-axles, articulated long haul and articulated B-double)
Payload per vehicle type	One load capacity (average payload)	Different loading capacities between a minimum and the maximum capacity per vehicle
Fuel consumption	Constant – independent of load	Variable and dependent on loading capacity used.
Backload per segment	Constant	Variable
Emissions from ship (imported product)	Calculated as per road analysis, with constant emission factors	Multiple assumptions to calculate emissions.
Emissions from refrigeration	Weighting by fuel factor	Factor combining fuel and motion
Volumes of fruit and vegetables	Mass per product type is distinguished	No distinction between product types (lumped volumes of F&V)
Consumer transport (from shops to CD)	100% of trip emissions attributed to F&V for grocery stores, 7.25% for supermarkets (CHOICE basket used)	Healthy Food Basket used. 30% of trip emissions attributed to F&V for both grocery and supermarket trips.
	Fixed number of trips	Variable number of trips
Scale	Individual trips and ABS CCD's	Aggregated over all supermarkets and grocery store trips

## **8.1. Model development**

The details of the model development are presented in Appendix B. The appendix includes:

- a visual representation of the probabilistic distributions presented in Table 8.1;
- the equations used to model the number of vehicles and the mix of types of vehicles;
- the calculation of fuel consumption as a function of percentage loading per type of vehicle;
- the model used for backhauling;
- the calculation of fuel used for shipping and refrigerated containers;

- the calculation used for refrigeration during road transport;
- the model used for the ‘last mile’ (consumer transport);
- the calculation of emissions per segment and total emissions per type of chain (MSC and MM).

## 8.2 Scenarios modelled

As indicated in Table 8.1, the effect of each of the transport legs in the diagrams for MSC and MM (Figures 8.2 and 8.3, respectively) were modelled. Only these two major chains were developed, given that supermarkets and greengrocers cumulatively account for 97% of the total fresh F&V trade. Further, only fresh product was considered. As previously discussed in the development of the deterministic model, the additional GHG emissions from the distribution of processed F&V are relatively small compared to the fresh trade, based on the assumptions of minimal transport directly to closest processors etc.

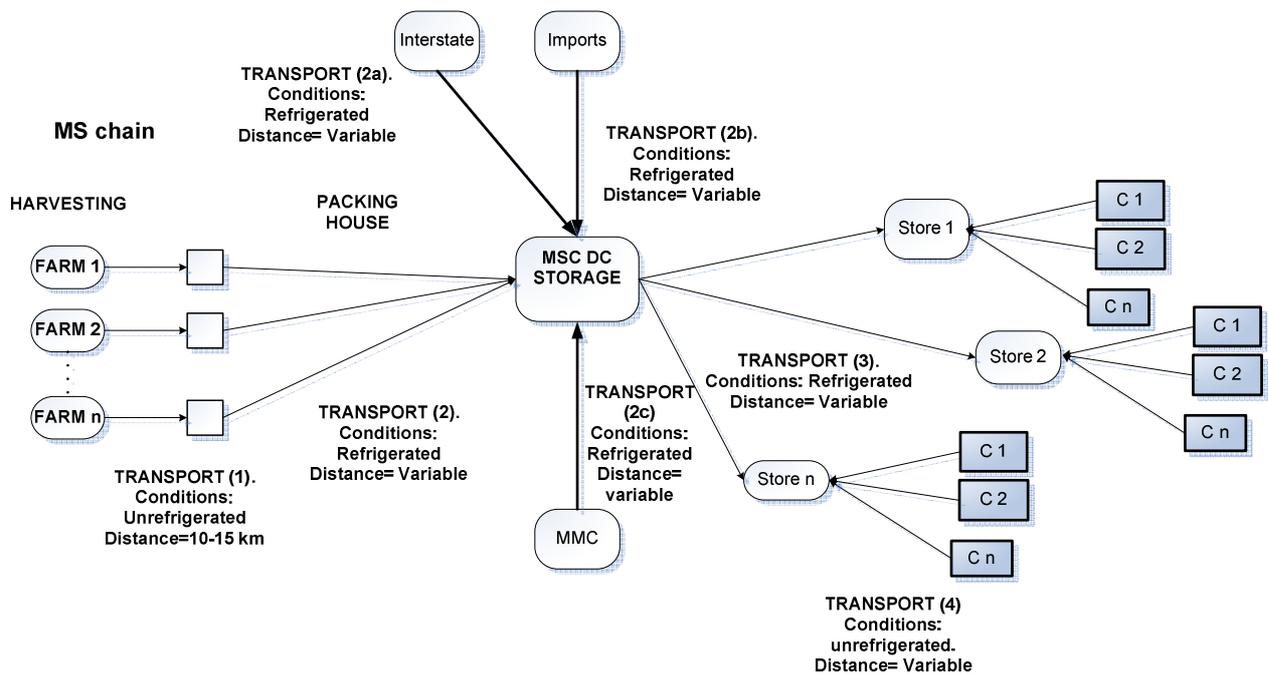


Figure 8.2. Schematic representation of MSC.

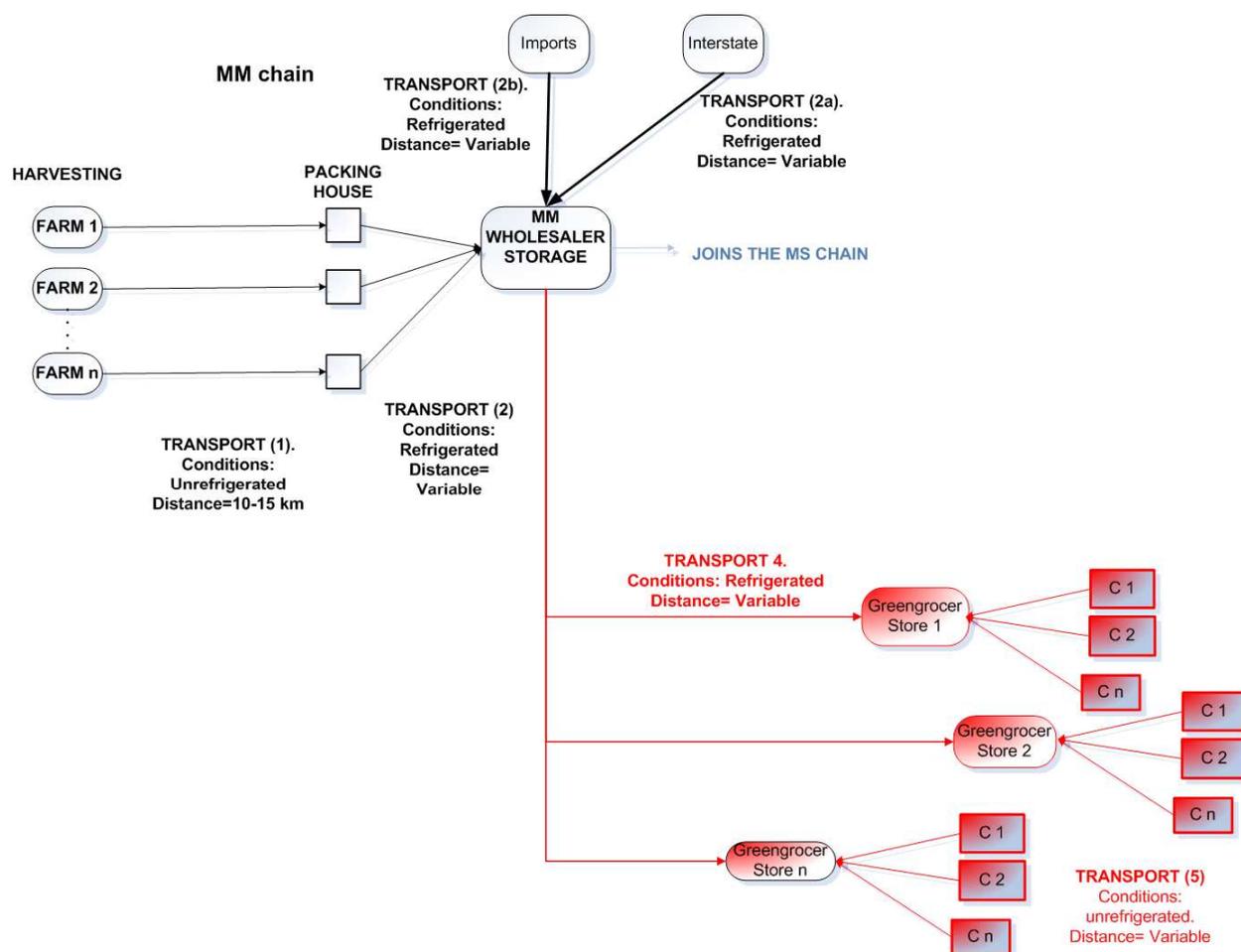


Figure 8.3. Schematic representation of MMC.

The operations and key assumptions per transport segment in Figures 8.2 and 8.3 are described below.

### Transport type assumptions:

1. During the farm-to-pack house segment, it is likely that transport is carried out through non-refrigerated (flat bed or side liner) trucks. It was assumed that all transport for this segment occurs in rigid, non-refrigerated 2 axle vehicles.
2. During the pack house-DCs/MM and interstate to DCs/MM segments, it is assumed that the trucks used are rigid (2 and 3 axles) and articulated (long haul and B-doubles).
3. From the Port of Melbourne-to-DCs/MM, a combination of LCVs (light and heavy), 2-axle and 3-axle rigid, semi-trailers and B-doubles is assumed.
4. From MM to DCs and MM/DCs-to-stores segments, a combination of LCVs (light and heavy), 2-axle and 3-axle rigid and articulated semi-trailers is assumed. B-doubles are restricted to certain routes and unable to travel through many urban areas. Therefore they mainly go to freight terminals (import, export and interstate focus) but cannot be used to move large loads between DCs and stores.
5. From shops to consumers' households, a range of vehicles need to be considered. This is further considered in the calculation of emissions factors for the consumer link (see Appendix B). Backhauling is investigated in the context of road transport only (i.e. imports backhauling is not analysed).

### Refrigerated transport assumptions

For vegetables and fruit, 60% and 48% of the total vegetable tonnage produced per year in Victoria is expected to be transported under refrigeration, respectively.

**Assumptions for shipping emissions:**

1. All imported product is transported in 20 ft refrigerated containers powered with mobile diesel generators, which in turn use marine diesel oil (MDO).
2. Each container can carry 21 tonnes of products. Normally, all containers are used at full capacity.
3. These units have a specific fuel consumption of 280 to 330 g/kWh. An average of 300 g/kWh was used.
4. The actual power consumption (kW) used per container vary widely and according to the type of container, the type of cargo and several other factors. In order to account for these variations, a VosePert model was introduced to model this variable, using a minimum of 1 kW (typical of chilled products with minimum temperature maintenance requirements) to 9 kW (typical of tropical fruit, with high temperature maintenances requirements)<sup>18</sup>.
5. The emissions factor for MDO used was 3.206 g CO<sub>2</sub>-e/g fuel (EnSys Energy & Systems Inc., 2007).
6. An average speed of 20.5 knots (or 38 km/h) was considered (Stopford, 2009).
7. The DEFRA’s values for marine freight transport (AEA, 2008) were used, where the emissions factors for small and large container vessels are 15 and 13 g CO<sub>2</sub>-e per tonne per km. An average of 14 g CO<sub>2</sub>-e/t km was used.

Other assumptions are presented in Table 8.3.

Table 8.3. Links, operations and responsible party for each of these in MSC and MM chains.

Link	Operations and assumptions
Harvesting	F&V are harvested and placed into large bins <sup>19</sup>
Transport 1	F&V are transported to packing house. On the basis of the information provided in submissions to the ACCC (Australian Competition and Consumer Commission, 2008), it is thought that very few growers own long distance transport vehicles. Most growers will hire a 3PL to transport their goods to supermarkets. From the farm-to-pack house segment, it is assumed that transport is carried out through non-refrigerated (flat bed or side liner) trucks. It is also assumed that all transport for this segment occurs in rigid, 2 axle vehicles. The opportunities for loading in return in this segment are small. Therefore, in this segment, the loading % for all types of trucks is set to zero.
Packing House	F&V are packed into 12 kg cartons or ‘one touch’ crates. Packing made on-site (in the case of large integrated grower/packers) or by a third party when the grower does not operate its own facility.
Transport 2	Packed F&V are transported directly to the DC/MM using trucks that can fit 12 pallet or 22 pallet. It is assumed that the trucks used are rigid (2 and 3 axles) and articulated (long haul and B-doubles). The percentages used per type of vehicle were derived from ABS data, which shows that rigid and articulated trucks carry 25.5% and 71.7% of the tonnes of food carried.  It is also assumed that trucks are dispatched empty to collect the product from nearby depots and that there is a high backhauling component, as part of 3PLs strategies to minimize costs. On the basis of Hassall (2003), it is estimated that the loading % ranges between 33% and 66% for rigid and articulated trucks, respectively. For rigid and articulated trucks (all types), between 33% and 66%.
Transport 2a, 2b and 2c	For MSC: (2a) applies to interstate trade flows entering Victoria, (2b) applies to imports of fresh fruit and vegetables to DCs; (2c) applies to transport from MM to supermarkets.  For MM: (2a) applies to interstate trade flows entering Victoria through MM, (2b)

<sup>18</sup> www.thermoking.com/aboutus/tradepubs/2040/2040summer08.pdf

<sup>19</sup> Aprox. external dimensions= 1165mmx1165mmx730mm. Cubic capacity=755 L (about 0.5 tonnes).

	<p>applies to imports of fresh fruit and vegetables to MM; (2c) applies to transport from MM to supermarkets,</p> <p>Backhauling for LCVS was assumed to range between 25% and 50% (Hassal, 2003).</p> <ul style="list-style-type: none"> <li>• From Melbourne Markets to DCs, backhauling is considered to be minimal. Therefore, the loading % is set to zero.</li> </ul>
Supermarket DC	Pick & pack for distribution to stores.
Transport 3	Distribution from DCs to stores, backhauling is considered to be minimal. Therefore, the loading % is set to zero.
Stores (S1...Sn)	Display of F&V
Transport 4	From shops to consumers' households, a range of vehicles need to be considered. The consumer's contribution is in the form of a 2-way travel. The total number of consumer vehicles is calculated by multiplying the trips per household (88.4) by the total number of households (1,294,450) considered in the analysis. The result is multiplied by the distances between households and the nearest supermarket ( $D_{s,c}$ ) and by the corresponding emissions factor. As mentioned in the backhauling section, the GHG emissions are doubled to include the travel on the 2-way travel incurred by consumers.
Consumer households (C1...Cn)	Consumption. In the attribution of the 'last mile' emissions, the fact that consumers shop for a mix of products (and not only fruit and vegetables) was to be taken into account through the use of a factor weighting the proportion of fresh F&V purchased by the consumer per trip. To build this factor, the contents of the Victorian healthy food basket proposed by Palermo et.al. (2007) were used to calculate a weight proportion of purchased fresh fruit and vegetables. All the basket comprises an average 30% of <b>fresh</b> F&V. Therefore, the emissions in the consumer segment were multiplied by a factor of 0.3.

A major assumption in Figure 8.3 is that all fresh F&V destined to be sold via greengrocers is sourced from Melbourne Markets. Therefore, channels where shipments from farms bypass MM and are distributed by wholesalers not located in Melbourne are ignored. Another case is brokers buying directly from farmers to later sell the produce to greengrocers. However, about 63% of all vegetable growers in Victoria sell vegetables through wholesalers located in Melbourne Markets, with an average 53% of vegetable revenue received through that outlet. The other major channels are selling direct to a processor and selling direct to retailers were other highly used outlets, producing 14% of revenue each (Crooks, 2009). Therefore, channels other than MSC, processors and MM represent less than 20% of the total trade.

The baseline scenario in terms of volumes per segment used is presented in Figure 8.4.

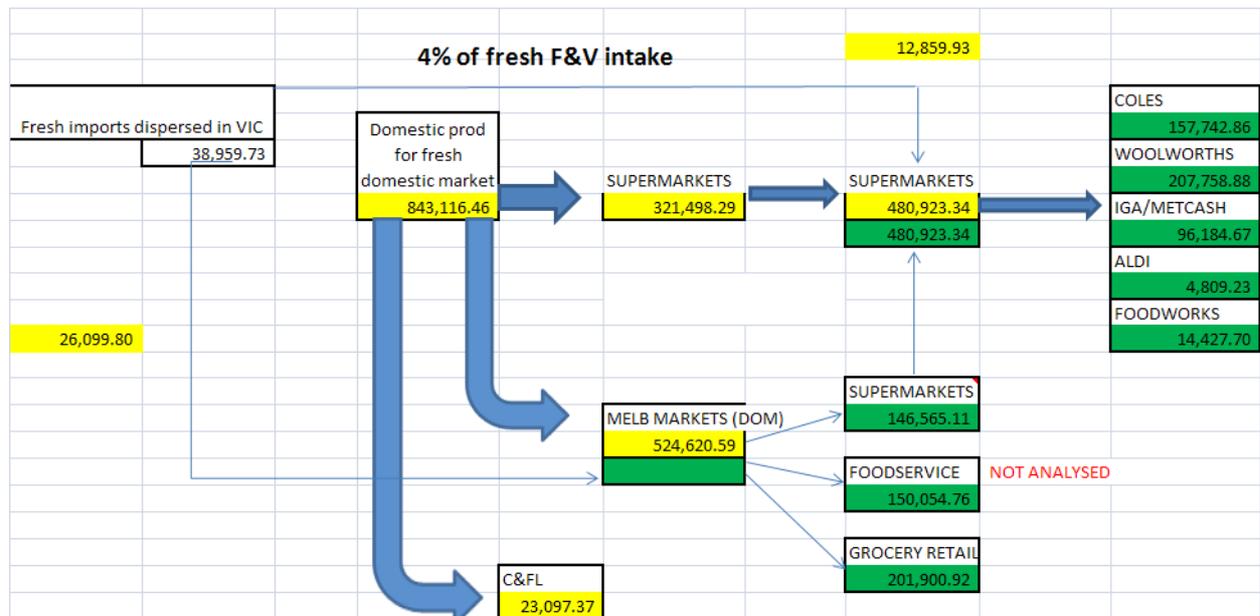


Figure 8.4. Baseline scenario showing the mass flows of fruit and vegetables (in tonnes) channelled through major supermarket chains (MSC), Melbourne Markets and other food distribution systems initiatives (e.g. farmers' markets, direct grower-consumer channels).

The baseline scenario takes into account products entering the fresh domestic Victorian chain only. Therefore, only import and interstate trade flowing into Victoria are considered.

## 9. Results from the Stochastic Analysis

A separation between the results from farm to fork (*i.e.* including the consumer contribution) and the results for commercial operations required to distribute products to stores (farm to store) was deemed necessary, to highlight opportunities of reduction in both cases.

### 9.1. Sensitivity analysis from farm to fork

This analysis takes into account all the links in the chain, including consumer travel.

Figures 9.1.1 and 9.1.2 present the maximum, mean and minimum GHG emissions for each link of the MSC chain, in the scenarios tested.

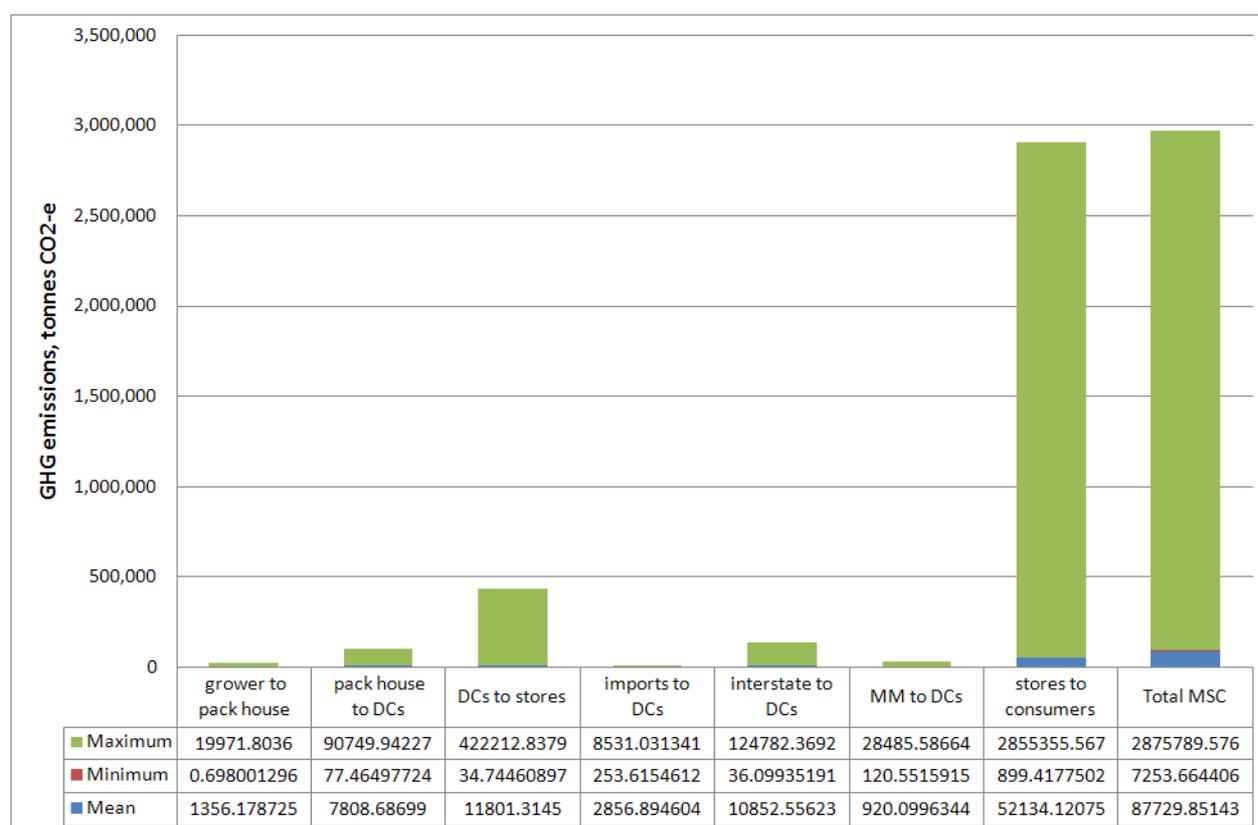


Figure 9.1.1. Maximum, mean and minimum GHG emissions (tonnes CO<sub>2</sub>-e) for each link of the MSC chain, using the variations of Table 8.1 for the sensitivity analysis.

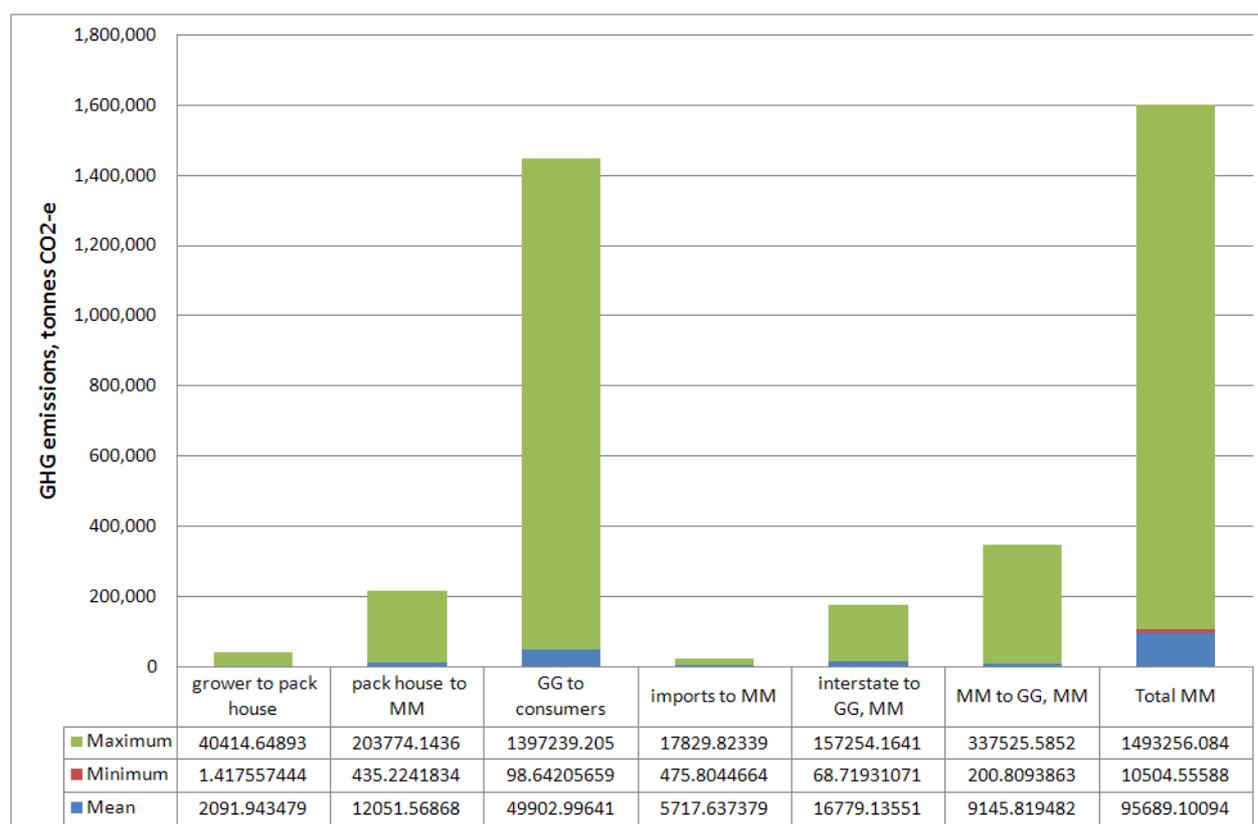


Figure 9.1.2. Maximum, mean and minimum GHG emissions (tonnes CO<sub>2</sub>-e) for each link of the MM chain, using the variations of Table 8.1 for the sensitivity analysis.

In Figures 9.1.1 and 9.1.2, the maximum GHG emissions can be interpreted as *the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria*. This maximum contribution is based on the potential values that all variables analysed can take within realistic supply chain conditions, as specified in Table 8.1.

In this context, the segments that had the maximum potential in MSC chains (Figure 9.1.1) were (in descending order of importance): transport of F&V from stores to consumers’ households, transport from DCs to stores and interstate transport to DCs. In the MM chains (Figure 9.1.2), the segments that had the maximum potential were (in descending order of importance): transport of F&V from greengrocers to consumers’ households, transport from MM to greengrocers and transport from pack houses to MM.

Figure 9.1.3 shows a comparison of average GHG emissions calculated for MM and MSC chains. Overall, the MM chain led to slightly higher GHG emissions averages than MSC chains. MM chains present higher emission averages in all comparable segments, except consumer travel.

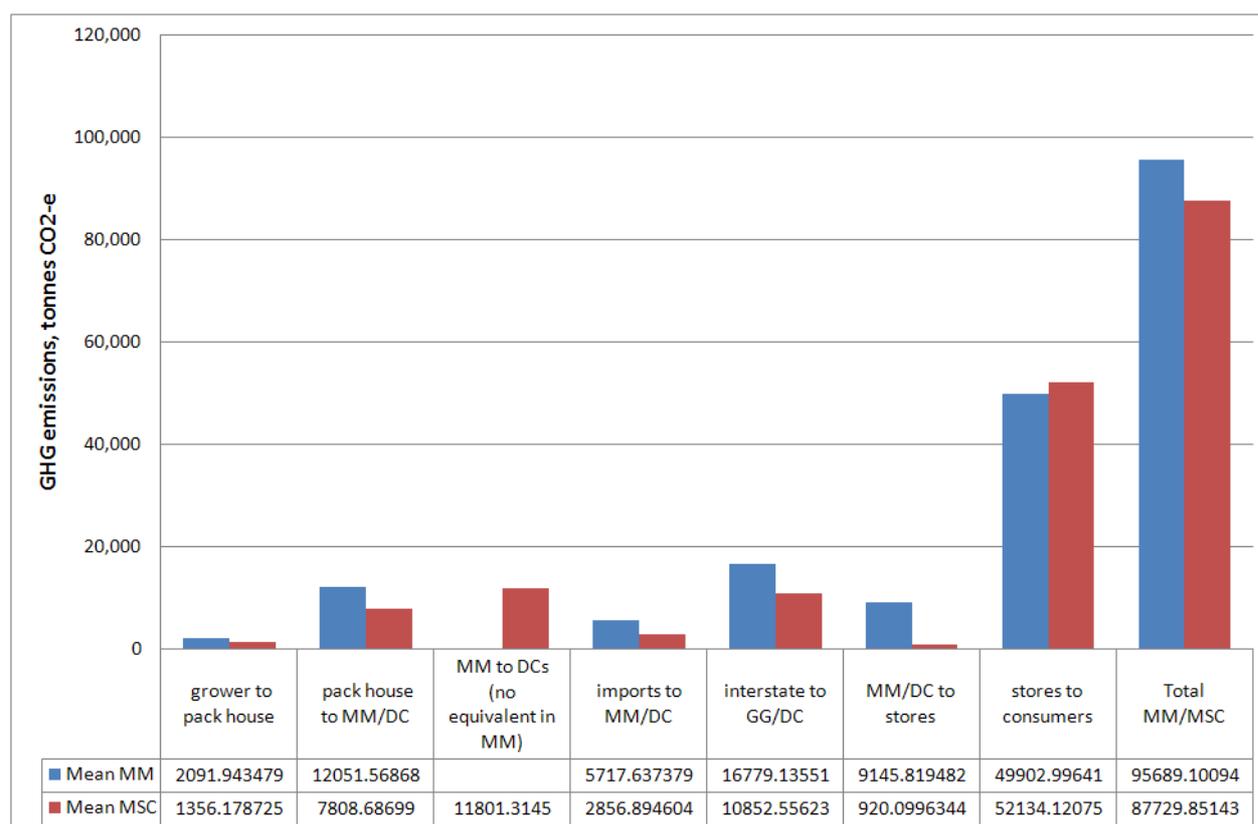


Figure 9.1.3. Comparison of average GHG emissions expected from each link of the MSC and MM chains.

Figures 9.1.4 and 9.5 show tornado charts, illustrating the input variable of major influence in the total GHG emissions of MSC and MM, respectively.

In general, the higher the rank correlation (either positive or negative), the more influence a variable has on the results. Correlations of less than 0.3 (either negative or positive) are small and can reflect spurious results, e.g. stating a correlation between unrelated factors. Therefore they have been ignored.

Further, a positive correlation means that when the variable is large, the results (e.g. emissions) are also large. Conversely, a negative correlation means that when the variable is large, the results are small.

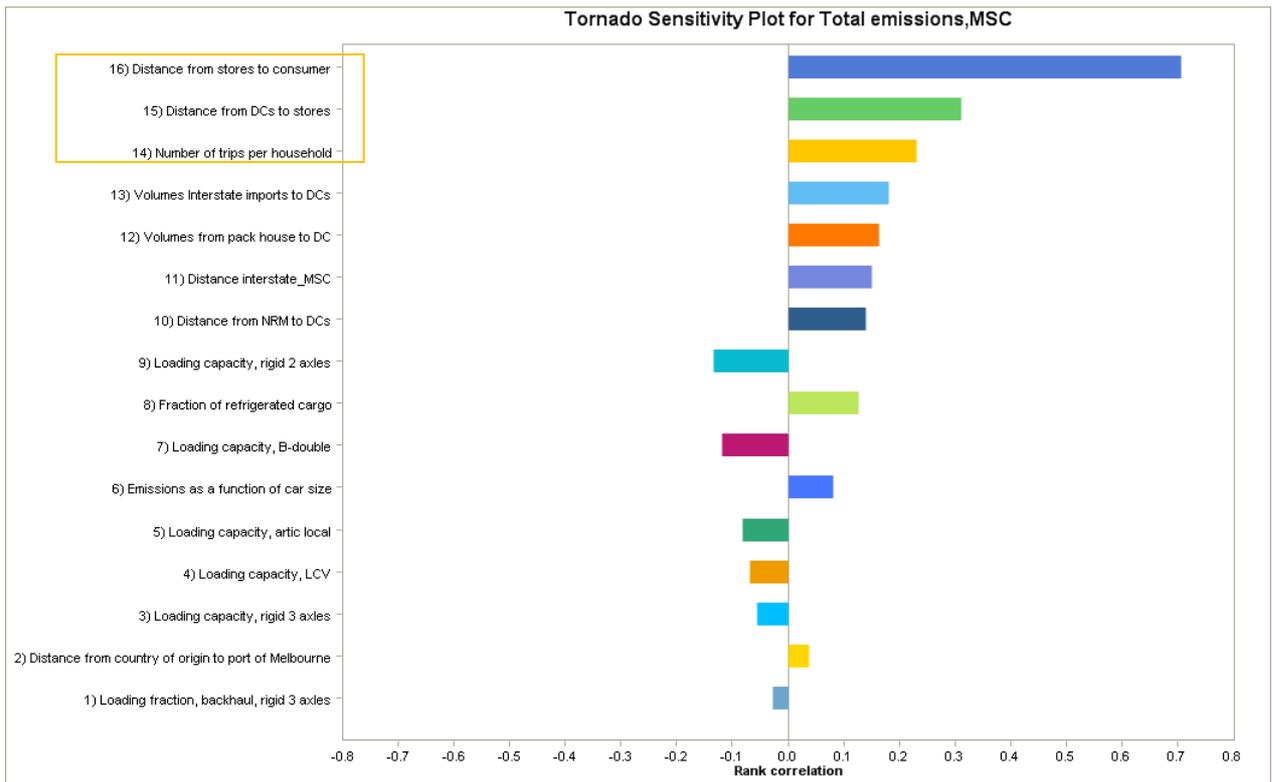


Figure 9.1.4. Tornado sensitivity plot for MSC.

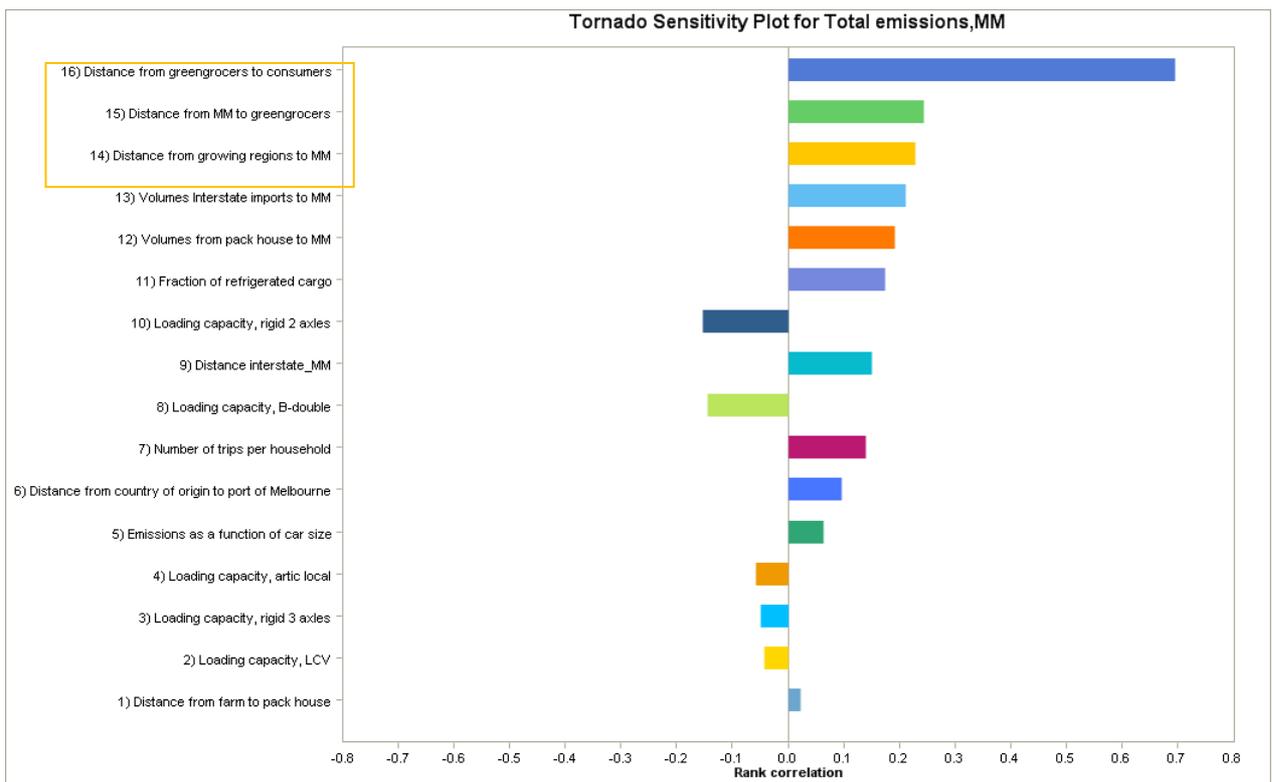


Figure 9.1.5. Tornado sensitivity plot for MM.

Figures 9.1.4 and 9.1.5 indicate that the input factor with major influence on the GHG emissions of both chains are the distance from supermarket and greengrocer stores to consumers. Distances from DCs and MM to stores ranked as the second most important factor.

To further investigate the correlation between the factors of influence and emissions, spider plots showing the relationship between the changes in the major factors of influence and the resulting GHG emissions are presented in Figures 9.1.6 and 9.1.7 for MSC and MM, respectively. These results reflect the total GHG emissions from each chain.

In the spider plots, sensitivity analyses on the ‘Average GHG emissions’ output were performed by splitting up simulation data from input distributions into ten groups, in terms of their cumulative probability ( *i.e.* 0%-10%, 10%-20%, 20%-30%, ..., 90%-100%).

The simulation data was filtered for each of these groups to find the corresponding output values that occurred when the input variable being analysed lies within each percentile band listed above. The average GHG emissions are then calculated for the filtered data. The spider plot is produced by repeating this analysis across each of the ten groups for each selected input variable. The red horizontal line indicates the average of all simulation runs.

In general, the closer the plotted line is to a vertical position, the more influence the variable has on the output. Conversely, if the plotted line is close to a horizontal position (and close to the red line) the influence of the variable on the output is of a lesser significance.

Figures 9.1.6 and 9.1.7 show that the relationships between the distances travelled by consumers to reach their nearest supermarket / greengrocer and the resulting average GHG emissions were non-linear. For example, a change from an average distance of 5.6 km to 31.2 km to reach the nearest supermarket occurs in the last percentile (*i.e.* 90 to 100%). This jump reflects the fact that, while 80% of the distances between stores and consumers are below 5.5 km, the remaining 20% represents distances above this limit. This aspect is further discussed in Appendix E.

The rest of the variables show a relatively linear fashion.

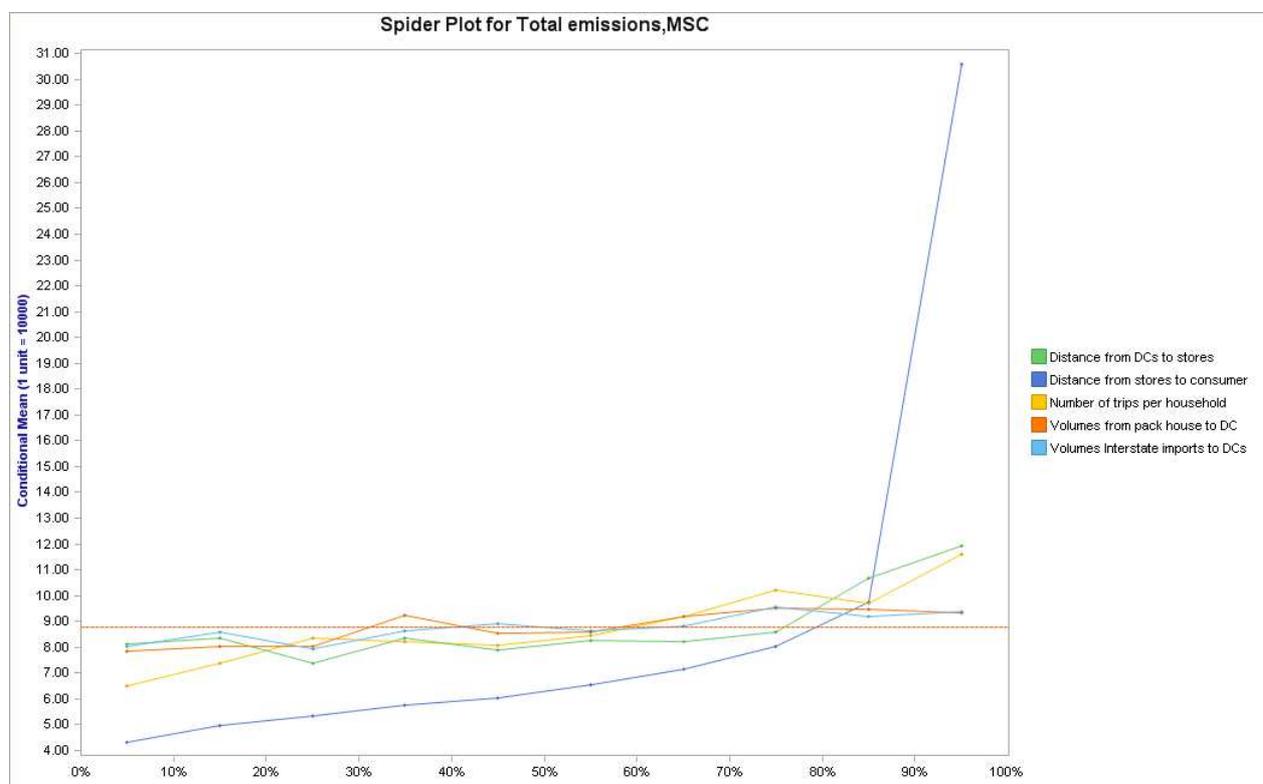


Figure 9.1.6. Spider plot showing the relationship between percentile changes of the major factors of influence and the resulting average GHG emissions in MSC.

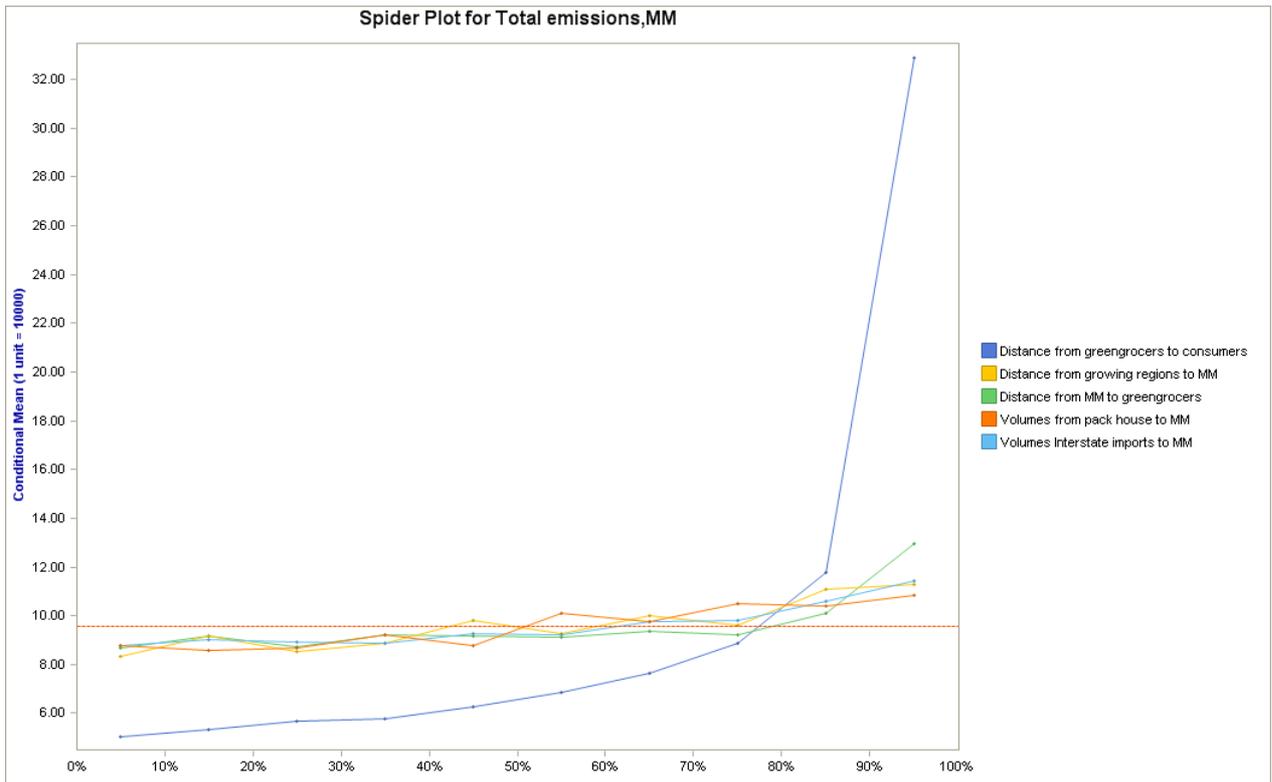


Figure 9.1.7. Spider plot showing the relationship between percentile changes of the major factors of influence and the resulting average GHG emissions in MM.

Figure 9.1.8 presents the spider chart for the total GHG emissions resulting from the sum of MSC and MM. Only the distances to supermarkets and greengrocers showed rank correlations higher than 0.4, which indicates their relative higher significance than other factors of influence.

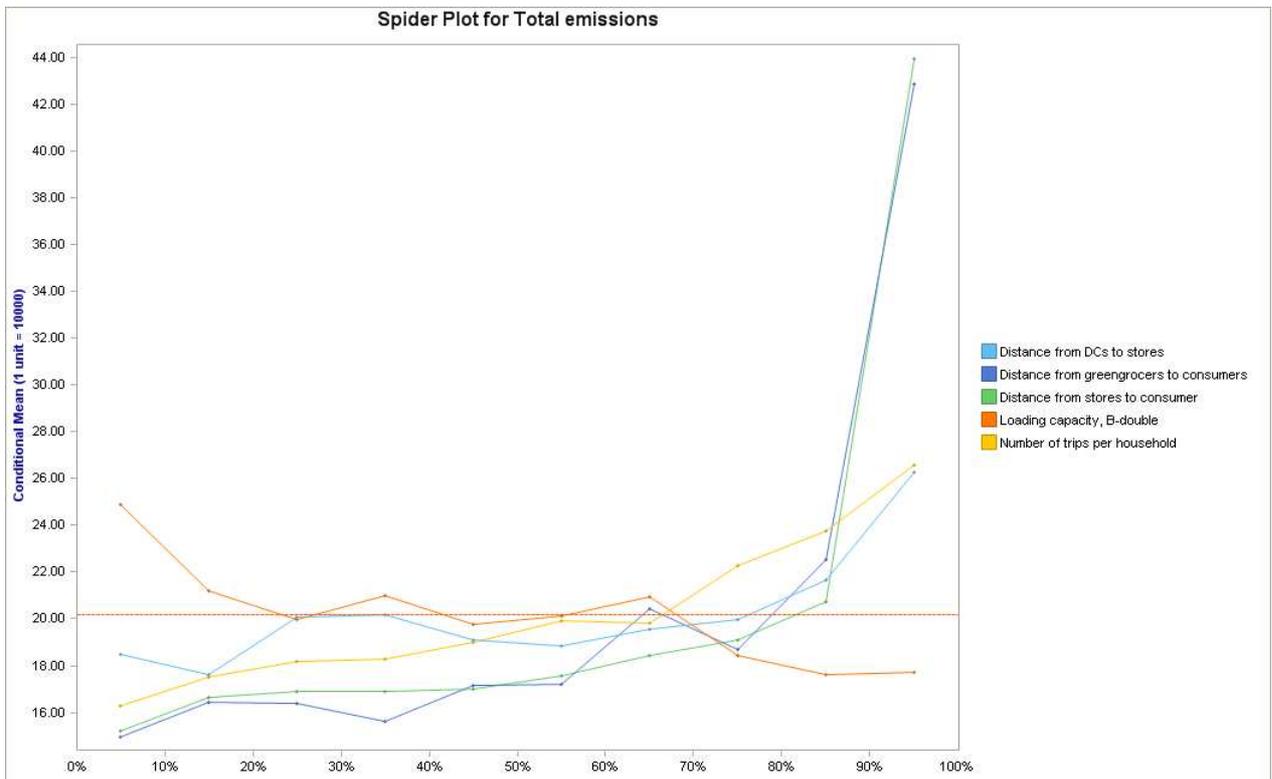


Figure 9.1.8. Tornado sensitivity plot for Total Emissions (MSC+MM).

Figures 9.1.9 and 9.1.10 show the spider plots with the top three factors affecting GHG emissions resulting from consumers travelling to MSC and greengrocers, respectively. This figure agrees with the discussion of Figure 9.6, in regards to the large effect of the last percentile and its relationship with the percentage of Victorian population living outside a radius of 5 km from the nearest supermarket. This point is further discussed in Appendix E.

These figures also highlight the fact that GHG emissions from consumers travelling to supermarkets are almost identical to the emissions from consumers travelling to greengrocers, despite the fact that the shopping frequency to supermarkets is twice the number of visits to greengrocers. Histograms C1.7 and C2.6 in Appendix C provide the estimated footprint of the consumers segment in MSC and MM chains, respectively. It is worth remembering that these estimates include a 30% factor for attribution of transport emissions to the proportion of F&V in the Healthy Food Basket model (Palermo et al., 2007). When the total basket is considered, the total carbon footprint of consumers travelling to shops is more significant, as discussed in Appendix E.

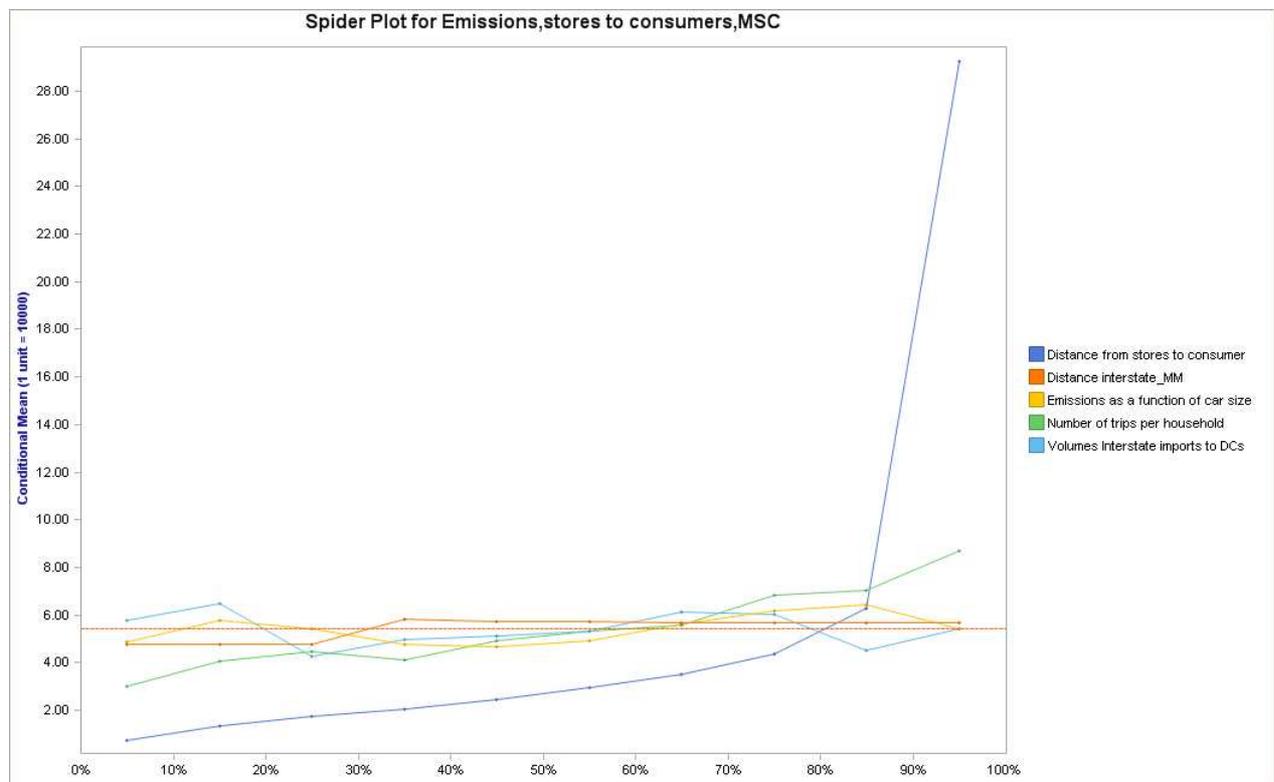


Figure 9.1.9. Spider plot showing the relationship between percentile changes of the major factors of influence and the resulting GHG emissions in consumer travel to supermarket stores.

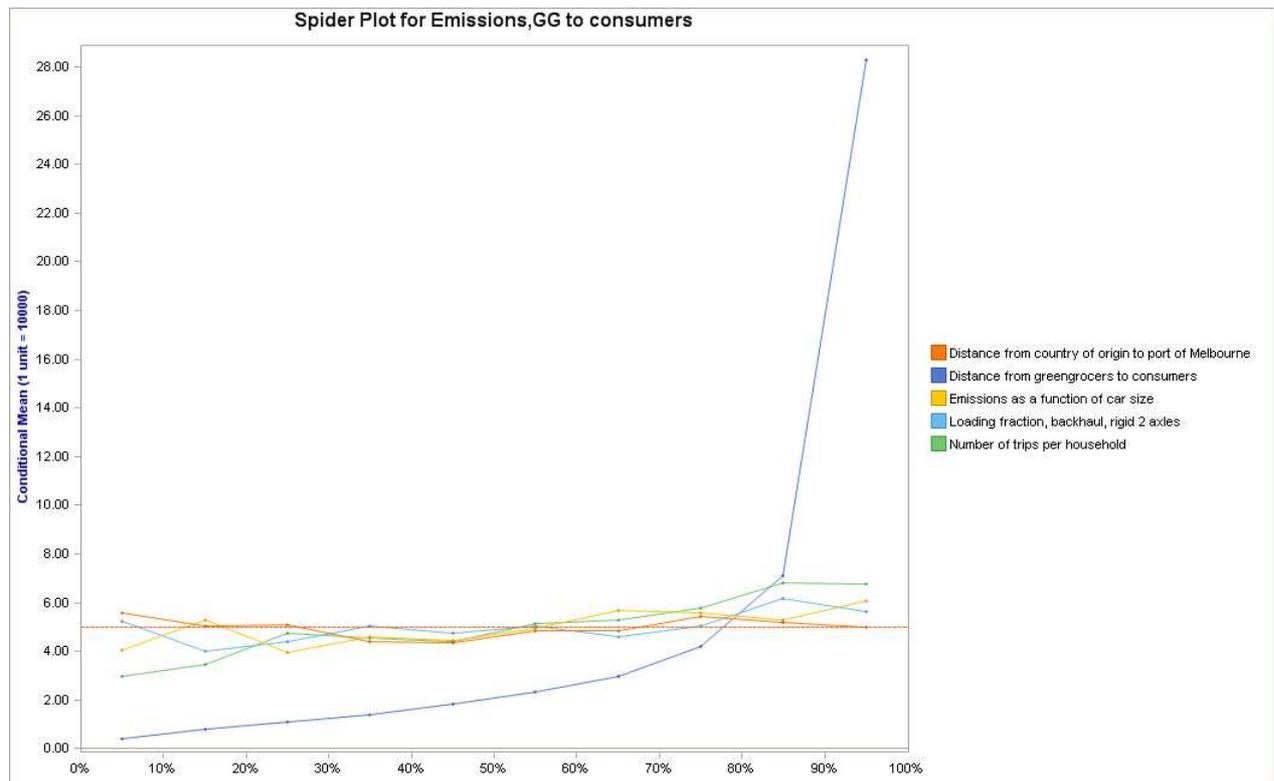


Figure 9.1.10. Spider plot showing the relationship between percentile changes of the major factors of influence and the resulting GHG emissions in consumer travel to specialised F&V stores.

The cumulative GHG emissions of MSC and MM chains are presented in Figure 9.1.11. The calculated carbon footprint from farm-to-fork distribution of fresh F&V consumed in Victoria and sold through greengrocers and supermarkets is likely to fall within 82,214 and 318,976 tonnes CO<sub>2</sub>-e. Rather than reflecting the resolution of the stochastic approach, this wide range relates to the degree in which changes in the variables selected (as per Table 8.1) affect the resulting distribution emissions. As the values of variables are refined (i.e. the variability is decreased), it should be expected that the resulting GHG emissions group closer to a mean value.

Given the importance of the consumer segment, the decrease in the uncertainty of variables that affect consumer travel would lead to this outcome. For example, more accurate estimations on the number of consumer travels, shopping habits and basket share of fresh and processed fruit and vegetables in trips to supermarkets and greengrocers. In this report, the travel intensity was based on a weekly average of 1.7 shopping trips per Australian household. This number was extracted from Metcash (2008) citing a 2007 value provided by AC Nielsen. From this value and also based on data released by Metcash, it was assumed that consumer travel to greengrocers is approximately half the number of trips to supermarkets (for a discussion on this subject see Appendix E). However, a 2010 value reported by Freshlogic<sup>20</sup> indicates that the weekly average could be as high as 4 trips to supermarkets or greengrocers.

Uncertainty on consumer trips was the reason to select the number of travels to stores as a variable for the sensitivity analysis of MSC and MM chains. Given that this factor ranked among the five most influential variables in both chains, increased accuracy on this estimate would deliver more accurate carbon footprints of consumer travel. Also, the percentage of F&V (30% in the Victorian healthy food basket and 7% in the CHOICE basket) significantly impacts the carbon footprint. Until such estimates are released, it is difficult to present a more accurate estimate of GHG emissions during farm-to-fork distribution of food.

<sup>20</sup> Freshlogic (2010). Veginsights: the market-Q4 09. A vegetable market platform analysis plus a profile of the three-month period ending 31 Dec 2009. Page 27.

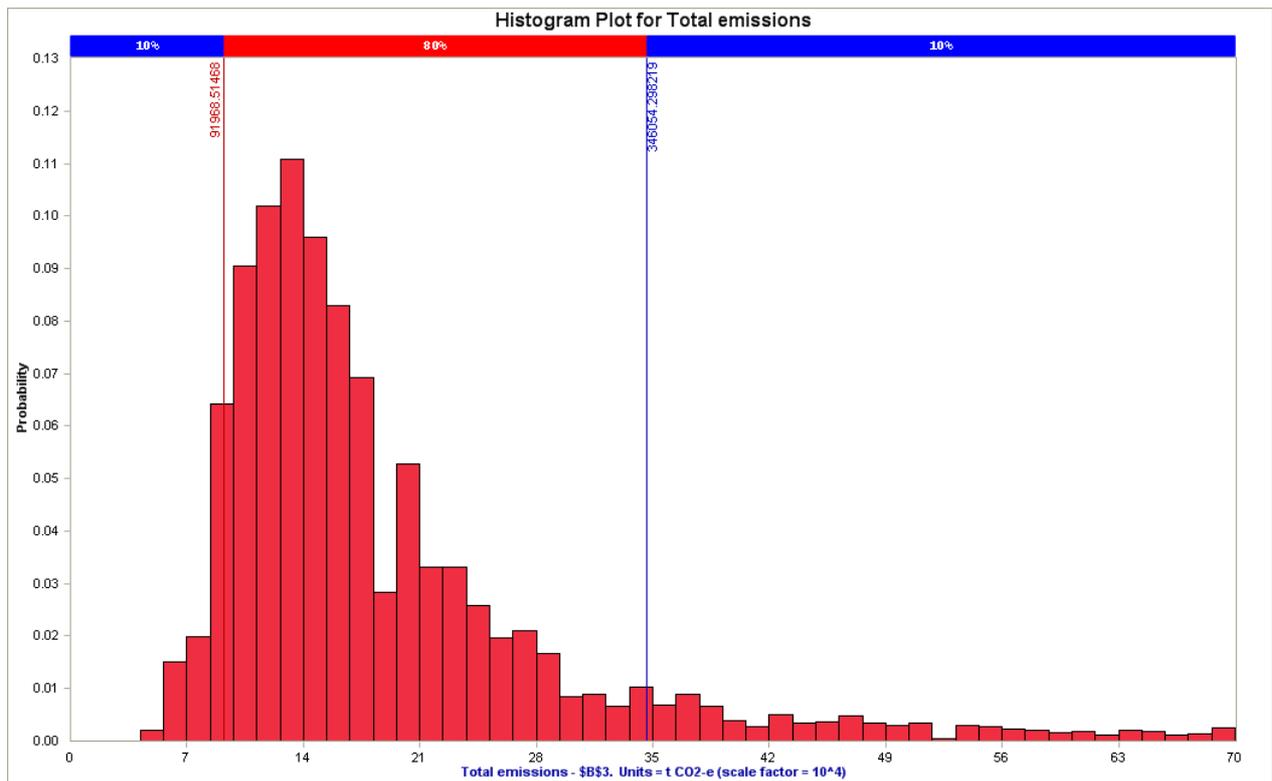


Figure 9.2.11. Histogram showing the distribution of potential GHG emissions arising from fresh F&V distribution through both MSC and MM chains in Victoria (from farm to fork). There is an 80% probability of the emissions falling within 91,969 and 346,054 t CO<sub>2</sub>-e/year.

Appendix C presents the histograms of GHG emissions expected for each link of the MSC and MM chains. Appendix D shows the spider plots for each segment of the MSC and MM chains.

## 9.2 Sensitivity analysis from farm to store

This analysis takes into account all the links in the F&V supply chain prior to reaching the consumer, thus basically zooming on the details of the commercial supply chain.

Figures 9.2.1 and 9.2.2 present the maximum, mean and minimum GHG emissions for each link of the MSC chain, in the scenarios tested.

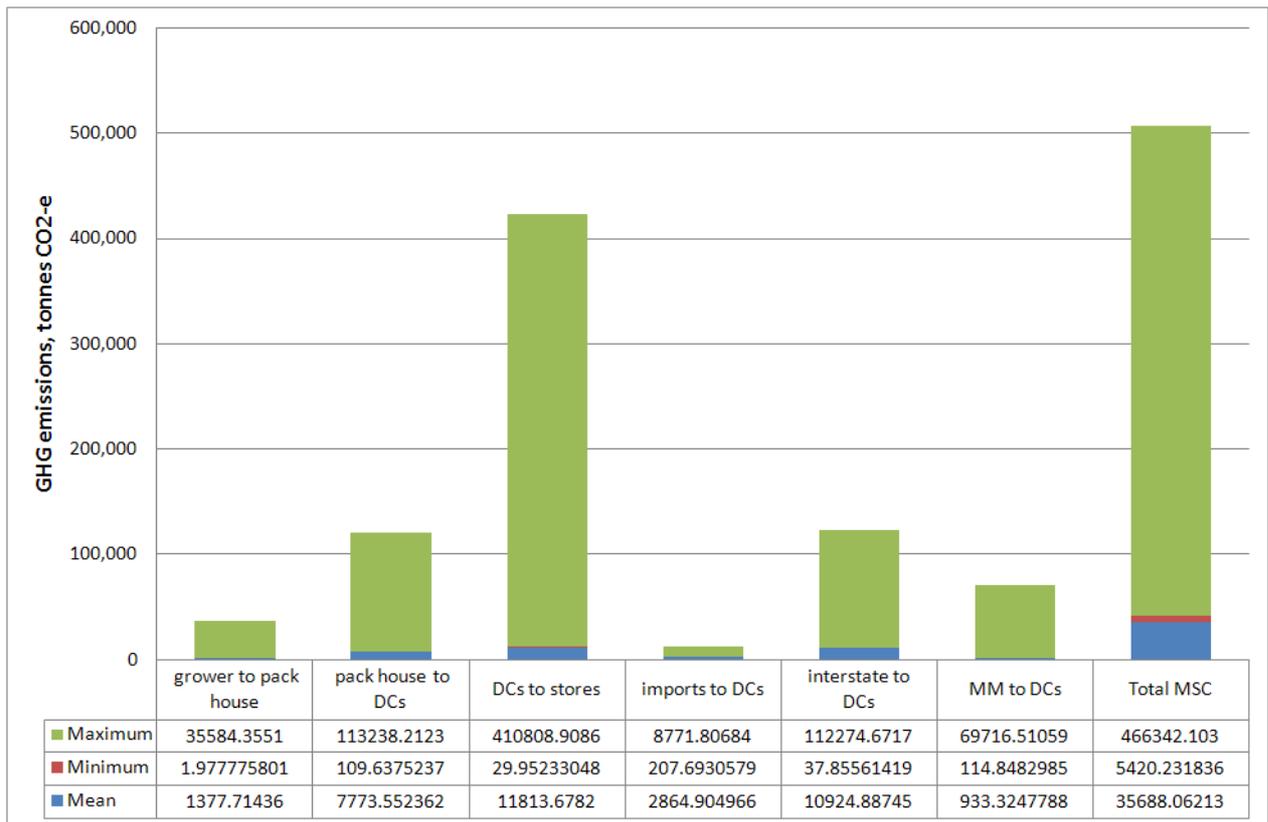


Figure 9.2.1. Maximum, mean and minimum GHG emissions (tonnes CO<sub>2</sub>-e) for each link of the MSC chain, using the variations of Table 8.1 for the sensitivity analysis.

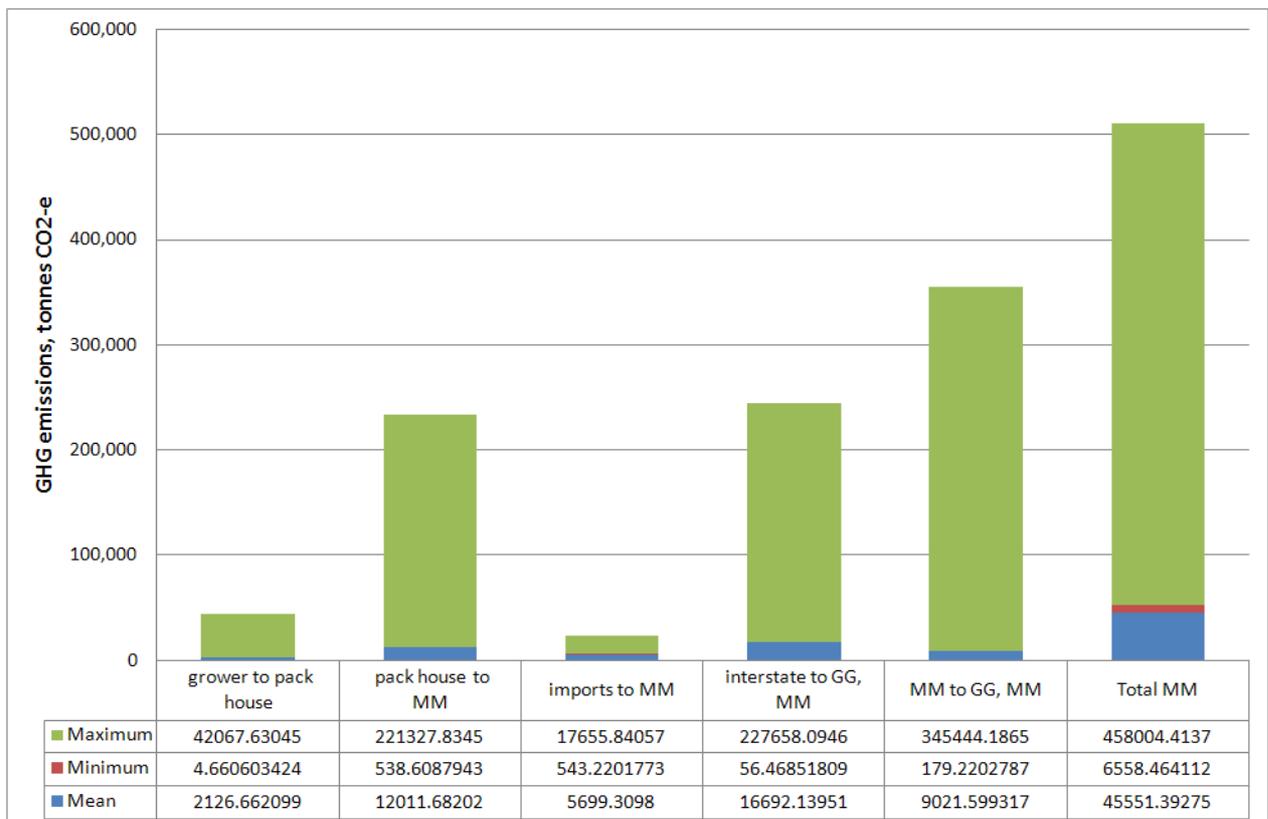


Figure 9.2.2. Maximum, mean and minimum GHG emissions (tonnes CO<sub>2</sub>-e) for each link of the MM chain, using the variations of Table 8.1 for the sensitivity analysis.

As defined in 9.1, the maximum GHG emissions are interpreted as *the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria*. This maximum contribution is based on the potential values that all variables analysed can take within realistic supply chain conditions, as specified in Table 8.1.

In Figures 9.2.1 and 9.2.2, the segments that have the maximum potential in MSC chains (Figure 9.2.1) were (in descending order of importance): transport from DCs to stores, pack house-to-DCs and interstate transport to DCs. Note that differences between the 2<sup>nd</sup> and 3<sup>rd</sup> factors were marginal. In the MM chains (Figure 9.2.2), the segments that have the maximum potential were (in descending order of importance): transport from MM to greengrocers, transport from interstate to MM and transport from pack houses to MM. Again, differences between the 2<sup>nd</sup> and 3<sup>rd</sup> factors were marginal.

Figure 9.2.3 shows a comparison of average GHG emissions calculated for MM and MSC chains, which basically enhances the resolution of Figure 9.1.3.

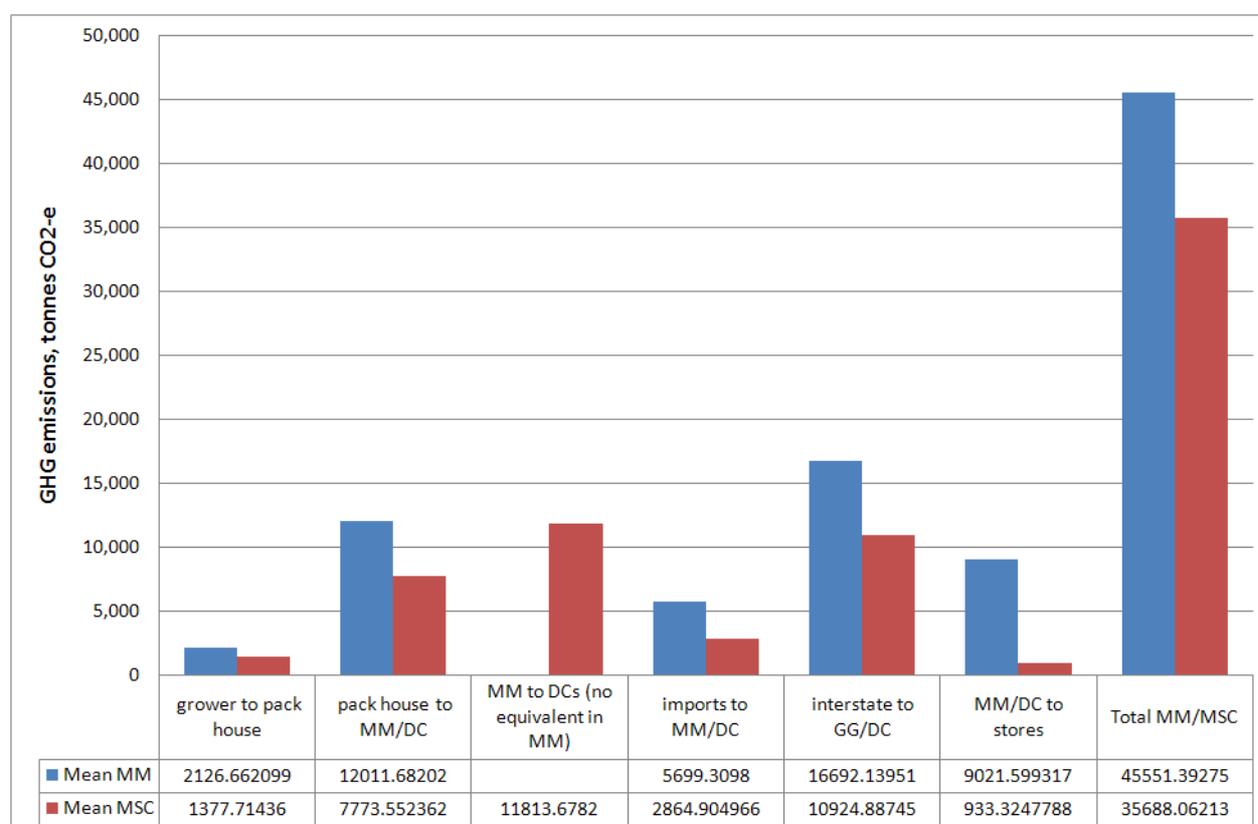


Figure 9.2.3. Comparison of average GHG emissions expected from each link of the MSC and MM chains.

Figures 9.2.4 and 9.5 show tornado charts, illustrating the input variable of major influence in the total GHG emissions of MSC and MM, respectively.

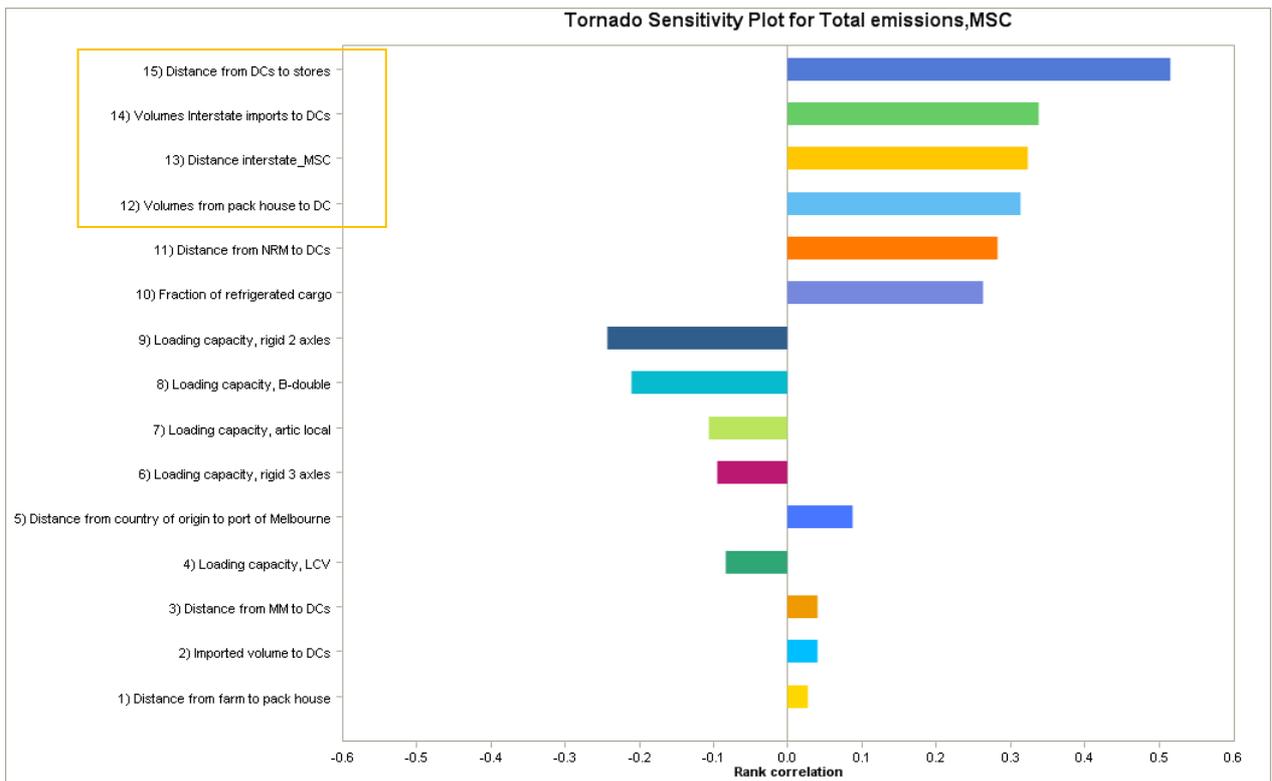


Figure 9.2.4. Tornado sensitivity plot for MSC.

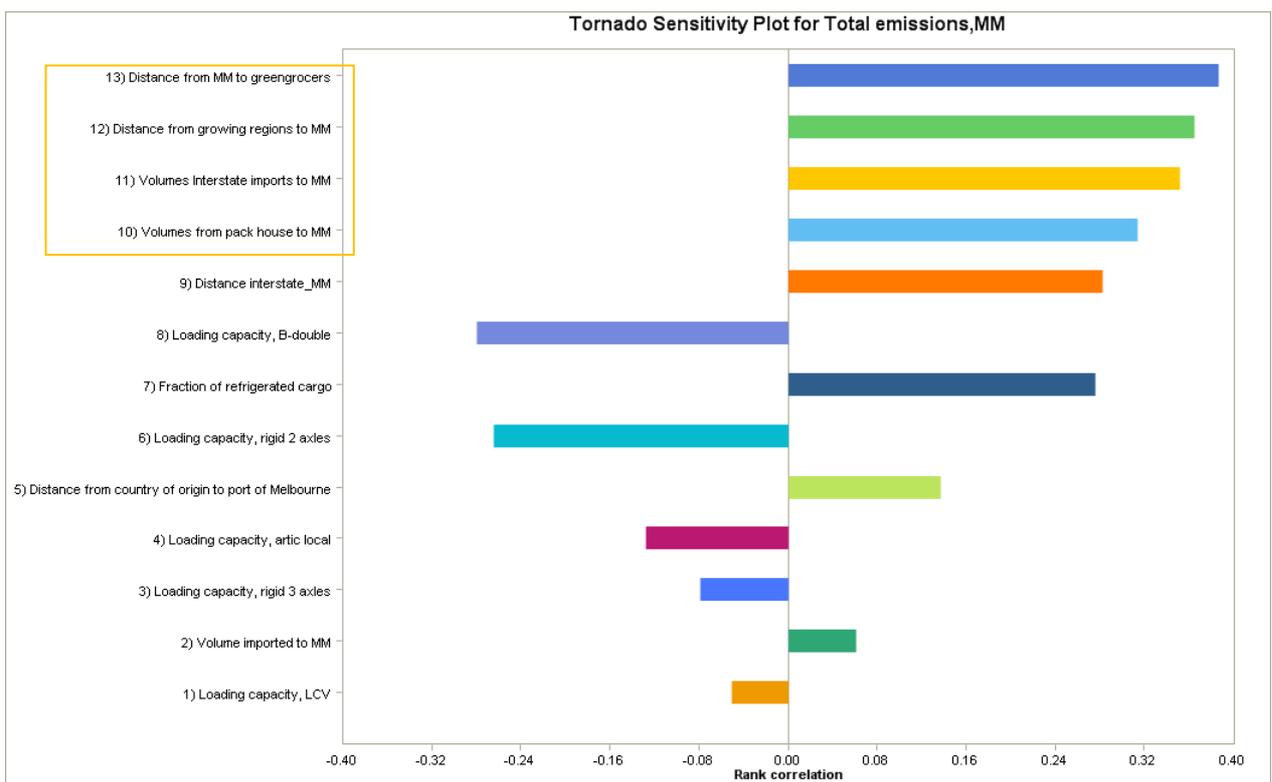


Figure 9.2.5. Tornado sensitivity plot for MM.

Figures 9.2.4 and 9.2.5 indicate that the input factors with major influence on the GHG emissions in both chains are the distance from DCs and MM to stores. In MSC, the volumes and distances imported from other states, and the volumes from pack houses to DCs are also important. In MM chains, interstate and pack house-to-MM volumes are important.

The correlation between the factors of influence and emissions was further investigated through spider plots (Figures 9.2.6 and 9.2.7 for MSC and MM, respectively). These results reflect the total GHG emissions from the pre-consumer chain activities.

Figures 9.2.6 and 9.2.7 show that the relationships between the distances from DCs to stores (i.e. supermarkets and greengrocers) and the resulting average GHG emissions are non-linear. Average GHG emissions increase 75% in the last 20<sup>th</sup> percentile, which reflects the wide geographical distribution of supermarket and greengrocer stores in Victoria (see Figures 5.4 and 5.7 in Chapter 5 and Figure E2 in Appendix E).

The rest of the variables show a relatively linear fashion.

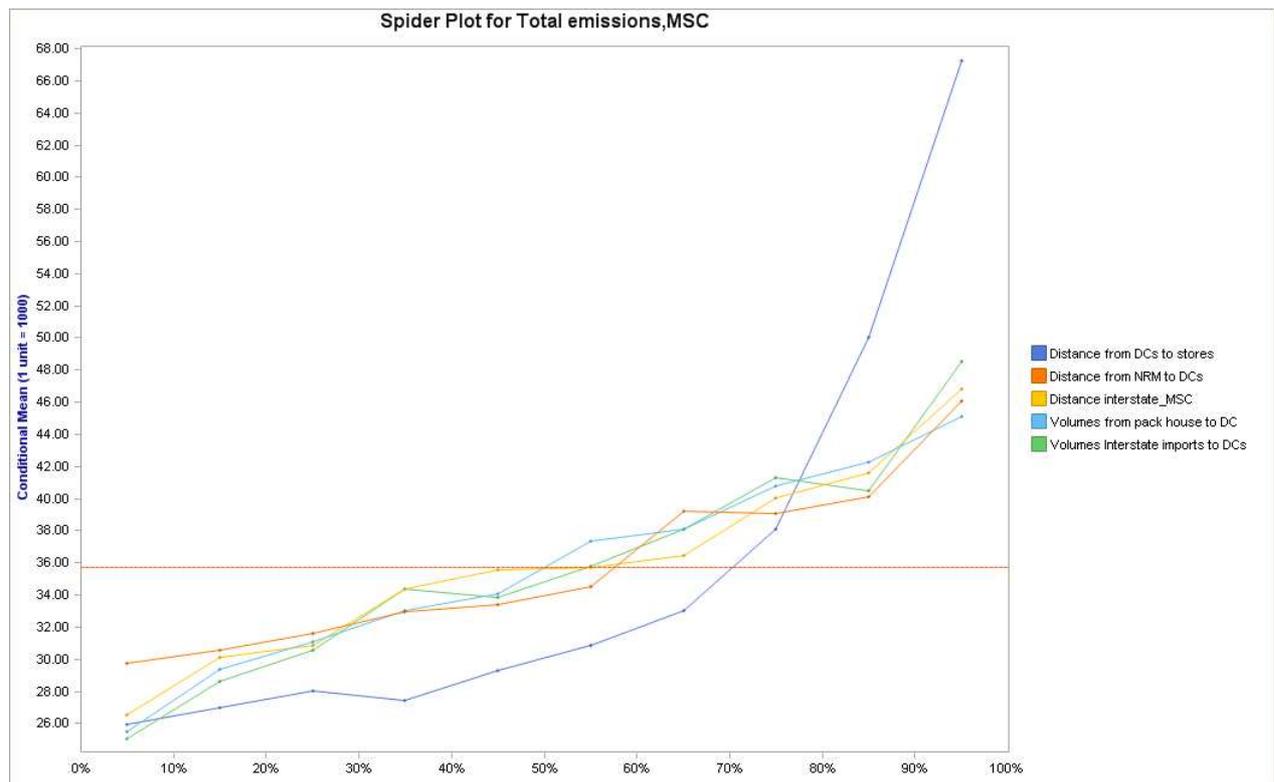


Figure 9.2.6. Spider plot showing the relationship between percentile changes of the major factors of influence and the resulting average GHG emissions in MSC.

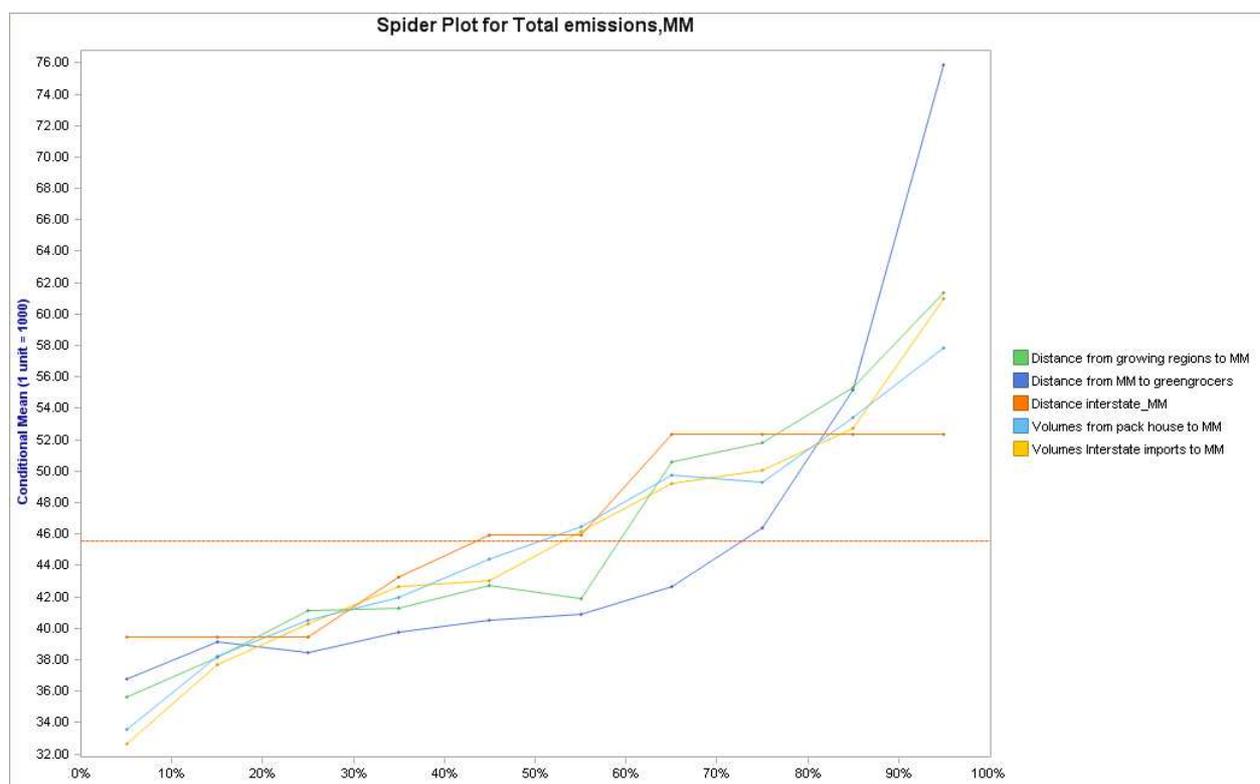


Figure 9.2.7. Spider plot showing the relationship between percentile changes of the major factors of influence and the resulting average GHG emissions in MM.

The cumulative GHG emissions of MSC and MM chains are presented in Figure 9.2.8. The calculated carbon footprint from farm-to-store distribution of fresh F&V consumed in Victoria and sold through greengrocers and supermarkets ranged from 44,752 to 124,062 tonnes CO<sub>2</sub>-e. Similarly to Figure 9.1.11, this wide range relates to the degree in which changes in the variables selected (as per Table 8.1) affect the resulting emissions. As the values of variables are refined (i.e. the variability is decreased), it should be expected that the resulting GHG emissions group closer to a mean value.

A major assumption discussed in Chapter 8 was that all fresh F&V destined to be sold via greengrocers is sourced from Melbourne Markets. Although data available justifies this generalisation, it is believed that greengrocers located away from Melbourne may have other sourcing channels (including intrastate shipments), which could have a significant impact.

Another source of uncertainty was the geographical distribution of stores and greengrocers. Although we captured a significant number of stores in the MSC case, complete location data for Victorian greengrocers was not readily available and multiple data sources were used to capture these locations. As a result, we believe that we captured between 60 and 70% of greengrocer stores.

Perhaps the major data constrain in this case is the split of F&V volumes per store. This data is confidential and efforts to collect data of volumes of fresh fruit and vegetables sold per store were not successful. Data on processed F&V was available, but the cost of this information was simply beyond the budget of this project.

Finally, the complexity of arrangements between supermarkets, wholesalers, 3PLs and suppliers is not captured in this estimate. For example, there may be cases where a supplier transports products directly from farm to stores, thus bypassing distribution centres. Cases where 3PLs make multiple deliveries in one single run are also not contemplated.

More accurate carbon footprint estimations for each segment and each chain require accurate information on the aspects mentioned above, in view of the importance of distances from MM

and DCs to stores. Rather than constraining the results to a set of assumptions that may be erroneous, the stochastic results present the range of GHG emissions expected in MSC and MM chains, within realistic boundaries set by the selection of variables and their potential values. The results need to be interpreted accordingly.

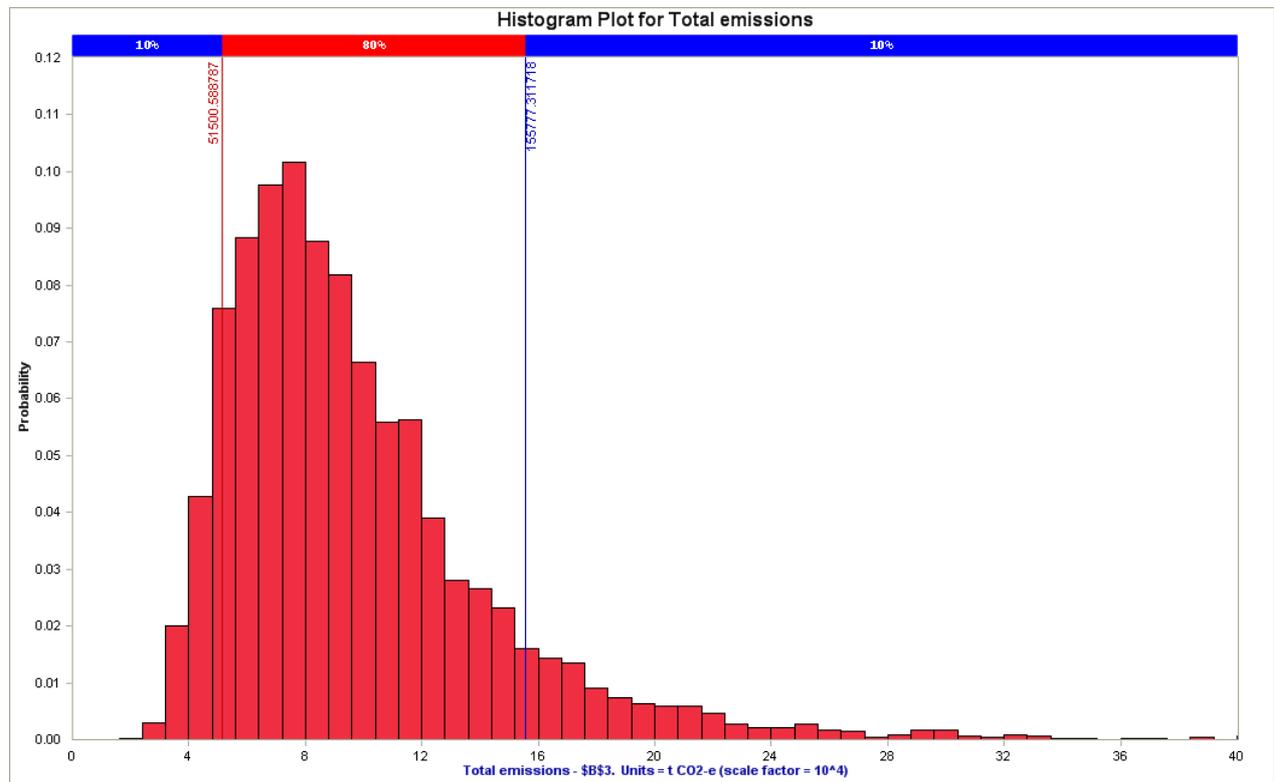


Figure 9.2.8. Histogram showing the distribution of potential GHG emissions arising from fresh F&V distribution through both MSC and MM chains in Victoria (from farm to store). There is an 80% probability of the emissions falling within 51,500 and 155,777 t CO<sub>2</sub>-e/year.

## 10 Conclusions and Recommendations

In this report two complimentary methodologies were applied to improve understanding on the features of F&V freight chains that contribute to GHG emissions and that could lead to supply chain vulnerability. The deterministic method focused on calculating summary statistics by aggregating detailed information across the F&V freight supply chain using a database model. Stochastic modelling was used to provide a better understanding in the context of uncertainty and variability in payloads, volumes, number of trips (etc) and their impact on the distribution of GHG emissions.

From the deterministic method, we now summarise the key features of GHG emissions in F&V freight supply chains. The analysis has shown that distance is the main driver of GHG emissions. This includes the non-even spread of F&V's grown across each Victorian NRM region and the distance from the NRM region to Melbourne. For example, the GHG emissions per tonne of watermelons were over five times that of celery. Watermelons had the highest GHG emissions per tonne, as they were only grown in Mallee (assuming no difference in truck type used), the furthest NRM from Melbourne. Distance is also a major driver since nearly 75% of Victorian consumption occurs in Melbourne. Taking a broader geographical view, the difference between Victorian grown and interstate grown products was substantial: the GHG emissions of transport for F&V grown interstate was at least four times that of Victorian grown produce. Whilst imported F&V had similar GHG emissions to interstate, inclusion of ground transport in the foreign country would likely make them significantly higher.

Variability of supply in Victoria throughout the year had a significant impact on GHG emissions from two perspectives: the total volume varies each month due to total supply variation; and the proportion coming from each NRM region varied significantly due to harvest conditions of each F&V. Throughout the year, there was over 50% variation between the highest and lowest transport GHG emissions of Victorian grown F&V, with the variation being higher for fruit. An important observation was that the very low total emissions around October suggests is likely due to the much greater amount of F&V transported from other states, at four times the GHG emissions per tonne. Conversely, the large GHG emissions during March suggest supply exceeds demand in Victoria for which a large amount of F&V is transported to other states or internationally during this period. In summary, the huge variability in seasonal supply is a major driver for the need of interstate/international transport of F&V at four times the GHG emissions.

Whilst vehicle types were a key determinant of GHG emissions, nearly two thirds of F&V volumes are assumed to be already transported by GHG efficient articulated diesel trucks. The scope for significant GHG reductions through moving towards more efficient existing vehicles will be limited if it is difficult to shift from LCV's to trucks. For this analysis, it was unknown which vehicle types were used on each supply chain path or for which F&V, which may introduce a bias. For example, LCV's or rigids may be used for roads unsuitable for articulated trucks or when the quantities transported are too small for a larger truck. If this information was available along with reasons why certain vehicle types were used, there may be scope to analyse specific options for optimising the use of each vehicle type as part of reducing GHG emissions. Similarly, varying the proportion of truck types used according to the type of trip (interstate, intrastate, intra-urban etc) would be likely to impact on these results, and would be a priority for further analysis.

Using the database model, three features of vulnerability were tested- 25% lost production in a NRM region; changes in transport mode and oil price spike scenarios. A 25% loss of production in a region led to small gains in GHG emissions (mostly less than 1%). Oil price spike scenarios of \$2/litre and \$2.80/litre were simulated against current prices. For Victorian produced and consumed F&V, this led to fuel prices of freight being up to 10% of farmgate value, though the main implications are on F&V transported interstate where the costs would be up to 40%. Further analysis is required here to better understand the implications to each supply chain participant.

A key question arising from the deterministic analysis is which of the identified major drivers (distance from growing region, seasonal variability, transport mode) presents the greatest opportunity for reducing GHG emissions, and how would it be implemented. This would present a complex analysis as there is a trade-off in costs of change, impact on the local economy, social/health value of current availability of F&V, and environment implications. For example, whilst the transport model may be the lowest hanging fruit, there will likely be additional costs in capital, road grades, infrastructure for loading/unloading vehicles and impacts on backloading.

Several additional questions could be asked in light of the analysis:

- What are the options for production of different F&V in NRM regions to create a seasonal supply pattern to Melbourne that reduces transport GHG emissions and interstate supply, without having adverse agronomic implications?
- What would be the implications of providing X% of Melbourne's F&V requirements from the surrounding regions?

The development of these two methodologies and the technical capability of the database model create possibilities for analysis of other commodities as well as additional detail of the supply chains on this report. In the presence of improved data in the future, the database model constructed for the Deterministic Analysis would likely be used to identify additional features or drivers of GHG emissions in F&V freight logistics. Inefficient freight movements at micro level scale could not be identified in this analysis as data on specific freight movements or companies were not available in the analysis. Inefficiencies that could be identified include: movements between DC's, quarantine at the Victoria border and the supply between states to accommodate temporary shortages.

The extent of data uncertainty previously discussed and the need to evaluate the sensitivity of GHG emissions to a large number of variables that extended beyond the capabilities of a determinist approach were the main factors driving the decision of using a second analysis tool, based on a stochastic modelling approach. This approach is described in Part B and Appendix B of this report.

The stochastic model was used to provide a wider picture of the key factors affecting GHG emissions for major supermarket chains (MSC) and Melbourne Markets-greengrocer chains (MM), which cumulatively account for 97% of the total F&V trade<sup>21</sup>. For the purposes of identifying the major factors affecting GHG emissions in Victorian F&V chains, MSC and MM were considered to be largely representative of current marketing methods. Further, only fresh F&V product entering the Victorian market (through state production, imports and interstate trade) was considered. Exports and F&V volumes leaving Victoria were not considered.

Two types of sensitivity analyses were developed: a complete farm-to-fork analysis (including consumer travel to shops) and a farm to store analysis that focused on results relevant to the commercial operations in the F&V supply chain.

#### Farm-to-Fork:

- The calculated carbon footprint from farm-to-fork distribution of fresh F&V consumed in Victoria and sold through greengrocers and supermarkets is likely to fall within 82,214 and 318,976 tonnes CO<sub>2</sub>-e. These results reflect the large data uncertainty –discussed in the deterministic analyses– and the extent to which changes in the variables selected affected the resulting emissions. As the values of variables are refined through more accurate information on commercial distribution of F&V (i.e. the variability is decreased), the resulting GHG emissions would group closer to a mean value.

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<sup>21</sup> The remaining trade is attributable to a wide variety of small grower-consumer channels, amply discussed by Estrada-Flores and Larsen (2010).

- In the major supermarket chains (MSC), the distribution segments that have the maximum contribution potential to GHG emissions were (in descending order of importance): transport of F&V from stores to consumers' households, transport from DCs to stores and interstate transport to DCs.
- In the Melbourne Markets (MM) chains, the segments that have the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of importance): transport of F&V from greengrocers to consumers' households, transport from MM to greengrocers and transport from pack houses to MM.

In the farm-to-fork analysis, the most significant factor in transport GHG emissions for fruit and vegetables was found to be consumer travel to purchase them. The significance of this factor is found to be greater than in the deterministic analysis, which is likely due to:

- a higher proportion of the consumer trip allocated to fresh fruit and vegetables (30% based on a healthy food basket, rather than 7.25% in the average); and
- refined allocations of truck types used in different supply chain legs. In particular, the assumption of LCVs used only for short trips led to a lower estimation of emissions for interstate segments.

Given the importance of the consumer segment, decreasing the uncertainty of variables that affect consumer travel would lead to more accurate carbon footprints. In particular, the number of consumer trips –which was assumed to be 1.7 weekly per household, but can be as high as 4 trips to supermarkets and greengrocers<sup>22</sup>– would have a significant influence. Other factors include shopping habits and basket share of fresh and processed fruit and vegetables in trips to supermarkets and greengrocers. Similarly, this analysis assumes that all consumer trips to supermarkets take place in cars. It does not account for those who shop on foot, cycle or public transport.

It is also important to note that the significance of the consumer trips is largely driven by the households located at distances over 5.5 km, despite the fact that these are a minority (less than 20% of the total Victorian households analysed). If the travel distance (or number of trips) of this minority of households were decreased, this would lead to a substantial decrease in the **total** F&V carbon footprint.

In the context of this analysis, which sought to uncover the most significant causes for GHG emissions in the transportation of fresh F&V, it would be incorrect to disregard the impact of distant households, which is the most significant factor. However, if the analysis was conducted excluding the percentage of households that are located beyond 5.5 km from the nearest supermarket/greengrocer, commercial operations such as interstate transport would be expected to be the most significant factor of GHG emissions. This is reflected in the farm-to-store analysis below. Further discussion on the impact of consumer travels is presented in Appendix E.

Farm-to-Store: While the farm-to-fork analysis presents results that may be of interest to policy makers and urban planners, a second analysis was conducted to pinpoint opportunities to decrease GHG emissions during commercial F&V chains. The following results can be highlighted:

- The calculated carbon footprint from farm-to-store distribution of fresh F&V consumed in Victoria and sold through greengrocers and supermarkets is likely to fall within 44,752 and 124,062 tonnes CO<sub>2</sub>-e. Again, these results reflect data uncertainty and the degree in which changes in the variables selected affected the resulting emissions. As the values of variables are refined (i.e. the variability is decreased), the resulting GHG emissions would group closer to a mean value.
- For MSC, the segments that had the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of importance):

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<sup>22</sup> Freshlogic (2010). *Veginsights: the market-Q4 09. A vegetable market platform analysis plus a profile of the three-month period ending 31 Dec 2009*. Page 27.

transport from DCs to stores, pack house-to-DCs and interstate transport to DCs. Differences between the GHG emissions of the 2nd and 3rd factors were marginal.

- In the MM chains, the segments that had the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of importance): transport from MM to greengrocers, transport from interstate to MM and transport from pack houses to MM. Again, between the GHG emissions of the 2nd and 3rd factors were marginal.
- Given the importance of the distance between DCs/MM to stores, decreasing the uncertainty of variables that affect this variable would lead to more accurate carbon footprints. Such variables include the specific channels used by greengrocers located in remote locations to source their products, the location of all Victorian greengrocers and the split of volumes from the DCs/MM to stores.

The greater significance of the distance from DCs / MM to stores is likely to result from the multiple trips to stores in distant locations and the low rate of backhauling assumed, compared to the packhouse-to-DC / MM trip. These findings could have implications for location and/or function of outlets and distribution centres, to decrease distances or increase backhauling opportunities.

Given the importance of the distance between DCs/MM to stores, decreasing the uncertainty of variables that affect this variable would lead to more accurate carbon footprints. Such variables include the specific channels used by greengrocers located in remote locations to source their products, the location of all Victorian greengrocers and the split of volumes from the DCs/MM to stores.

## **10.1 Recommendations**

Results presented in this report have identified where further priority analyses are needed. Here we note these analyses and the data acquisitions required to support them.

Seasonal variability of F&V supply was a major determinant of freight volumes and GHG emissions. However, due to the severe lack of suitable data on interstate transport, many questions around the seasonal implications of GHG emissions remain unanswered. This includes better understanding the inefficiencies of interstate (and intrastate) F&V GHG emissions at a more granular scale such as individual trip movements and companies. Such a more detailed analysis would help identify more tangible strategies to reduce GHG emissions. To do this, the key data requirements are: tonnes of individual F&V transported between each state in each week, as well as movements at company scale. If the latter will be impossible to obtain as complete data sets, then we recommend it be collected in part through surveys.

Whilst not considered in this analysis, we expect the seasonal variability in the demand of transport vehicles will also have implications on the level of backloading. We suggest additional investigations be carried out to assess the GHG efficiencies of the road transport from the NRM regions, throughout the year. This would need to be assessed in terms of types of vehicles throughout the year, backloading, and implications of peak demand and excess capacity.

The assumptions made around direct routes, no duplication of trips and provision of produce to the closest DCs (etc) first, are likely to lead to significant underestimates of the actual transport task. Closer investigation of the actual transport movements that happen in specific supply chains would be useful to understand the extent of this underestimation.

The scope of the international analysis needs to be expanded to incorporate freight movements between the growing regions in the country of origin to the port of country of origin. This would provide a fairer comparison with the Victorian and interstate supply chains.

An important analysis would be inclusion of GHG emissions for F&V consumed in food service outlets, and potential freight inefficiencies explored. This is a very complex supply chain and there are several thousand food outlets in Victoria. They vary in terms of small restaurants with local ownership, to large franchises with large complex supply chains. Sourcing of F&V for each restaurant would be hard to determine due to the large number of ownerships and large variety of local versus interstate suppliers. We suggest a GHG analysis of the food service industry be considered as part of further research.

In this report, GHG emissions of transport to and from the processor were considered, though a lot more information is needed on the freight movements to provide an accurate analysis. In particular data of F&V from different states or overseas for processing is much needed. Also, GHG emissions of activities within the processor need to be considered to provide a balanced comparison with fresh F&V supply chains.

In-depth understanding of the ‘last mile’ effect on food distribution systems is also of interest. For example:

- How do the ‘last mile’ emissions compare with the transport emissions from the rest of the fruit and vegetables supply chain? From the results of the stochastic analysis in Chapter 9, we learned that this component is the factor of greatest influence on the total GHG emissions of supermarket chains and greengrocers. However, is this the same for other product types?
- Given the significant contribution of rural households on the overall carbon footprint generated by consumers’ travel to their nearest supermarket shop, what innovative food distribution systems can be more effective in decreasing the ‘last mile’ to rural households? This question remains unanswered. Mostly, because it is difficult to compare systems that handle different volumes and have different supply chain efficiencies. However, substantial decreases in emissions in the consumer transport segment will only be possible if the transport distances from households located in “food desert” areas are tackled.
- What would be the impact of adding more food outlets to decrease consumers’ travel intensity? This relates to the point previously made. The commercial realities of mass distribution may inhibit this solution in rural areas. However, the transport of food by supermarkets to households, or increase in smaller outlets, were potential solutions offered by Estrada-Flores and Larsen (2010).
- If increasing the number of food outlets is an option to decrease the impact of the Victorian ‘last mile’, how these improvements compare with the increase in upstream distribution operations required to supply the extra stores? The stochastic analysis (Figure 9.3 in Chapter 9) showed that commercial distribution segments in general have a smaller carbon footprint than consumer travel, under the assumptions tested in the model. However, the commercial chain activities still contribute with 40% to 50% of the total carbon footprint. On this basis, increasing the distribution activities prior to reaching the stores would have an impact on overall GHG emissions. However, this only holds true for the fresh F&V. Mapping the entire food chain of products offered in supermarkets represents an enormous challenge that remains to be tackled. Further, trends for other products cannot be inferred by assuming that seafood or cereals would show similar trends than distribution operations for F&V.

## References



- ABARE (2008), "Energy in Australia 2008", Australian Bureau of Agricultural and Resource Economics pp. 1-93.
- ACIL Tasman (2008), "An Assessment of Australia's Liquid Fuel Vulnerability ", Department of Resources, Energy and and Tourism pp. 1-205.
- AEA (2008), "2008 Guidelines to Defra's GHG Conversion Factors: Methodology Paper for Transport Emission Factors", Department for Environment Food and Rural Affairs pp. 1-35.
- APPEA (2008), "Key Statistics 2008", Canberra, ACT, The Australian Petroleum Production and Exploration Association pp. 1-14.
- Apple & Pear Australia Limited. (2008), "Public submission to ACCC Grocery Inquiry by Horticulture Australia Ltd", p. 15.
- Arthur, W. C., Cechet, R. P., Divi, C. and Power, L. (2009), "Impacts of climate change on tropical cyclone hazard in the Australian region: implications for the wind loading code.", in Anderssen, R. S., R.D. Braddock. and Newham., L. T. H. (Eds.) 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation.
- Australian Bureau of Statistics (2008), Agricultural Commodities 2007-08, 7121.0. Data cubes.
- Australian Bureau of Statistics (2008a), "9208.0 Survey of Motor Vehicle Use", pp. 1-48.
- Australian Bureau of Statistics (2008b), "71210DO006\_200708 Agricultural Commodities, Australia, 2007-08", Table.
- Australian Bureau of Statistics (2008c), "Agricultural Commodities 2007-08", 7121.0. Data cubes.
- Australian Bureau of Statistics (2008d)," 75030DO001\_200708 Value of Agricultural Commodities Produced, Australia, 2007-08", Table.
- Australian Bureau of Statistics (2009), "9309.0 Motor vehicle census", pp. 1-28.
- Australian Competition and Consumer Commission (2008), "Report of the ACCC inquiry into the competitiveness of retail prices for standard groceries", Commonwealth of Australia pp. 1-457.
- Babu, S. C. and Sanyal, P. (2009), "Introduction to food security: concepts and measurement", Food Security, Poverty and Nutrition Policy Analysis, Academic Press, San Diego, pp. 5-15.
- Bardi, U. (2009), "Peak oil: the four stages of a new idea", Energy, Vol. 34 No. 3, pp. 323-326.
- Barnes, P. and Oloruntoba, R. (2005), "Assurance of security in maritime supply chains:conceptual issues of vulnerability and crisis management", Journal of International Management, Vol. 11 No. 4, pp. 519-540.
- Blanco, E. E. and Craig, A. J. (2009), "The value of detailed logistics information in carbon footprints", MIT Center for Transportation and Logistics pp. 1-7.
- Botzen, W. J. W., Bouwer, L. M. and van den Bergh, J. C. J. M. (2010), "Climate change and hailstorm damage: Empirical evidence and implications for agriculture and insurance", Resource and Energy Economics, Vol. In Press, Corrected Proof.
- Breierova, L. and Choudhari, M. (2001), "An introduction to sensitivity analysis", pp. 1-67.
- Brooke, C. and Kinrade, P. (2006), "Climate change impacts in Western Port", Report prepared for the Western Port Greenhouse Alliance, CSIRO and Marsden Jacob Associates pp. 1-45.
- Burns, C. M. and Inglis, A. D. (2007), Measuring food access in Melbourne: Access to healthy and fast foods by car, bus and foot in an urban municipality in Melbourne, Health & Place, Vol. 13 No. 4, pp. 877-885.

- Burgio-Ficca, C. (2010), "Apples and oranges: Competition is looming and the popularity of frozen meals is reducing demand for fresh produce", IBISWorld Industry Report G5122. Fruit and Vegetable Retailing in Australia, pp. 1-29.
- Burgio-Ficca, C. (2010), "Supermarkets and other grocery stores in Australia", IBISWorld Industry Report G5111, pp. 1-45.
- CDI Pinnacle Management (2008), "Public submission to ACCC Grocery Inquiry by Horticulture Australia Ltd", in Australia, H. (Ed., p. 110.
- Cechet, B. (2005), "Climate change impact on the pavement maintenance and rehabilitation costs associated with the Australian National Highway Network", in Oxley, L. and Kulasiri, D. (Eds.) MODSIM 2005 International Congress on Modelling and Simulation. , pp. 489-496.
- CFVIWA (2008), "Submission Prepared by the Chamber of Fruit and Vegetable Industries in WA Inc. (CFVIWA) Regarding the Issues Paper Released by the ACCC Inquiry Into the Competitiveness of Retail Prices for Standard Groceries", pp. 1-6.
- Chandra, C. and Grabis, J. (2007), Supply Chain Configuration Concepts, Solutions, and Applications Springer Science+Business Media, New York.
- Cleland, D. J. (2010), "Towards a sustainable cold chain", 1st IIR International Cold Chain Conference,, Cambridge UK, pp. 1-8.
- Crooks, S. (2009), Australian vegetable growing farms: an economic survey, 2007-08, ABARE research report 09.15,, Canberra ACT, pp. 1-82.
- CSIR. 2005. Second Annual State of Logistics Survey for South Africa: defining research priorities for developmental logistics. CSIRO Build Environment, ISBN 0-7988-5559-2
- CSIRO, Maunsell Australia. and Fox., P. (2007), "Infrastructure and Climate Change Risk Assessment for Victoria", Report to the Victorian Government, pp. 1-177.
- D'Souza, R. M., Becker, N. G., Hall, G. and Moodie, K. B. A. (2004), "Does ambient temperature affect foodborne disease?", Epidemiol., Vol. 15, pp. 86-92.
- D'Souza, R. M., Hall, G. and Becker, N. G. (2008), "Climatic factors associated with hospitalizations for rotavirus diarrhoea in children under 5 years of age.", Epidemiol. Infect., Vol. 136, pp. 56-64.
- Deo, R. C., McAlpine, C. A., Syktus, J., McGowan, H. A. and Phinn, S. (2007), "On Australian Heat Waves: Time Series Analysis of Extreme Temperature Events in Australia, 1950 - 2005", in Oxley, L. and Kulasiri, D. (Eds.) MODSIM 2007 International Congress on Modelling and Simulation. , pp. 626-635.
- Department for Environment Food and Rural Affairs (2010), "UK Food Security Assessment: Detailed Assessment", pp. 1-145.
- Department of Agriculture Fisheries and Forestry (2009), "Submission to the Senate Select Committee on Fuel and Energy", pp. 1-11.
- Department of Climate Change (2009), "Climate change risks to Australia's Coast", Australian Government pp. 1-172.
- Department of Resources Energy and Tourism (2009), "National Energy Security Assessment", Barton, ACT, Commonwealth of Australia pp. 1-30.
- Department of Transport Victoria (2008a). Greenhouse gas emissions abatement potential of the Victoria Transport Plan.  
[www.transport.vic.gov.au/.../The\\_Nous\\_Group\\_Transport\\_abatement\\_wedges.pdf](http://www.transport.vic.gov.au/.../The_Nous_Group_Transport_abatement_wedges.pdf)
- Dessai, S. and van der Sluijs, J. (2007), "Uncertainty and Climate Change Adaptation - a Scoping Study", Utrecht, Netherlands Environmental Assessment Agency pp. 1-97.
- Deuter, P. (2008), "Defining the impacts of climate change on horticulture in Australia", Garnaut Climate Change Review, Horticulture Australia Ltd, pp. 1-23.

- Duinmeijer, A. G. P., Bouwknegt, R. (2004), "Reliability Rail Infrastructure 2003", Utrecht, The Netherlands, Prorail.
- EnSys Energy & Systems Inc. (2007), "Analysis of Impacts on Global Refining & CO2 Emissions of Potential MARPOL Regulations for International Marine Bunker Fuels.", Report prepared for the US Environmental Protection Agency. pp. 1-79.
- Ericksen, P. J. (2006), "Assessing the vulnerability of food systems to global environmental change: a conceptual and methodological review.", GECAFS Working Paper 3., School of Geography and the Environment, University of Oxford.
- Estrada-Flores S. (2008), "Thermography as a tool to detect energy-saving opportunities in cold chain equipment", Chain of Thought.The Newsletter of Food Chain Intelligence, pp. 1-14.
- Estrada-Flores, S. (2008). A review on food safety risks in the supply chain of fresh horticultural products. Report FCI002/2008, Food Chain Intelligence.
- Estrada-Flores, S. (2009) Method for Estimating the Change in Food Safety Risks Across a Food Transport and Distribution Network: Phase 1. A review on food safety risks in the supply chain of fresh horticultural products, pp 1-78.
- Estrada-Flores, S. (2009), "Technology Platform 2: Adaptation and Mitigation Technologies", Opportunities and challenges faced with emerging technologies in the Australian vegetable industry Horticulture Australia Ltd pp. 1-109.
- Estrada-Flores, S. (2010), "Technology Platform 3: Emerging Technologies for Quality and Safety.", Opportunities and challenges faced with emerging technologies in the Australian vegetable industry Horticulture Australia Ltd pp. 1-90.
- Estrada-Flores, S. and Larsen, K. (2010), "Best Practice Food Distribution Systems ", Victorian Eco-Innovation Lab (VEIL) pp. 1-158.
- Estrada-Flores, S., Higgins, A.J., Larsen, K. (2009). Food distribution systems in a climate-challenged future: fruit and vegetables as a case study. Proceedings of the Food, Farming & Health Conference, Melbourne, 77-88.
- Fiksel, J. (2003), "Designing resilient, sustainable systems", Environmental Science and Technology, Vol. 37 No. 23, pp. 5330-5339.
- Fiksel, J. (2006), "Sustainability and resilience: towards a systems approach", Sustainability: Science, Practice & Policy, Vol. 2 No. 2.
- Freshlogic. (2008), "Report on issues relevant to the ACCC inquiry into the competitiveness of retail prices for standard groceries:Prepared for Coles Supermarkets.", p. 68.
- Fruit Growers Victoria Ltd. (2008), "Public submission to ACCC Grocery Inquiry by Horticulture Australia Ltd", p. 4.
- Future Fuels Forum (2008), *Fuel for Thought: the Future of Transport Fuels: Challenges and Opportunities*, Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australia
- Garrett, K. A., Dendy, S. P., Frank, E. E., Rouse, M. N. and Travers, S. E. (2006), "Climate change effects on plant disease: Genomes to ecosystems", Annual Review of Phytopathology, Vol. 44 No. 489-509.
- Gnansounou, E. (2008), "Assessing the energy vulnerability: Case of industrialised countries", Energy Policy, Vol. 36 No. 10, pp. 3734-3744.
- Growcom (2008), "Background and options paper on emissions trading and horticulture", pp. 1-20.
- Growcom (2008), Growcom background and options paper on emissions trading and horticulture, Report EDMS 26372, www.grow.com.au.
- Guerin, M. T., Martin, S. W., Reiersen, J., Berke, O., McEwen, S. A., Fririksdóttir, V., Bisailon, J. R. and Lowman, R. (2008), "Temperature-related risk factors associated with the colonization of

broiler-chicken flocks with *Campylobacter* spp. in Iceland, 2001-2004", *Preventive Veterinary Medicine*, Vol. 86 No. 1-2, pp. 14-29.

Gunderson, L. and Holling, C. S. (2002), *Panarchy: understanding transformation in human and natural systems*, Island Press, Washington DC.

Gupta, E. (2008), "Oil vulnerability index of oil-importing countries", *Energy Policy*, Vol. 36 No. 3, pp. 1195-1211.

Hall, C. A. S., Powers, R. and Schoenberg, W. (2008), "Peak oil, EROI, investments and the economy in an uncertain future", in Pimentel, D. (Ed.) *Biofuels, solar and wind as renewable energy systems*, Springer, Ithaca, NY, pp. 109-132.

Hall, G. V., D'Souza, R. M. and Kirk, M. D. (2002), "Foodborne disease in the new millennium: out of the frying pan and into the fire?", *Med. J. Aust.*, Vol. 177, pp. 614-618.

Harvey, M. e. a. (2004), "Impact of Climate Change on Road Infrastructure", *Austrroads Inc* pp. 1-142.

Hassall, K. (2003), "Achievable Rigid Truck Productivity Gains through Performance Based Standards", *Urban Logistics Group, Department of Civil and Environmental Engineering, University of Melbourne*, pp. 1-24.

HELCOM (2006), "Climate Change in the Baltic Sea area", *HELCOM Stakeholder Conference on the Baltic Sea Action Plan, Helsinki, Finland*, pp. 1-48.

Hennessy, K., Fitzharris, B., Bates, B. C., Harvey, N., Howden, S. M., Hughes, L., Salinger, J. and Warrick, R. (2007), "Climate Change 2007: Impacts, Adaptation and Vulnerability.", in M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and Hanson, C. E. (Eds.) *Contribution of Working Group II to the Fourth Assessment Report of the IPCC.*, Cambridge University Press, Cambridge, UK pp. 507-540.

Hertwich, E. G. and Peters, G. P. (2009), "Carbon footprints of nations: a global, trade-linked analysis", *Environmental Science & Tehcnology*, Vol. 43 No. 16, pp. 6414-6420.

Higgins, A. J., Miller, C., Archer, A. A., Ton, T., Fletcher, C. S. and McAllister, R. R. J. (2009), "Challenges of operations research practice in Agricultural Value Chains", *Journal of the Operational Research Society*, Vol. In press.

Higgins, AJ, Estrada-Flores, S., Singh, G, Ton, T. (2007). *State of Logistics. Final report submitted to Food Futures Flagship.*

Hranac, R., Sterzin, E., Krechmer, D., Rakha, H., Farzaneh, M., (2006), "Empirical studies on traffic flow in inclement weather.", *Publication No. FHWA-HOP-07-073.*, Federal Highway Administration, Washington, DC.

Hutchins, D. A., Teyssii, J.-L., Boisson, F., Fowler, S. W. and Fisher, N. S. (1996), "Temperature effects on uptake and retention of contaminant radionuclides and trace metals by the brittle star *Ophiothrix fragilis*.", *Marine Environmental Research*, Vol. 41 No. 4, pp. 363-378.

Industry Taskforce on Peak Oil & Energy Security (2010), "The oil crunch: a wake-up call for the UK economy. ", in Roberst, S. (Ed. *Second report of the UK TPOES*, London, UK., pp. 1-60.

Jacxsens, L., Luning, P. A., van der Vorst, J., G.A.C., Devlieghere, F., Leemans, R. and Uyttendaele, R. (2009), "Simulation modelling and risk assessment as tools to identify the impact of climate change on microbiological food safety – The case study of fresh produce supply chain", *Food Research International*.

James, S. J. and James, C. (2010), "The food cold-chain and climate change", *Food Research International*, Vol. In Press, Accepted Manuscript.

Jaykus, L., Woolridge, M., Frank, J. M., Miraglia, M., McQuatters-Gollop, A., Tirado, C., Clarke, R. and Friel, M. (2008), "Climate change: implications for food safety.", *Rome, Italy.*, Food and Agriculture Organization. p. 49.

- Jüttner, U. (2005), "Supply chain risk management—understanding the business requirements from a practitioner perspective", *International Journal of Logistics Management*, Vol. 16 No. 1, pp. 120-141.
- Karl, T. R., Melillo, J. M. and Peterson, T. C. E. (2009b), "Global Climate Change Impacts in the United States," pp. 1-188.
- Keay, K. and Simmonds, I. (2005), "The association of rainfall and other weather variables with road traffic volume in Melbourne, Australia," *Accident Analysis and Prevention*, Vol. 37, pp. 109-124.
- Koetse, M. J. and Rietveld, P. (2009), "The impact of climate change and weather on transport: An overview of empirical findings", *Transportation Research Part D: Transport and Environment*, Vol. 14 No. 3, pp. 205-221.
- Kovats, R. S., Edwards, S. J., Charron, D., Cowden, J., D'Souza, R. M., Ebi, K. L., Gauci, C., Gerner-Smidt, P., Hajit, S., Hales, S., Hernandez-Pezzi, G., Kriz, B., Kutsar, K., McKeown, P., Mellou, K., Meene, B., O'Brien, S., van Pelt, W. and Schmid, H. (2005), "Climate variability and campylobacter infection: an international study..", *Int. J. Biometeorol.*, Vol. 49, pp. 207-214.
- Lai, L.-H. (2010), "Risk estimate of rice damaged due to flood", *Nonlinear Analysis: Real World Applications*, Vol. In Press, Corrected Proof.
- Larsen, K., Ryan, C. and Abraham, A. B. (2008), "Sustainable and Secure Food Systems for Victoria: What do we know? What do we need to know?", *Victorian Eco-Innovation Lab (VEIL)* pp. 1-152.
- Leonardi, J. and Browne, M. (2009), "Method for assessing the carbon footprint of maritime freight transport: European case study and results.", in *14th Annual Logistics Research Network Conference*, Cardiff, UK, pp. 132-139.
- Lewis, L., Onsongo, M., Njapau, H., Schurz-Rogers, H., Luber G. , Kieszak, S. and al., e. (2005), "Aflatoxin contamination of commercial maize products during an outbreak of acute aflatoxicosis in eastern and central Kenya", *Environm.Health Perspectives*, Vol. 113 No. 12, pp. 1763-1767.
- Marques, A., Nunes, M. L., Moore, S. K. and Strom, M. S. (2010), "Climate change and seafood safety: human health implications", *Food Research International*, Vol. In Press, Accepted Manuscript.
- McInnes, K. L., Hubbert, G. D., Macadam, I. and O'Grady, J. G. (2007), "Assessing the impact of climate change on storm surges in Southern Australia", in Oxley, L. and Kulasiri, D. (Eds.) *MODSIM 2007 International Congress on Modelling and Simulation.* , pp. 1653-1659.
- Metcash (2008), "Public submission to ACCC Grocery Inquiry ", pp. 1-74.
- Miraglia, M., De Santis, B. and Brera, C. (2008), "Climate change: Implications for mycotoxin contamination of foods", *Journal of Biotechnology*, Vol. 136 No. Supplement 1, pp. S715-S715.
- Molloy, S. L., Dreelin, E. A., Rose, J. B. and Kris, H. (2008), "Extreme Weather Events and Human Health", *International Encyclopedia of Public Health*, Academic Press, Oxford, pp. 536-544.
- Niall, S. and Walsh, K. (2005), "The impact of climate change on hailstorms in Southeastern Australia", *International Journal of Climatology*, Vol. 25 No. 14, pp. 1933-1952.
- O'Halloran, N, Fisher, P. and Rab, A. (2008). Options for mitigating greenhouse gas emissions for the Australian Vegetable Industry. Discussion paper 6. Horticulture Australia Limited project VGO8107.
- Oh, C. H. and Reuveny, R. (2010), "Climatic natural disasters, political risk, and international trade", *Global Environmental Change*, Vol. In Press, Corrected Proof.
- Palermo, C., Walker, K., Hill, P., McDonald, J. and Wilson, A. (2007), "Development of a healthy food basket for Victoria", *Australian and New Zealand Journal of Public Health*, Vol. 31 No. 4, pp. 360-363.

- Pallas, T. (2009), "National local government and public works engineering conference", pp. 1-29.
- Paterson, R. R. M. and Lima, N. (2010), "How will climate change affect mycotoxins in food?", Food Research International, Vol. In Press, Corrected Proof.
- Pitera, K. (2008), "Interpreting Resiliency: An Examination of the Use of Resiliency Strategies within the Supply Chain and Consequences for the Freight Transportation System", Department of Civil and Environmental Engineering, Seattle, WA, University of Washington.
- Portland Group and SAHA (2008), "Four key supply chains opportunities for innovation", NSW Department of State and Regional Development. pp. 1-180.
- Preston, B. L., Abbs, D., Beveridge, B. and al., e. (2007), "Spatial approaches for assessing vulnerability and consequences in climate change assessments", in Oxley, L. and Kulasiri, D. (Eds.) MODSIM 2007 International Congress on Modelling and Simulation. , pp. 261-267.
- Rab, MA., Fisher, P., & O'Halloran, N.,. (2008). Preliminary estimation of the carbon footprint of the Australian vegetable industry. Horticulture Australia Limited project VGO8107.
- Riddell, A. (2009), "Agribusiness in Australia", IBISWorld Industry Report X0005, pp. 1-44.
- Riddell, A. (2009), "Citrus, banana and other fruit growing in Australia", IBISWorld Industry Report A0114, pp. 1-44.
- Riddell, A. (2009), "Fruit and vegetable processing in Australia", IBISWorld Industry Report C2130, pp. 1-44.
- Riddell, A. (2009), "Fruit and vegetable wholesaling in Australia", IBISWorld Industry Report F4715, pp. 1-45.
- Riddell, A. (2009), "Fruit juice drink manufacturing in Australia", IBISWorld Industry Report C2187, pp. 1-41.
- Riddell, A. (2009), "Grape growing in Australia", IBISWorld Industry Report A0114, pp. 1-38.
- Riddell, A. (2009), "Stone fruit growing in Australia", IBISWorld Industry Report A0114, pp. 1-35.
- Riddell, A. (2009), "Vegetable growing in Australia", IBISWorld Industry Report A0113, pp. 1-36.
- Robinson, B. and Powrie, S. (2004), "Oil depletion: the crucial factors in transport planning", 27th Australasian Transport Research Forum, Adelaide, Australia, pp. 1-13.
- Royal Commission into the Grains Storage, Handling and Transport. 1988. Australia Government Publishing Service, Canberra. Volumes 1 to 3. ISBN: 0 644 0723 2 6.
- Sallman, N. (2009), "Apple & pear growing in Australia", IBISWorld Industry Report A0114, pp. 1-37.
- Saunders, C., Barber, A. and Taylor, G. (2006), "Food Miles - Comparative Energy/Emissions performance of New Zealand's Agriculture Industry", Agribusiness and Economics Research Unit (AERU), Lincoln University pp. 1-103.
- Schaafsma, A. W. and Hooker, D. C. (2007), "Climatic models to predict occurrence of Fusarium toxins in wheat and maize", International Journal of Food Microbiology, Vol. 119 No. 1-2, pp. 116-125.
- Smith, A., Watkiss, P., Tweddle, G., McKinnon, A., Browne, M., Hunt, A., Treleven, C., Nash, C. and Cross, A. (2005), "The validity of Food Miles as an Indicator of Sustainable Development", Oxon, UK, DEFRA p. 103.
- Stern, E. and Zehavi, Y. (1990), "Road safety and hot weather: a study in applied transport geography", Transactions of the Institute of British Geographers, Vol. 15, pp. 102-111.
- Stewart, M. (2007), "Impact of Climate on Current Price Volatility of Fruit and Vegetables", Herald Sun.
- Stopford, M. (2009), Maritime Economics, Routledge, New York, NY.

- Strosnider, H., et al. (2006), "Workgroup Report: Public Health Strategies for Reducing Aflatoxin Exposure in Developing Countries", *Environ. Health Perspectives*, Vol. 114 No. 12, pp. 1898-1903.
- Sullivan, J. K. (1977), "Effects of salinity and temperature on the acute toxicity of cadmium to the estuarine crab *Paragrapsus gaimardii* (Milne Edwards).", *Australian Journal of Marine and Freshwater Research*, Vol. 28 No. 6, pp. 739-743.
- Svensson, G. (2000), "A conceptual framework for the analysis of vulnerability in supply chains ", *International Journal of Physycal Distribution & Logistics Management*, Vol. 30 No. 9, pp. 731-749.
- Tassou, S. A., De-Lille, G. and Ge, Y. T. (2008), "Food Transport Refrigeration-Approaches to Reduce Energy Consumption and Environmental Impacts of road transport", *Applied Thermal Engineering*, pp. 1-10.
- ten Veldhuis, J. A. E., Clemens, F. H. L. R., Sterk, G. and Berends, B. R. (2010), "Microbial risks associated with exposure to pathogens in contaminated urban flood water", *Water Research*, Vol. In Press, Accepted Manuscript.
- The NSW Chamber of Fruit & Vegetable Industries Inc (2008), "Submission to the ACCC Inquiry," pp. 1-7.
- The World Bank (2009), "Global Economic Prospects ", Washington, DC., pp. 1-196.
- Ugalde, D., Brungs, A., Kaebernick, M., McGregor, A. and Slattery, B. (2007), "Implications of climate change for tillage practice in Australia", *Soil and Tillage Research*, Vol. 97 No. 2, pp. 318-330.
- van der Vorst, J., G.A.C., Tromp, S. and van der Zee, D. J. (2009), "Simulation modelling for food supply chain redesign: Integrated decision making on product quality, sustainability and logistics", *International Journal of Production Research*, pp. 1-21.
- Van Dyk, F.E. and Maspero, E. 2004. An analysis of the South African fruit logistics infrastructure. *ORiON*, 20(1), 55-72.
- Victorian Department of Transport (2008b). The Melbourne metropolitan freight movement task. Policy and Communications Division.
- Wagner, S. M. and Bode, C. (2006), "An empirical investigation into supply chain vulnerability", *Journal of Purchasing and Supply Management*, Vol. 12 No. 6, pp. 301-312.
- Wang, C.-H. and Wang, X. (2009), "Hazard of extreme wind gusts to buildings in Australia and its sensitivity to climate change", in Anderssen, R. S., R.D. Braddock. and Newham., L. T. H. (Eds.) 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation.
- William, D., Friedlingstein, P., Amadou, T. G. and Gregory, J. M. e. a. (2007), "Global Climate Projections", in Meehl, G. and Stocker, T. F. (Eds.) IPCC 4th Assessment Report, pp. 747-845.
- Williams, A. G., Pell, E., Webb, J., Evans, D., Moorhouse, E., Watkiss, P. (2009), "Comparative Life Cycle Assessment of Food Commodities Procured for UK Consumption Through a Diversity of Supply Chains", Final Report for Defra Project FO0103, DEFRA pp. 1-25.
- Williams, A. G., Pell, E., Webb, J., Evans, D., Moorhouse, E., Watkiss, P. (2009), "Comparative Life Cycle Assessment of Food Commodities Procured for UK Consumption Through a Diversity of Supply Chains", Final Report for Defra Project FO0103, DEFRA pp. 1-25.
- Woolworths Limited (2008), "Public submission to ACCC Grocery Inquiry ", pp. 1-34.
- World Economic Forum (2008), "Consignment-level carbon reporting", pp. 1-18.
- World Economic Forum (2009), "Supply chain decarbonization: the role of logistics and transport in reducing carbon emission", in Doherty, S. and Hoyle, S. (Eds.), pp. 1-41.



## Appendix A. Development of a Supply Chain Database Tool

The Supply Chain Database Tool is implemented in MS Access 2003 and run by opening the file “VEIL\_FV\_Emissions.mdb”.

### A1 Overview of Database and Base Data

The Supply Chain Database Tool consists of Access queries performed on Excel input tables in order to obtain estimates of emissions produced by the transport and distribution of fruits and vegetables in Victoria. The tool aims to provide relative (instead of absolute) measures of emissions indicative of the efficiencies that can be obtained from a base scenario with the application of various food transport and distribution policies and strategies. The tool covers food transport between the National Resource Management (NRM) regions, listed grocery stores, the major supermarket chains (Coles, Woolworth, IGA/Foodworks, Aldi), and distribution centres (DCs), major food processing centres (Simplot, McCain, National Foods, SPC) and Melbourne Market Authority (MMA). Figure A1 shows a map of the Victorian NRMs and the locations of these fruit and vegetable production and distribution points.

Due to limitations resulting from the absence or unavailability of data, the Database Tool has applied several simplifying assumptions to the supply chain by assuming that produce moves in the shortest route from NRMs and export/import points to distribution centres, processors or MMA and then to supermarkets and grocery stores. Households only travel to the nearest supermarket and grocery store to purchase their fruits and vegetables.

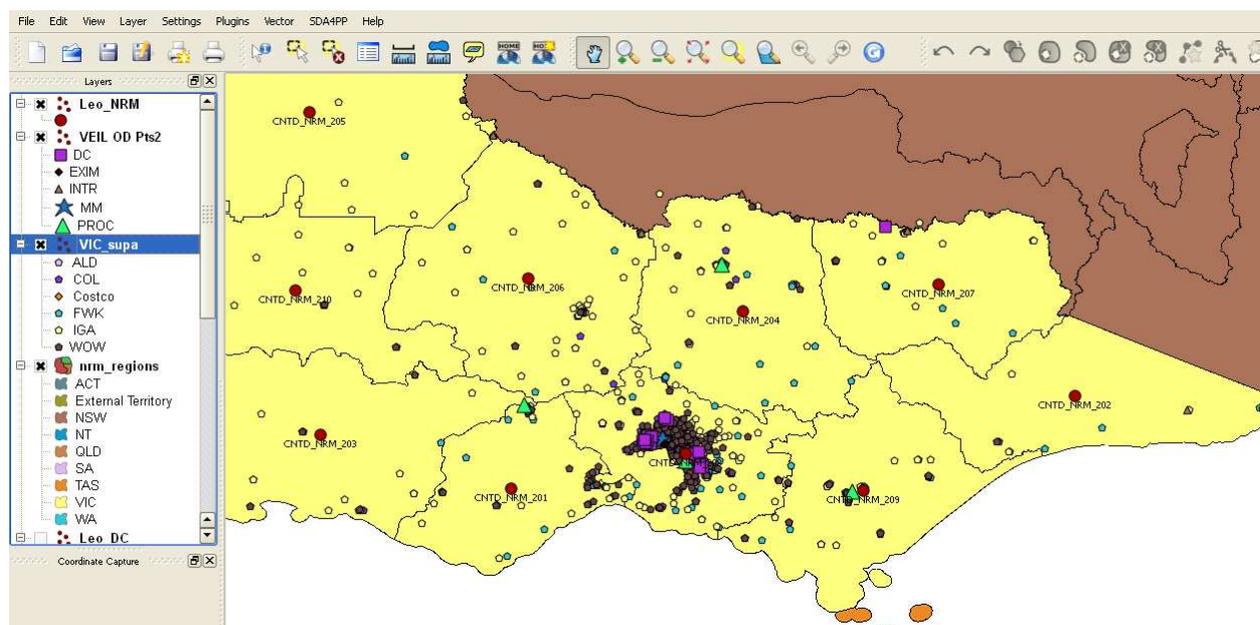


Figure A1. Victorian NRMs, distribution centres, food processing centres, and major supermarket locations.

Excel tables are used to store the input data and various scenario parameters for the base scenario. The Excel sheets are accessed using linked tables, denoted by the objects with the Excel icon in the Tables window of Figure A2.

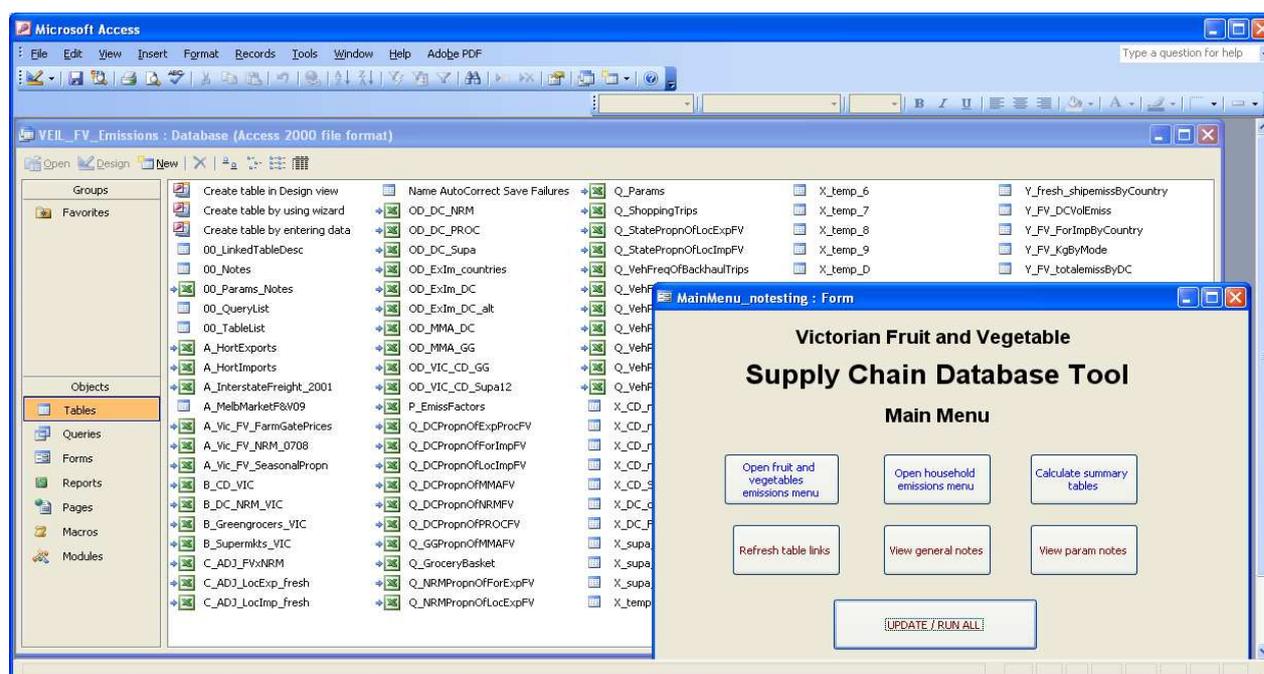


Figure A2. Components (tables, forms, queries) and main menu of the database tool. The tables objects list shows the linked tables to the Excel files. The main menu has three main parts: a) a fruit and vegetables emissions menu, b) household emissions and c) calculation of summary tables.

Table A1 describes the contents of the linked tables and identifies the associated Excel source workbook and sheet. Some of the principal data and assumptions used to define the base scenario include:

- Fruit production in Victoria for 2007-2008 is taken from Table 2 FRUIT AND NUTS PRODUCTION, NRM REGION–Victoria–Year ended 30 June 2008, ABS Catalog No. 71210DO007\_200708. This table is in sheet “FVxNRM” of file “Fruit and vegetable summary\_rev1.xls” and accessed using the table link “A\_Vic\_FV\_NRM\_0708”.
- Vegetable production in Victoria for 2007-2008 is taken from Table 2 VEGETABLE PRODUCTION, STATE AND NRM–Victoria–2007–08, ABS Catalog No. 71210DO005\_200708. This table is in sheet “FVxNRM” of file “Fruit and vegetable summary\_rev1.xls” and accessed using the table link “A\_Vic\_FV\_NRM\_0708”.
- Foreign export data for 2007-2008 from Dept. of Primary Industries Horticulture Exports Imports by State and Port. Export points are the given ports of entry (Melbourne, Brisbane, Sydney). This table is in sheet “Exports” of file “Horticulture Exp Imp by State and Port.xls” and accessed using the table link “A\_HortExports”.
- Foreign import data for 2007-2008 from Dept. of Primary Industries Horticulture Exports Imports by State and Port. Import points are the given ports of entry (Melbourne, Brisbane, Sydney). This table is in sheet “Imports” of file “Horticulture Exp Imp by State and Port.xls” and accessed using the table link “A\_HortImports”.
- Volumes of fruit and vegetables imported into Victoria from interstate for 2007-2008 are obtained from the 2001 ABS Freight Movements data, presented in table “A\_InterstateFreight\_2001”. The 2007 volumes for fruit and vegetables are obtained by multiplying the 2001 volumes for the commodity “Food (for human and animal consumption)” by the parameter “FoodFreightExpFactor”. “FoodFreightExpFactor” is entered in sheet “AddlParams” of file “VEIL\_Misc\_Params.xls” and accessed using the table link “Q\_Params”.
- Collection districts (CD) contain information on households and consumers. CD population values for 2006 are accessed using the table link “B\_CD\_VIC” and are then scaled up to 2007 levels using the factor “PopnExpfactor”. “PopnExpfactor” is entered in sheet “AddlParams” of file “VEIL\_Misc\_Params.xls” and accessed using the table link “Q\_Params”.

- The proportion of F&V in a representative supermarket trolley is obtained from the CHOICE grocery basket described in Table 8.6. This table is entered in sheet “GroceryBasket” of file “VEIL\_Misc\_Params.xls” and accessed using the table link “Q\_GroceryBasket”.

Table A1 Excel sources and linked tables used to access the input data and parameters for the base scenario.

LinkedTable	Description	SourceFile	SheetName
00_Params_Notes	Additional notes from VEIL_Misc_Params.xls	VEIL_Misc_Params.xls	Notes
A_HortExports	Volumes of F&V exports from Victoria to overseas destinations via ports for 2007-2008	Horticulture Exp Imp by State and Port.xls	Exports
A_HortImports	Volumes of F&V imports into Victoria from overseas sources via ports for 2007-2008	Horticulture Exp Imp by State and Port.xls	Imports
A_InterstateFreight_2001	Volume (in tonnes) of interstate trade between Australian states in 2001	ABS 2001 interstate freight.xls	Table1 Tonnes
A_Vic_FV_FarmGatePrices	Farm gate prices for 2007-2008 for selected fruits and vegetables	Fruit and vegetable farm gate prices.xls	FV_FarmGatePrices
A_Vic_FV_NRM_0708	Volumes of production of 7 fruits and 28 vegetables in Victoria for 2007-2008	Fruit and vegetable summary_rev1.xls	FVxNRM
A_Vic_FV_SeasonalPropn	Monthly allocation of volumes and emissions based on seasonal availability	Fruit and vegetable summary_rev1.xls	Seasonal
B_CD_VIC	Names and attributes of Victorian collection districts	VEIL OD Pts2.xls	VIC_CD2006
B_DC_NRM_VIC	Names and attributes of NRM centroids, distribution centres (DC), Melbourne Market (MM), processing centres, and export/import points.	VEIL OD Pts2.xls	VIC_Orig_pts
B_Greengrocers_VIC	Names and attributes of Victorian grocery stores	VEIL OD Pts2.xls	VIC_greengrocers
B_Supermkts_VIC	Names and attributes of Victorian supermarkets	VEIL OD Pts2.xls	VIC_supa
OD_ExIm_countries	Sea distances between Australian ports and partner countries	VEIL_OD_DC.xls	ExIm_countries
OD_DC_NRM	Route distance matrix for transport from NRMs to DCs, MM, and PROCs	VEIL_OD_DC.xls	DC_NRM
OD_DC_PROC	Route distance table for transport from PROCs to DCs and MM	VEIL_OD_DC.xls	PROC_DC
OD_DC_Supa	Route distance table for transport from DCs to supermarkets	VEIL_OD_supermkts.xls	OD_DC_Supa
OD_ExIm_DC	Route distance table for transport between export/import points and NRM, DC, MM, PROCs	VEIL_OD_DC.xls	ExIm_DC_long
OD_ExIm_DC_alt	Shortened route distance table for transport between export/import points and NRM, DC, MM, PROCs	VEIL_OD_DC.xls	ExIm_DC_alt
OD_MMA_DC	Route distance table for transport from MM to DCs	VEIL_OD_DC.xls	MMA_DC
OD_MMA_GG	Route distance table for transport from MM to grocery stores	VEIL_OD_greengrocers..xls	OD_MMA_GG
OD_VIC_CD_GG	Route distance table for transport between collection districts and nearest grocery store	VEIL_OD_greengrocers..xls	OD_CD_GG
OD_VIC_CD_Supa12	Route distance table for transport between collection districts and two nearest supermarkets	VEIL_OD_supermkts.xls	VIC_CD_dist12
P_EmissFactors	Table of emission factors per transport mode, type and fuel for delivery trip, refrigeration and backhaul trips. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	EMISSION FACTORS
Q_DCPropnOfExpProcFV	Proportion of exported processed F&V imports allocated to DCs. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	DCPropnOfExpProcFV
Q_DCPropnOfForImpFV	Proportion of foreign F&V imports allocated to DCs. See	VEIL_Misc_Params.xls	DCPropnOfForImpFV

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LinkedTable	Description	SourceFile	SheetName
	00_Params_Notes for details.		
Q_DCPropnOfLocImpFV	Proportion of local F&V imports allocated to DCs. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	DCPropnOfLocImpFV
Q_DCPropnOfMMAFV	Proportion of F&V volumes from MM allocated to DCs. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	DCPropnOfMMAFV
Q_DCPropnOfNRMFV	Proportion of F&V volumes from NRM allocated to DCs, MM and PROCs. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	DCPropnOfNRMFV
Q_DCPropnOfPROCFV	Proportion of F&V volumes from PROCs allocated to DCs. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	DCPropnOfPROCFV
Q_GGPropnOfMMAFV	Proportion of F&V volumes from MM allocated to grocery stores. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	GGPropnOfMMAFV
Q_GroceryBasket	Table of items and weights in the CHOICE grocery basket	VEIL_Misc_Params.xls	GroceryBasket
Q_NRMPropnOfForExpFV	Proportion of foreign F&V exports sourced to NRMs. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	NRMPropnOfForExpFV
Q_NRMPropnOfLocExpFV	Proportion of local F&V exports sourced to NRMs. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	NRMPropnOfLocExpFV
Q_Params	Table of additional single value parameters.	VEIL_Misc_Params.xls	AddlParams
Q_StatePropnOfLocExpFV	Proportion of local F&V imports allocated to states based on 2008 population. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	StatePropnOfLocExpFV
Q_StatePropnOfLocImpFV	Proportion of local F&V imports allocated to states. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	StatePropnOfLocImpFV
Q_VehFreqOfBackhaulTrips	Proportion of vehicles by mode, type and fuel that perform backhaul trips. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	VehFreqOfBackhaulTrips
Q_VehFreqOfRefrigTrips	Proportion of vehicles by mode, type and fuel that contain refrigeration. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	VehFreqOfRefrigTrips
Q_VehPayload	Average payload of vehicles by mode and type. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	VehPayload
Q_VehPropnOfDCTrips	Proportion of vehicles by mode, type and fuel allocated for transport of F&V volumes from DCs to supermarkets or from MM to grocery stores. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	VehPropnOfDCTrips
Q_VehPropnOfExlmTrips	Proportion of vehicles by mode, type and fuel allocated for transport of local and foreign export/import volumes. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	VehPropnOfExlmTrips
Q_VehPropnOfNRMTrips	Proportion of vehicles by mode, type and fuel allocated for transport of F&V volumes from NRM to DCs, MM and PROCs. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	VehPropnOfNRMTrips
Q_VehPropnOfSupaTrips	Proportion of vehicles by mode, type and fuel allocated for transport of F&V volumes from collection districts to supermarkets or grocery stores. See 00_Params_Notes for details.	VEIL_Misc_Params.xls	VehPropnOfSupaTrips

## A2 Structure of Database Tool

The database tool has 2 secondary menu buttons and five action buttons as shown in the main menu in Figure A2.

The secondary menus are described as follows:

1. The fruit and vegetables (F&V) emissions menu (as shown in Figure B3) provides options for investigating the processes involved in computing the trips made, vehicle kilometres (veh-kms) covered and emissions associated with fruit and vegetable transport and distribution in Victoria;
2. The household emissions menu (as shown in Figure B5) provides options for investigating the processes involved in computing the trips made, vehicle kilometres covered and emissions associated with the purchase of fruit and vegetables by households grouped by collection districts (CDs).

The five action buttons are described as follows :

1. The button “UPDATE/RUN ALL” at the bottom of the menu allows a complete run of F&V and household emissions calculations to be performed with just one click. Otherwise, the individual buttons in the F&V emissions menu and household emissions menu allow the user to examine the individual components of the simulation process.
2. After a simulation run is completed, “Calculate summary tables” performs additional computations to extract tables containing summary values.
3. The button “Refresh table links” allows the user to specify a new directory as the source of all the Excel-based input data.
4. The button “View general notes” provides general information on tables and parameter used by the model.
5. The button “View param notes” provides more detail on the contents of the parameter tables.

### ***A3 Emissions Menu for Fruit and Vegetable Transport***

Figure A3 shows the components of the fruit and vegetable (F&V) emissions menu. Boxes with red or purple text indicate tables of input data. Boxes with black text indicate tables of intermediate results from queries while boxes with blue text indicate tables of final results.

When read from top to bottom, the F&V emissions menu diagrams the estimation process as follows:

1. From the topmost row, input data is obtained on F&V production levels in Victoria, as well as volumes of F&V imports from foreign and local (interstate) sources, and F&V exports to foreign and local destinations.
2. Next row displays the input data used to allocate the F&V volumes to the NRMs or distribution and processing centres.
  - a. (left) Input data on table of proportions used to allocate the export volumes to the different source NRMs (and destination states for local exports)
  - b. (centre) Input data on table of proportions used to allocate the production volumes to grocery stores (GG), Melbourne Market (MMA), supermarket distributions centres (DCs), and F&V processing centres (PROCs).
  - c. (right) Input data on table of proportions used to allocate the import volumes to the different supermarket distributions centres (DCs), F&V processing centres (PROCs) or Melbourne Market (MMA).
3. Using data from (1) and (2), calculate the F&V volumes transported.
  - a. (left) Estimated F&V volumes transported from the NRMs to interstate capital (local export) or shipping port (foreign export).
  - b. (centre) Estimated F&V volumes transported from the NRMs to the different grocery stores (MMA-GG), supermarket distributions centres (DCs), F&V processing centres (PROCs) or Melbourne Market (MMA), or from MMA-to-DCs, or from PROCs-to-DCs.
  - c. (right) Estimated F&V volumes transported from interstate capitals (local import) or shipping port (foreign import) to the different supermarket distributions centres (DCs), F&V processing centres (PROCs) or Melbourne Market (MMA).

- d. Aggregating the volumes transported to DCs from NRMs, PROCs and MMA (3b) and local and foreign imports (3c) , gives the table of “F&V total volumes transported to DC”.

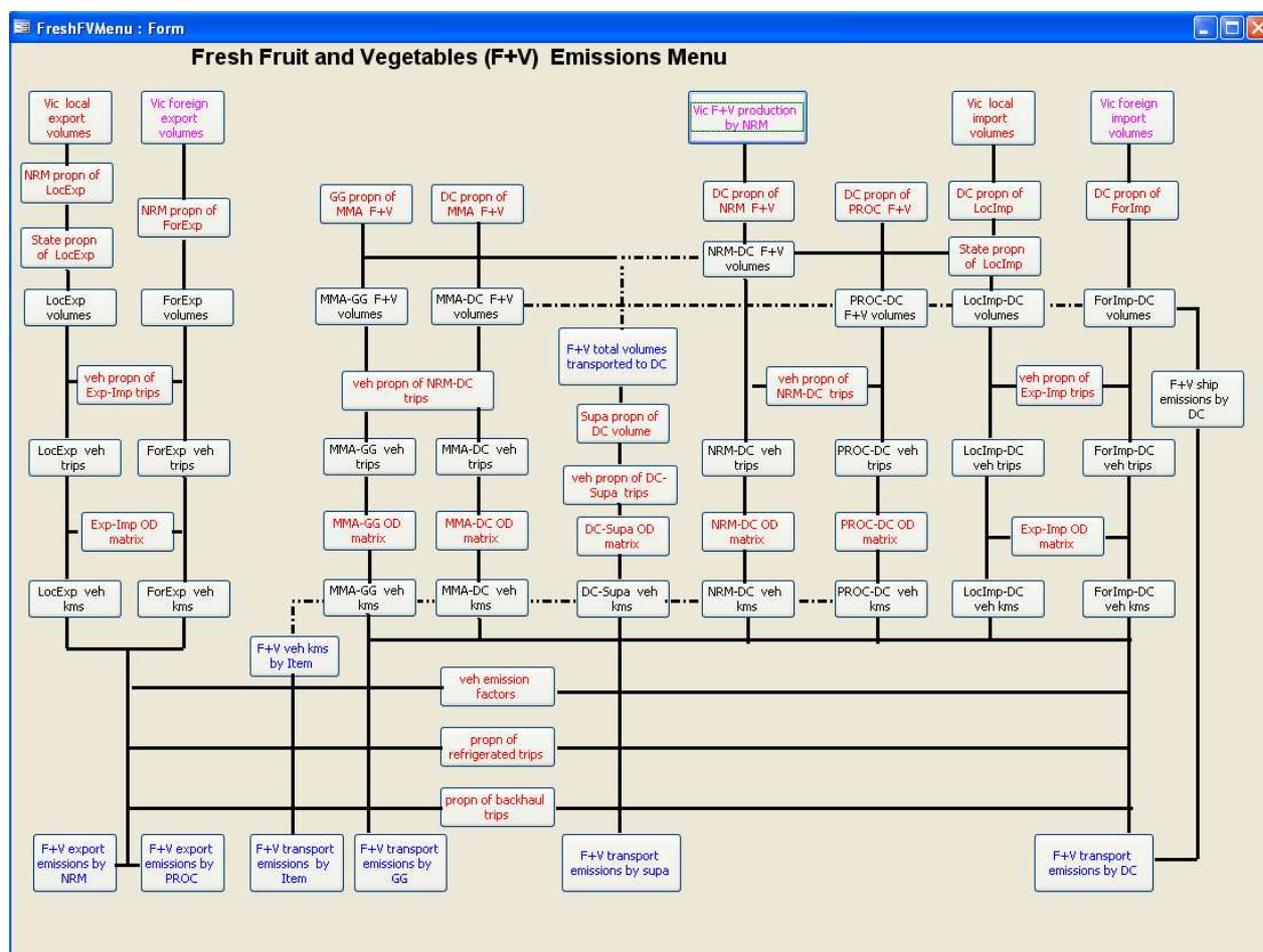


Figure A3. Components of the F&V emissions model. When read from top to bottom, the model shows in sequence process for: a) the distribution of F&V production into GGs and DCs, b) the computation of vehicle trips, c) the calculation of vehicle kms covered, and finally d) the calculation of emissions and fuel use produced by the trips.

4. Next row displays the input data used to indicate how much of the F&V volumes are transported by which mode/type of vehicle.
  - a. (left) Input data on proportions of F&V volumes for import or export transported by vehicle mode/type.
  - b. (centre) Input data on proportions of F&V volumes from Victorian production transported by vehicle mode/type.
  - c. (right) Input data on proportions of F&V volumes for import or export transported by vehicle mode/type.
5. Using data from (3) and (4), calculate the number of trips required to transport the F&V volumes using the vehicle mode/types specified.
  - a. (left) Estimated number of trips made from the NRMs to interstate capital (local export) or shipping port (foreign export).
  - b. (centre) Estimated number of trips made from the NRMs to the different grocery stores (MMA-GG), supermarket distributions centres (DCs), F&V processing centres (PROCs) or Melbourne Market (MMA), or from MMA-to-DCs, or from PROCs-to-DCs.
  - c. (right) Estimated number of trips made from interstate capitals (local import) or shipping port (foreign import) to the different supermarket distributions centres (DCs), F&V processing centres (PROCs) or Melbourne Market (MMA).

6. Next row displays the input data used to indicate the distances between origin-destination (OD) points for the trips. These distances represent route distances via the road network obtained from Google Earth.
7. Using data from (5) and (6), calculate the vehicle kilometres (veh-kms) covered by the trips.
  - a. (left) Estimated veh-kms covered for F&V volumes transported from the NRMs to interstate capital (local export) or shipping port (foreign export).
  - b. (centre) Estimated veh-kms covered for F&V volumes transported from the NRMs to the different grocery stores (MMA-GG), supermarket distributions centres (DCs), F&V processing centres (PROCs) or Melbourne Market (MMA), or from MMA-to-DCs, or from PROCs-to-DCs.
  - c. (right) Estimated veh-kms covered for F&V volumes transported from interstate capitals (local import) or shipping port (foreign import) to the different supermarket distributions centres (DCs), F&V processing centres (PROCs) or Melbourne Market (MMA).
  - d. “DC-Supa veh kms” calculates the veh-kms covered for F&V volumes transported from DCs to the local supermarkets.
  - e. “MMA-GG veh kms” calculates the veh-kms covered for F&V volumes transported from MMA to the grocery stores.
  - f. “F&V veh kms by Item” calculates the aggregated veh-kms covered for each F&V item or product type.
8. “veh emission factors” displays the input data used to indicate the emissions factors for the vehicle modes associated with transport portion, refrigeration portion and return (backhaul) portion of the trip.
9. “propn of refrigerated trips” displays the input data used to indicate the proportion of the vehicles used that are refrigerated.
10. “propn of backhaul trips” displays the input data used to indicate proportion of the vehicles that make a return (backhaul) trip.
11. Using data from (7), (8), (9) and (10), calculate the emissions (in kilograms) produced by the trips.
  - a. “F&V ship emissions by DC” calculates the estimated emissions from shipping F&V volumes imported by DCs from partner countries to Australian ports.
  - b. “F&V export emissions by NRM” calculates the estimated emissions for F&V volumes exported from the NRMs.
  - c. “F&V transport emissions by Item” aggregates the estimated emissions from all sources by F&V item or product type. Figure B4 shows the MS Access representation of this query.
  - d. “F&V transport emissions by GG” calculates the estimated emissions for F&V volumes delivered to the grocery stores from MMA.
  - e. “F&V transport emissions by supa” calculates the estimated emissions for F&V volumes delivered to the supermarkets from DCs.
  - f. “F&V transport emissions by DC” calculates the estimated emissions for F&V volumes delivered to the DCs from all sources.

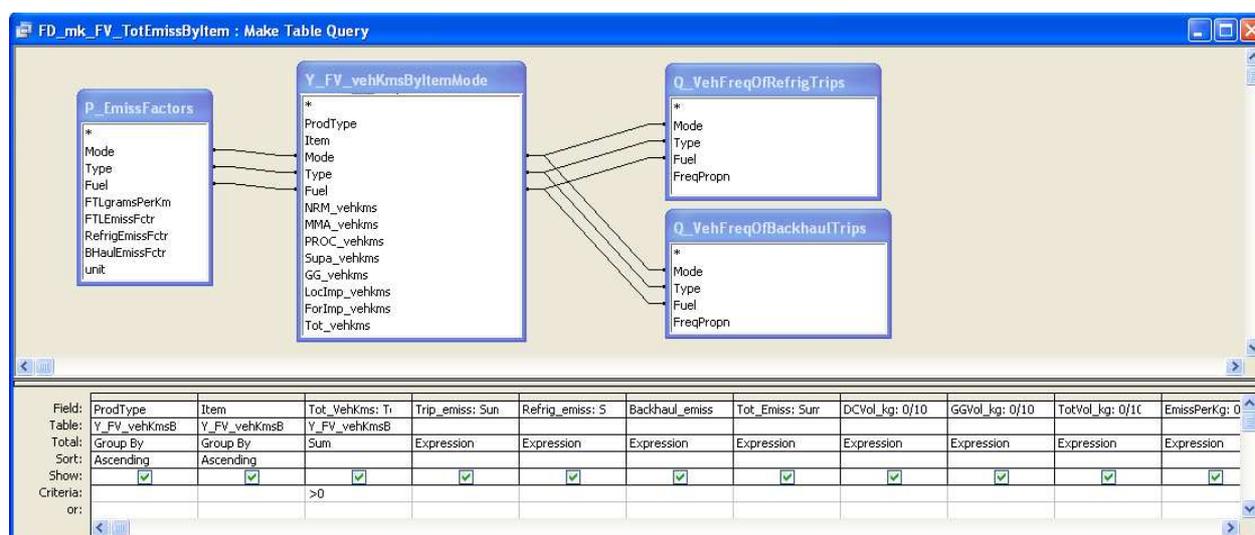


Figure A4. Query for calculating the total emissions by vehicle mode/type.

### A4 Emissions Menu for Household Trips

The calculation of emissions for household trips assumes that each household makes an average 30.40 trips to the supermarket per year and 15.51 trips to the grocery store per year. These are estimates derived from the total 88.4 trips (1.7 trips per household per week x 52 weeks) to food sources that an average household makes in a year (Metcash, 2008).

A simple rule has been applied to allocate trips between the collection districts (CDs) and supermarkets and grocery stores.

- i. If the nearest supermarket to a given CD is within 50 km, the per capita supermarket trips is multiplied with the population of a collection district (CD) to obtain the total trips in a year made from the centroid of that CD to the supermarket.
- ii. For the same CD, if the nearest grocery store is within 20 km, the per capita grocery stores trips is multiplied to the population of a collection district (CD) to obtain the total trips in a year made from the centroid of that collection district to the grocery store. These trips are added to the supermarket trips. If the grocery store is farther than 20 km, no grocery store trips are added.
- iii. If both the nearest supermarket and grocery store are more than 50 kilometers away, only supermarket trips are made to whichever is closer between the supermarket or grocery store.
- iv. The emissions are then computed from the vehicle kilometres covered by each (two-way) trip.

Figure B5 shows the components of the household emissions menu. Boxes with red or purple text indicate tables of input data. Boxes with black text indicate tables of intermediate results from queries while boxes with blue text indicate tables of final results.

Read from top to bottom, the household emissions menu diagrams the estimation process as follows:

12. From the topmost row, “Preferred supa by CD” is the input data on the distances of supermarkets from each collection district. The two supermarkets nearest to each CD are identified and grocery trips are made from the CD to these supermarkets only.
13. “Catchment popn by supa” aggregates the population of CDs within each supermarket catchment. Populations are allowed to be double counted in this process.
14. “Demand propn by supa” assigns a proportion of fruits and vegetable volume to be delivered to the supermarket from a DC based on the supermarket’s catchment population and its distance from the DC.
15. “CD-Supa OD matrix” and “CD-GG OD matrix” contains the distances between the CDs and the nearest supermarket and grocery store, respectively.



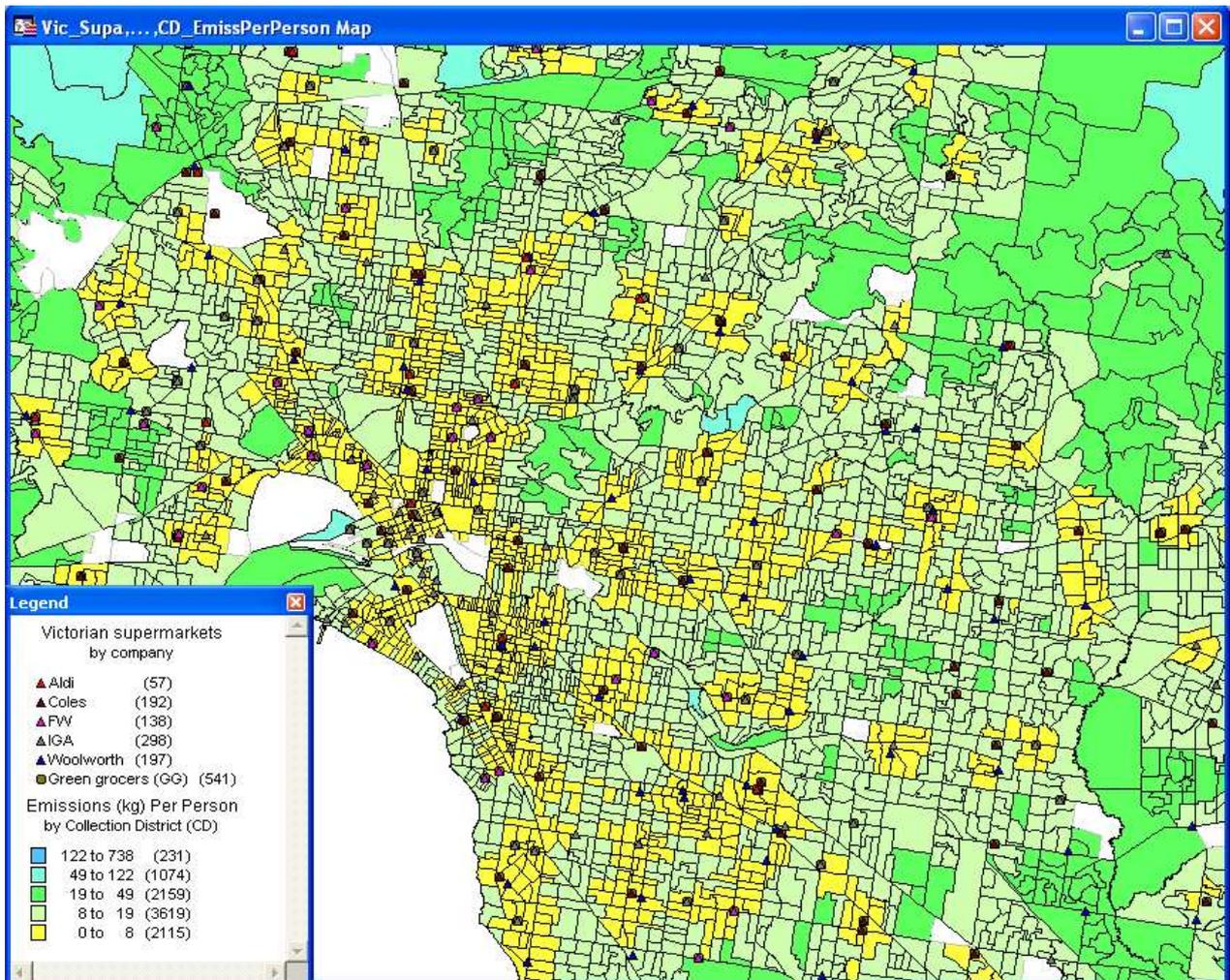


Figure A6. Sample thematic map illustrating the distribution of household emissions for supermarket and grocery store trips from collection districts.

## Appendix B. Development of Stochastic Model

### B1 Handling of transport distances in MS Chain and MM models

All the distributions illustrated in this section and the Monte Carlo simulations have been developed using ModelRisk, a risk modelling program. All simulations were performed using 5,000 iterations.

#### Segment from Farm to Packing House ( $D_{F,PH}$ )

With no information about specific distances from farms to packing houses, it was assumed that the distances between these would be between 0 and 20 km. To represent the potential distance variability in this segment, a normal distribution (as shown in Figure B1.1) was selected.

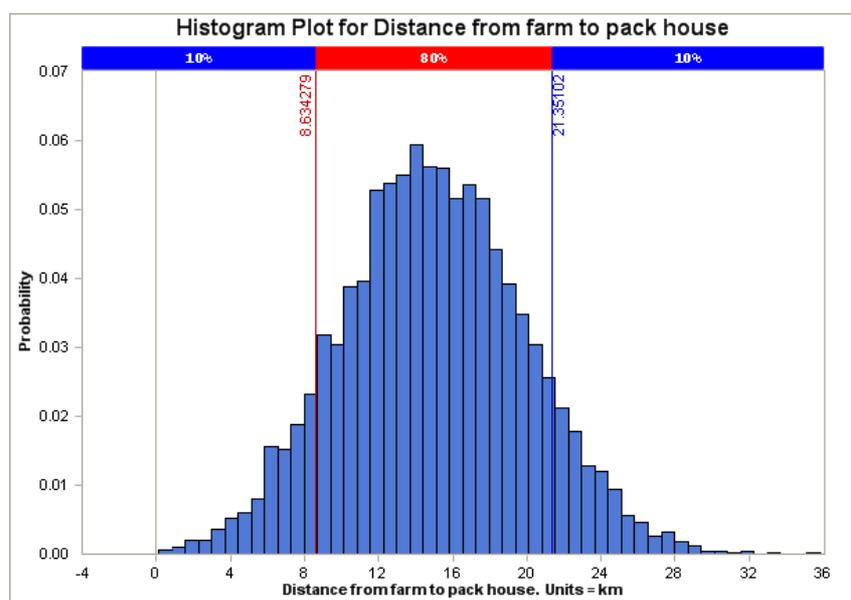


Figure B1.1. Normal distribution used to represent the segment from Victorian farms to packing houses.

#### Segment from growing region (NRM) to DCs ( $D_{NRM,DC}$ )

This segment was represented by two sets of data: one was the results calculated through the deterministic SCDT model, where the distance between the centroid of the NRM and the DCs is used to represent the segment. The second set of data is the calculation between the 16 most important fruit and vegetable production areas in Victoria (eight for vegetables and eight for fruit, as detailed in Section 2.1) and DCs.

The two sets of data were combined into a single set and each value was weighted by assuming a 30% probability for produce transported in the NRM centroid and 70% probability for produce transported from the 16 specific growing regions. All combinations for all distribution centres for the major supermarket chains were used (*i.e.* Woolworth's, Coles, Aldi, FoodWorks and IGA).

Data was modeled using a discrete distribution, where the distance from growing region to DC can take one of the several explicit discrete values shown in Figure B1.2 and where a probability factor is assigned to each value, as discussed before.

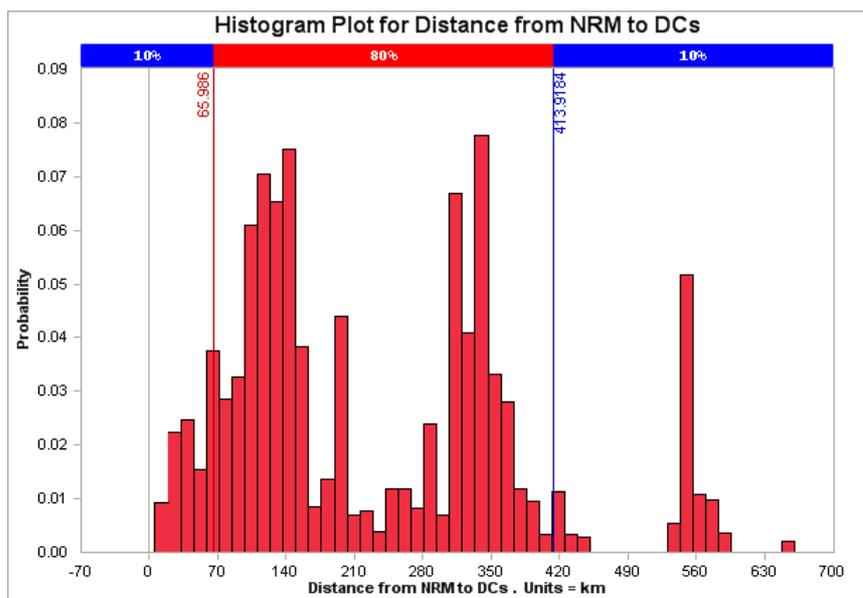


Figure B1.2. Discrete distribution used to represent the segment from Victorian growing regions (*i.e.* packing house) to DCs.

### Segment from growing region (NRM) to MM ( $D_{NRM\_MM}$ )

Similarly to the explanation above, this segment was represented by two sets of data: one was the results calculated through the deterministic SCDT model, where the distance between the centroid of the NRM and Melbourne Markets (MM) is used to represent the segment. The second set of data was built using the distances between the 16 most important fruit and vegetable production areas in Victoria (eight for vegetables and eight for fruit) and MM.

The two sets of data were combined into a single set and each value was weighted by assuming a 30% probability for produce transported in the NRM centroid and 70% probability for produce transported from the 16 specific growing regions.

Data was modelled using a discrete distribution, where the distance from growing region to MM can take one of the several explicit discrete values shown in Figure B1.3, and where a probability factor is assigned to each value.

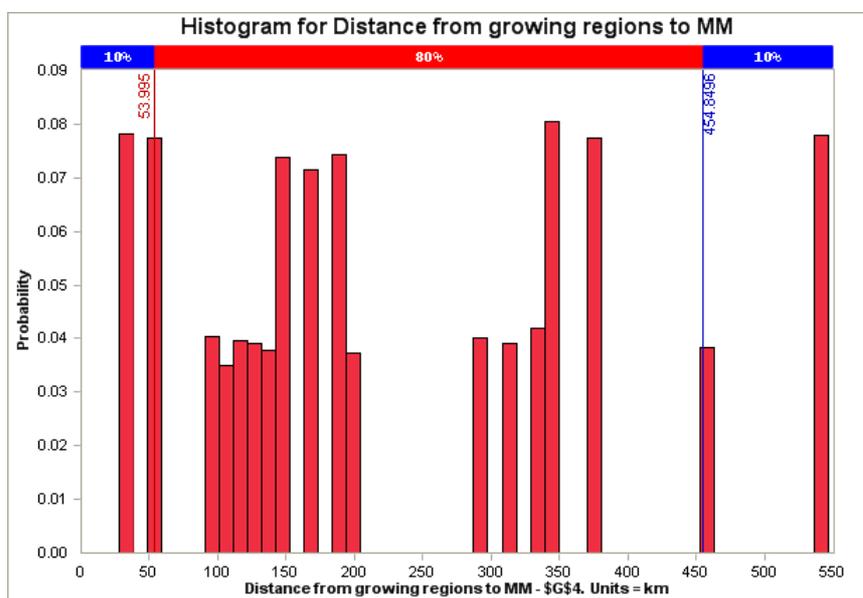


Figure B1.3. Discrete distribution used to represent the segment from Victorian growing regions (i.e. packing house) to MM.

**Segment from imports to MM and DCs ( $D_{L_{DC/MM}}$ )**

A list of countries exporting fruit and vegetables in a fresh state and dispersing these goods in Victoria was generated from DPI data (2009)<sup>23</sup>. An extra segment of 25 km was added to account for the transport of goods to distribution centres<sup>24</sup> located within Melbourne and the Melbourne Markets. Distances and port locations were sourced from two websites: [www.portdistances.com](http://www.portdistances.com) and <http://www.worldportsource.com/>.

The importing frequencies of each country were factored in a discrete distribution, as per the previous segment.

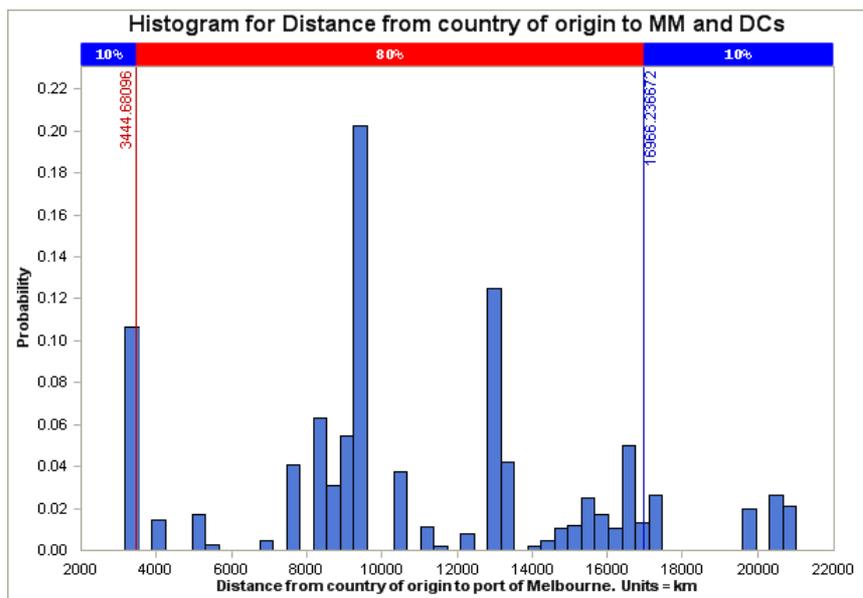


Figure B1.3. Discrete distribution used to represent the segment from country of origin to DCs/Melbourne Market.

**Segment from interstate F&V entering the Victorian chain ( $D_{Inter\_MM}$  and  $D_{Inter\_MSC}$ )**

Distances from the entry point of flows arriving from trading states into Victoria were calculated through the SCDT model. These distances only consider the point of arrival to Victorian territory. Transport activities from the original points of production to the Victorian entry point are ignored.

Figures B1.4a and B1.4b present the discrete distributions used for MSC and MM, which factors the probabilities of sourcing from different states, based on the same probabilities used in the SCDT model.

<sup>23</sup> Data provided by J. Creese, DPI Strategic Market Analysis officer.

<sup>24</sup> All Dcs arer located within this distance, except one Woolworth’s DC located in Albury

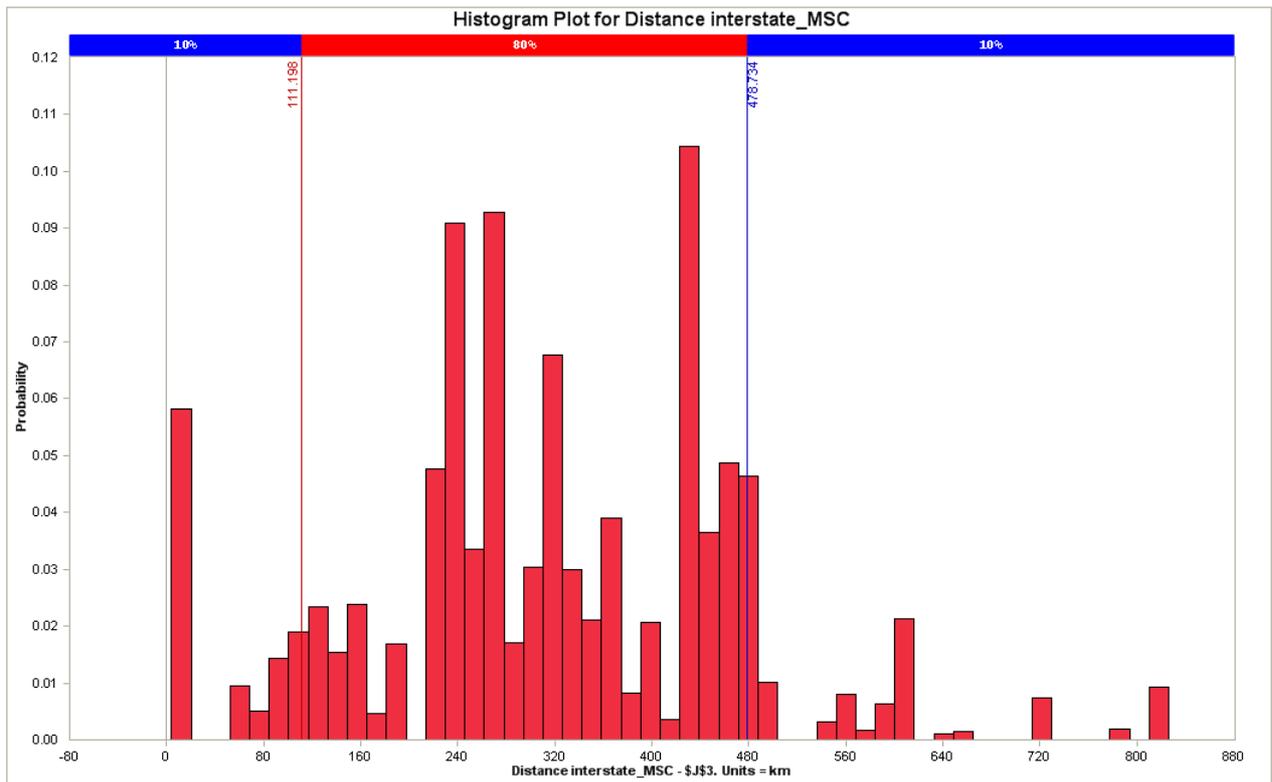


Figure B.1.4a. Discrete distribution used to represent the segment from the interstate trade at the point of entry into the Victorian geographical limits to DCs.

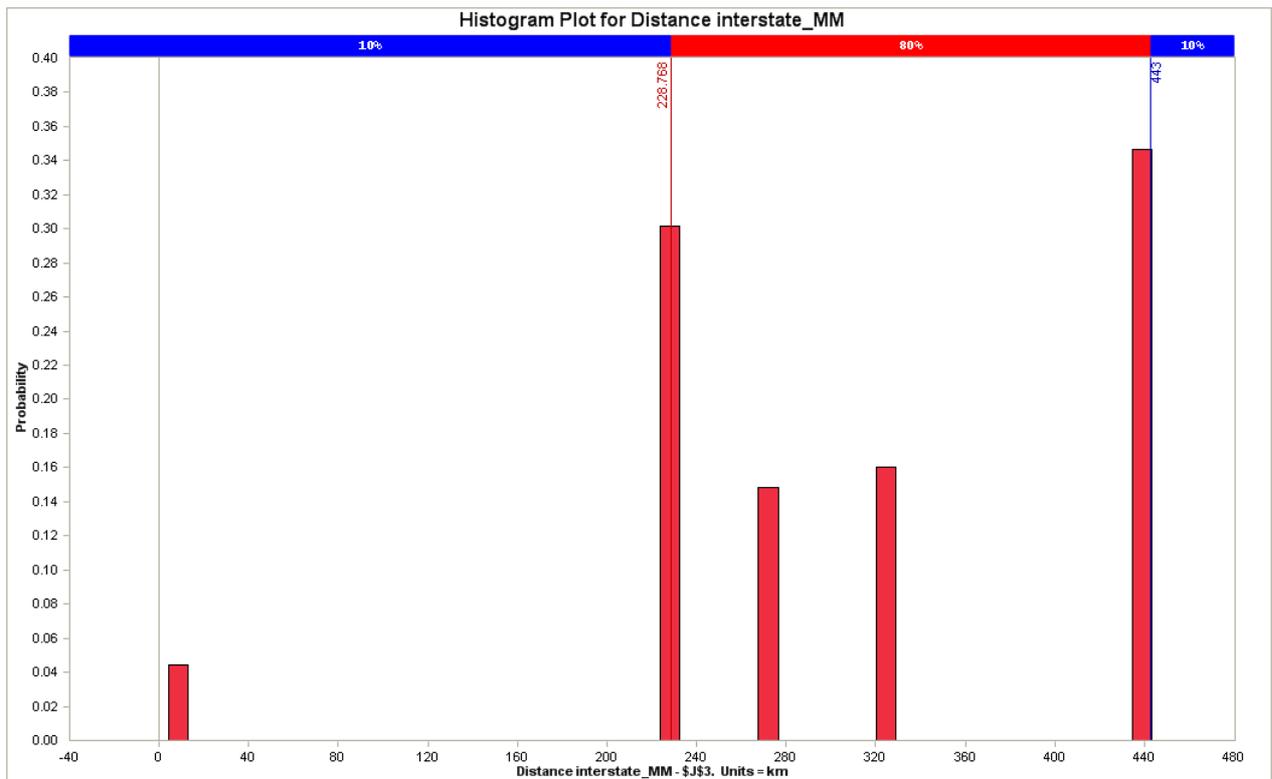


Figure B.1.4b. Discrete distribution used to represent the segment from the interstate trade at the point of entry into the Victorian geographical limits to MM.

**Segment from MM to DCs ( $D_{MM\_DC}$ )**

Data sourced through the SCDT model was used to build a discrete uniform distribution (Figure B1.5). The distance values represent all the potential distances from MM to all DCs from the 5 major supermarket chains analysed in this report.

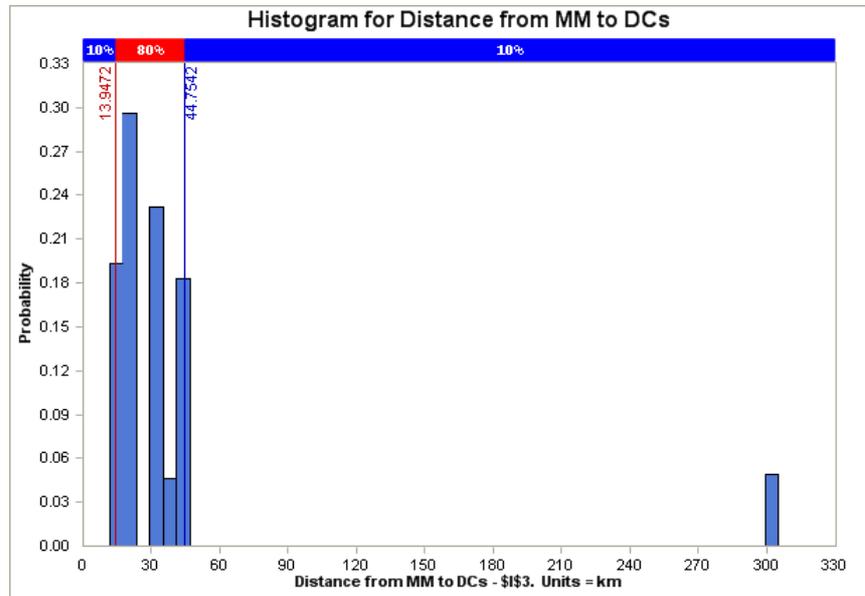


Figure B1.5. Discrete uniform distribution used to represent the segment from Melbourne Market to Victorian DCs.

### Segment from DCs to stores ( $D_{DC\_s}$ )

Data sourced through the SCDT model was used to build a discrete uniform distribution (Figure B1.6). The distance values represent all the potential combinations from all supermarket DCs to their respective stores in Victoria.

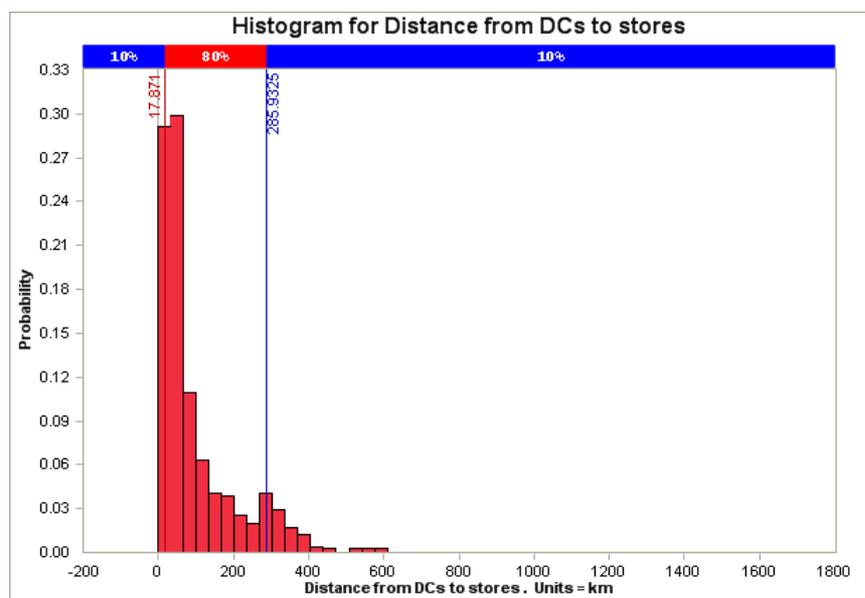


Figure B1.6. Discrete uniform distribution used to represent the segment from DCs to Victorian stores (all supermarkets).

### Segment from MM to greengrocers ( $D_{MM\_GG}$ )

Data sourced through the SCDT model was used to build a discrete uniform distribution (Figure A1.7). The distance values represent all the potential distances from MM to 540 greengrocers based in Victoria used on the analysis.

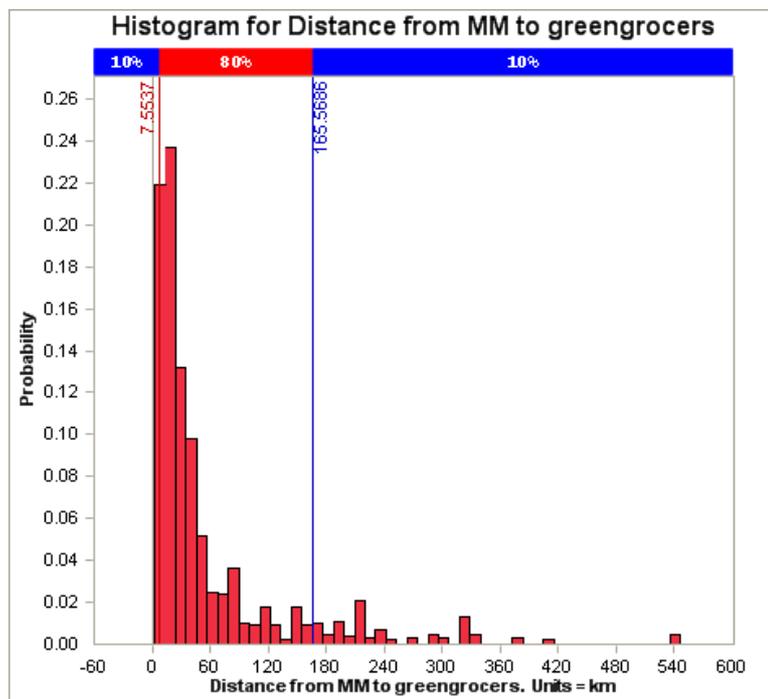


Figure B1.7. Discrete uniform distribution used to represent the segment from MM to a sample of 540 greengrocers based in Victoria.

### Segment from MS stores to consumers ( $D_{s_c}$ )

Data sourced through the SCDT model was used to represent the distances between MS stores and the centroid of 9,298 collection districts (CDs) in Victoria was used to represent this segment. However, it was assumed that the probabilities for each distance value were not the same, as more populated CDs would be likely to be more heavily represented than CDs with less population. Therefore, each CD distance value was weighted by a factor based on the CD population with respect to the total Victorian population.

This data set was used to build a discrete distribution, where the distance from stores to consumers can take one of the several explicit discrete values shown in Figure B1.8, and where the probability factor based on CD population is assigned to each value.

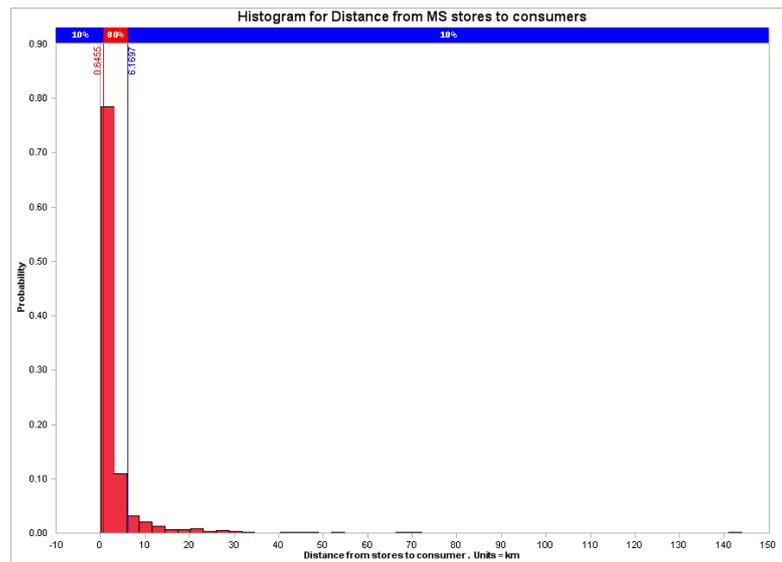


Figure B1.8. Discrete distribution used to represent the segment from MS stores to the 9,298 collection districts based in Victoria.

**Segment from greengrocers to consumers ( $D_{GG_c}$ )**

Data sourced through the SCDT model was used to represent the distances between greengrocers and the centroid of 9,298 collection districts (CDs) in Victoria was used to represent this segment. The rationale used to weight each distance with a population factor used in the previous segment was also used in this segment.

This data set was used to build a discrete distribution, where the distance from greengrocers to consumers can take one of the several explicit discrete values shown in Figure B1.9, and where the probability factor based on CD population is assigned to each value.

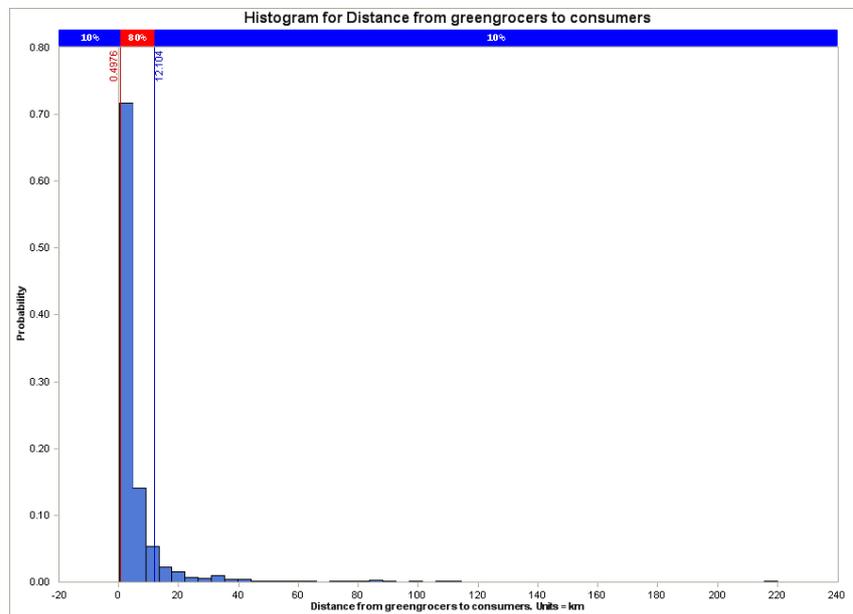


Figure B1.9. Discrete distribution used to represent the segment from greengrocers to the 9,298 collection districts based in Victoria.

**B2 Stochastic modelling of volumes**

Table B2.1 F&V volumes channelled through the MSC option (baseline scenario).

<b>MSC</b>	<b>TONNES</b>
<i>From farms to packing house</i>	<i>342,688</i>
<i>From packing house (NRM) to DC</i>	<i>342,688</i>
<i>From imports to DCs</i>	<i>14,365</i>
<i>From MM to DCs</i>	<i>154,238</i>
<i>Fron interstate to DCs</i>	<i>1,117,413</i>
<i>From DCs to stores</i>	<i>1,628,704</i>
<i>From stores to consumers</i>	<i>1,628,704</i>

*Table B2.2. F&V volumes channelled through the MM option (baseline scenario).*

<b>MM</b>	<b>TONNES</b>
From farms to packing house	475,442
From packing house (NRM) to MM	475,442
From imports to MM	23,671
Fron interstate to DCs	820,734
From MM to GG	1,319,847
From GG to consumers	1,319,847

These baseline scenarios were used to model the variations in flows of product through a stochastic model, as described in Chapter 8. This variation was performed to test the sensitivity of the model to changes in volumes in different segments that were thought to be major factors contributing to GHG emissions in each chain.

For the MSC, these were:

- a) The volumes of product from production to pack house to DC (Figure B2.1).

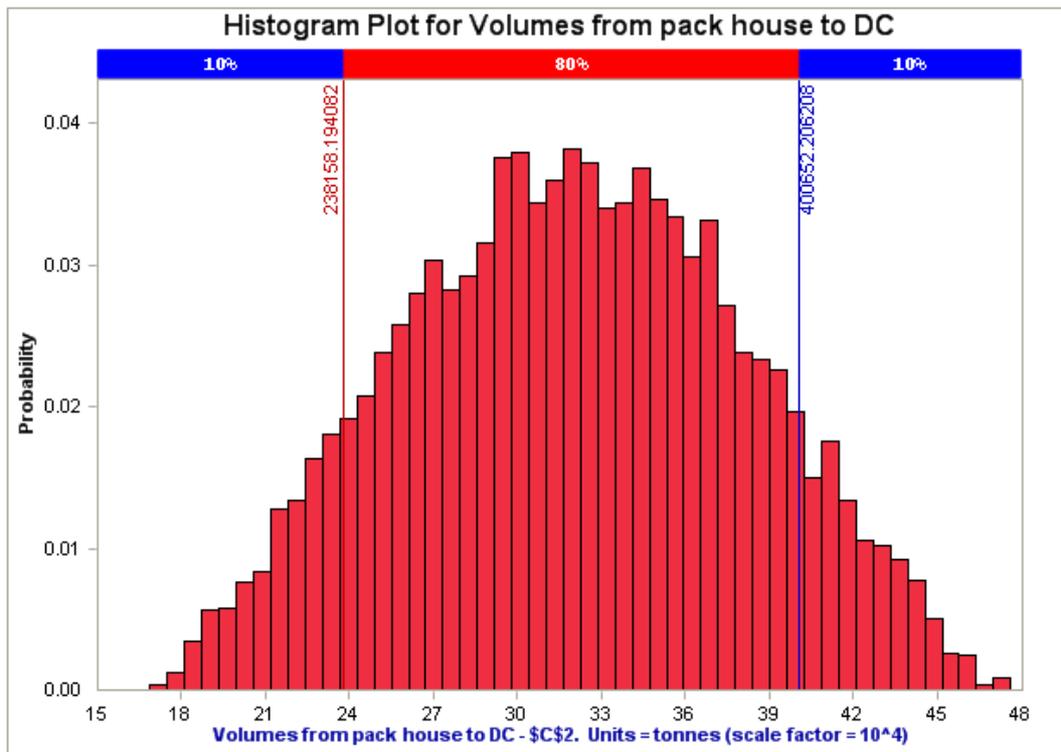


Figure B2.1. Variation of volumes of F&V from production to DC in the MSC chain.

b) The volumes of product imported to DC (Figure B2.2).

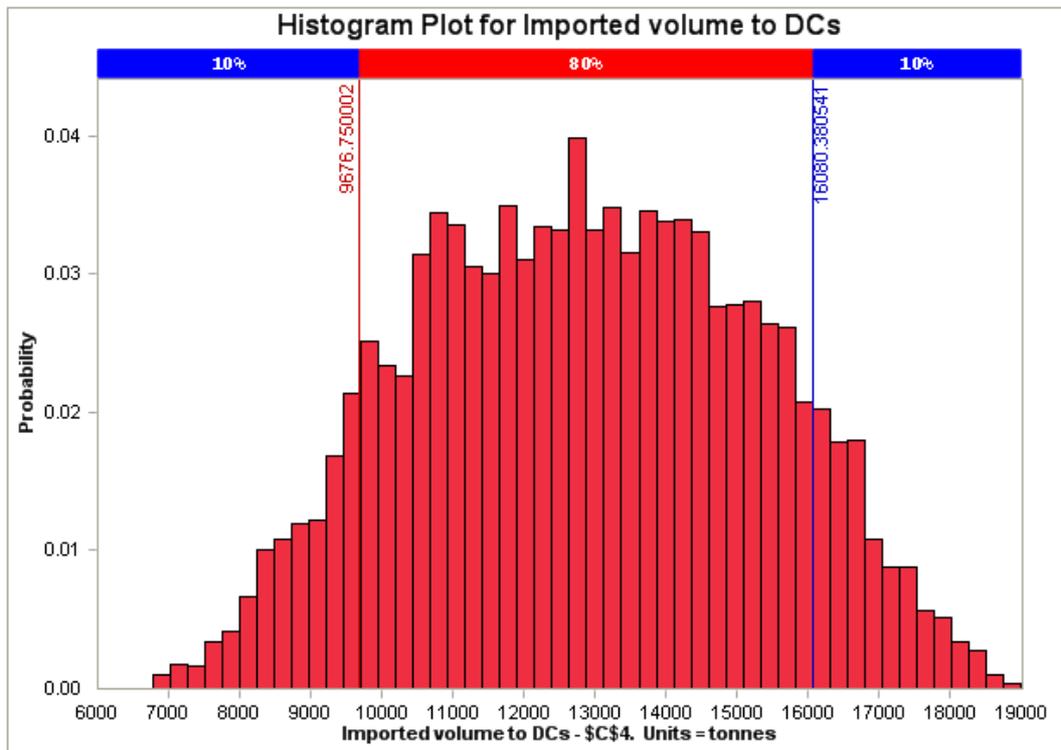


Figure B2.2. Variation of imported volumes of F&V to DC in the MSC chain.

c) The volumes of product brought from interstate to DC. In this case, the attribution of emissions is calculated using the distances from the point of entry to Victoria to DCs (Figure B2.3).

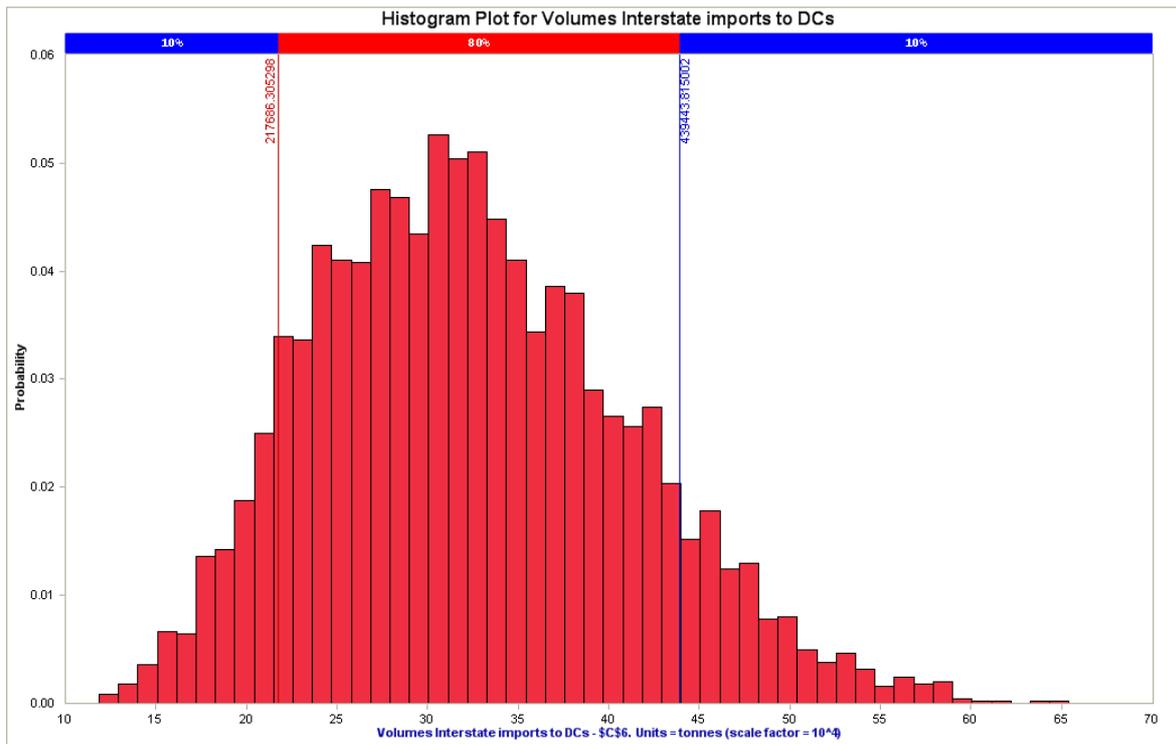


Figure B2.3. Variation of volumes of F&V from other states to DC in the MSC chain.

For the MM chain, the volumes varied were:

- a) The volumes of product from production to MM (Figure B2.4).

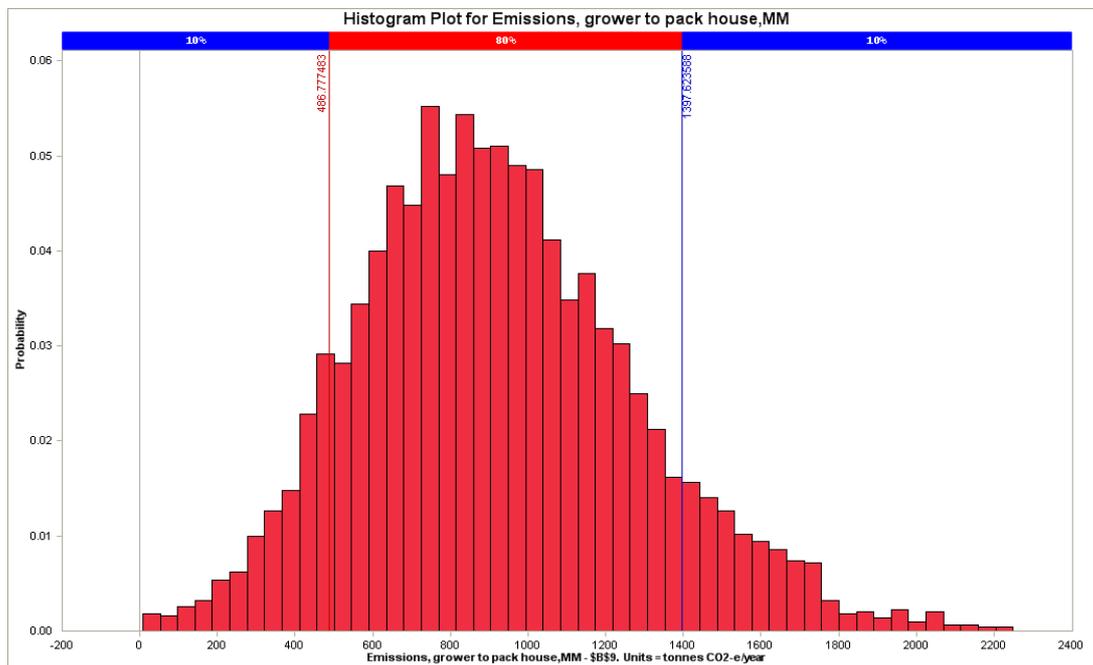


Figure B2.4. Variation of volumes of F&V from production to MM in the MM chain.

- b) The volumes of product imported to MM (Figure B2.5).

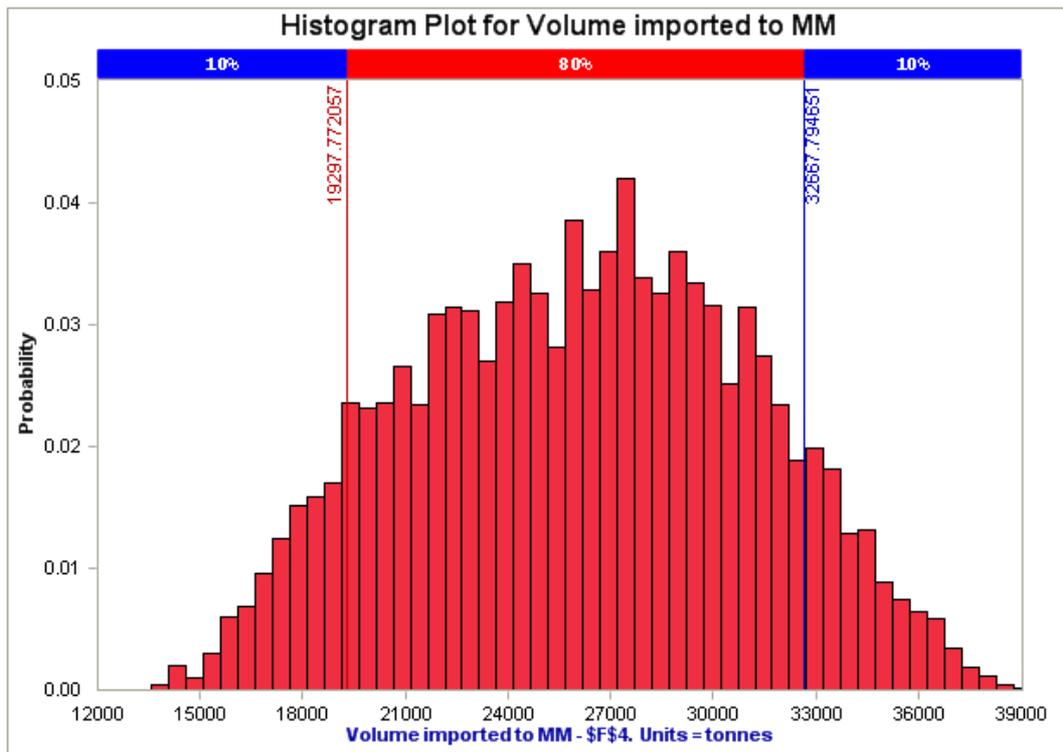


Figure B2.5. Variation of imported volumes of F&V to MM in the MM chain.

- c) The volumes of product brought from interstate to MM. In this case, the attribution of emissions is calculated using the distances from the point of entry to Victoria to MM (Figure B2.6).

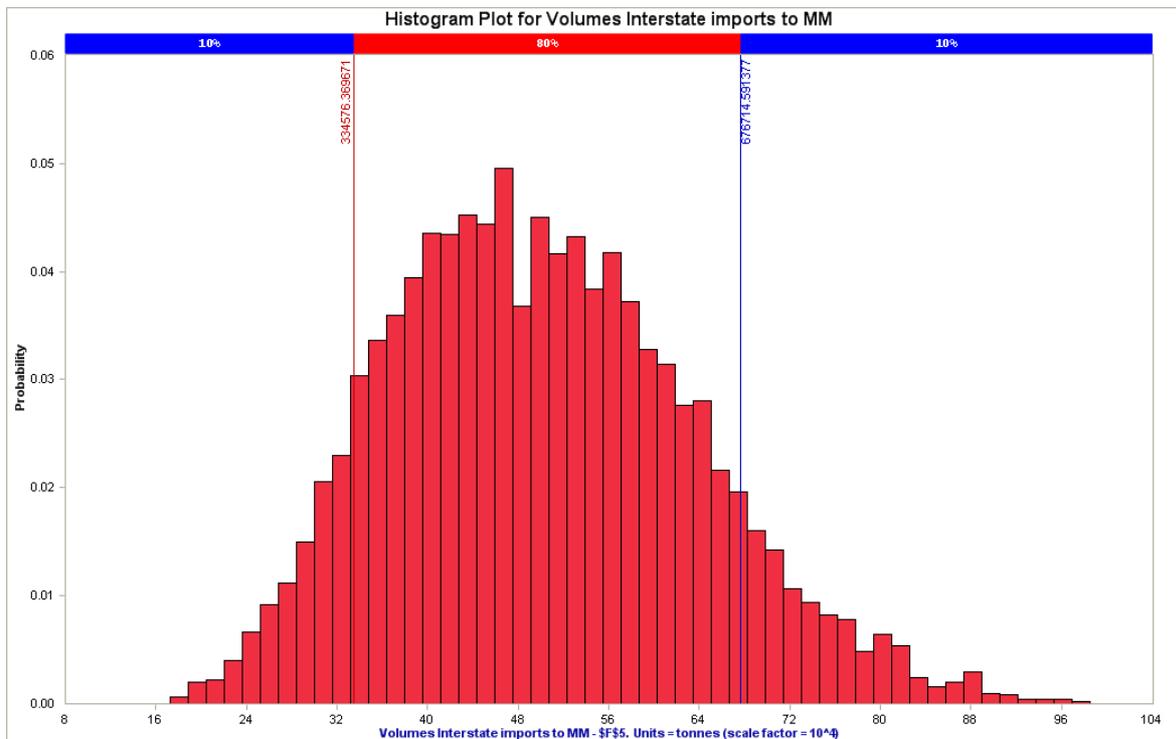


Figure B2.6. Variation of volumes of F&V from other states to MM in the MM chain.

Each of these volumes become  $V_{F&V\_S}$  in the equations described next.

### **B3 Calculation of the payload per vehicle type**

The load capacity per type of vehicle took into account that the average load carried per trip in Victoria is as follows:

- Light commercial vehicles= 0.4 tonnes;
- Rigid trucks= 6 tonnes;
- Articulated trucks= 22.5 tonnes (Australian Bureau of Statistics, 2008a).

ABS defines this average load as follows: “Average load carried is calculated by dividing the total weight carried by the number of trips made while carrying a load”. Therefore, these averages only encompass laden vehicles and do not take into account empty return trips (backloading).

The ABS average loads were used as the mode in Eqs.(4) to (6). In the case of rigid 3 axles and B-doubles, the mode was assumed to be 11.5 and 27.5 tonnes, respectively, since it is suspected that the average values for the rigid and articulated trucks provided by ABS (6 and 22.5 tonnes) would not represent the normal use for heavy vehicles. Further, although mode and mean are different in a Pert distribution<sup>25</sup>, it was considered that most vehicles would have a payload close to the mean. Therefore, LCs were calculated as follows:

$$LC_{LCV} = VosePert(0,0.4,2) \dots \dots \dots (1)$$

$$LC_{Rigid} = VosePert(0,6,13) \dots \dots \dots (2)$$

$$LC_{Rigid} = VosePert(0,11.5,23) \dots \dots \dots (3)$$

$$LC_{Art1} = VosePert(0,22.5,40) \dots \dots (4)$$

$$LC_{ArtB2} = VosePert(0,27.5,55) \dots \dots (5)$$

Where *VosePert* is the Pert distribution function in ModelRisk.

Note that while the maximum loading capacity of B-doubles can be up to 100 tonnes, it is unlikely that these trucks are being used to carry F&V. Therefore, the upper limit on Eq. (5) remains as 55 tonnes for payload.

### **B4 Calculation of the number of vehicles per link**

The loading capacity *LC* affects in two calculations: a) the calculation of the number of vehicles required for transporting F&V throughout the chain; and b) the calculation of the emission factor, which is dependent on the load carried by the vehicle. The latter is further discussed in the next section.

In regards to the calculation of the number of vehicles per link, the following assumptions were made in regards to the modes of transport:

1. From the farm-to-pack house segment, it is likely that transport is carried out through non-refrigerated (flat bed or side liner) trucks. It was assumed that all transport for this segment occurs in rigid, 2 axle vehicles.
2. For the pack house-DCs/MM segment, it is likely that the trucks used are rigid (2 and 3 axles) and articulated (long haul and B-doubles).

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<sup>25</sup> The mode of a set of data values is the value(s) that occurs most often.

3. For the Port of Melbourne-to-DCs/MM and interstate to DCs/MM, a combination of LCVs (light and heavy), 2-axle and 3-axle rigid, semi-trailers and B-doubles is assumed.
4. From MM to DCs and MM/DCs-to-stores segments, it has been assumed that a combination of LCVs (light and heavy), 2-axle and 3-axle rigid and semi-trailers are used. B-doubles are restricted to certain routes and unable to travel through many urban areas. Therefore they mainly go to freight terminals (import, export and interstate focus) but cannot be used to move large loads between DCs and stores.
5. From shops to consumers' households, a range of vehicles need to be considered. This is further considered in the calculation of emissions factors for the consumer link.

A generic set of equations were set to calculate the number of vehicles required to move fresh fruit and vegetables:

$$N_{LCV} = \frac{V_{F&V}}{LC_{LCV}} * X_{LCV} \dots\dots\dots (6)$$

$$N_{Rig_{2x}} = \frac{V_{F&V}}{LC_{Rig_{2x}}} * X_{Rig_{2x}} \dots\dots\dots (7)$$

$$N_{Rig_{3x}} = \frac{V_{F&V}}{LC_{Rig_{3x}}} * X_{Rig_{3x}} \dots\dots\dots (8)$$

$$N_{Art_l} = \frac{V_{F&V}}{LC_{Art_l}} * X_{Art_l} \dots\dots\dots (9)$$

$$N_{Art_{B2}} = \frac{V_{F&V}}{LC_{Art_{B2}}} * X_{Art_{B2}} \dots\dots\dots (10)$$

Where:

- N= Number of vehicles moving fresh fruit and vegetables in Victoria for domestic trade;
- X= Fraction of fruit and vegetables carried by each type of vehicle;
- V<sub>F&V</sub>= Volume of fruit and vegetables for the corresponding stage and type of chain (e.g. from farm to packing house; from stores to consumers) (tonnes).
- LC= Load capacity (tonnes);
- LCV= Light commercial vehicle;
- Rig<sub>2x</sub>= Rigid trucks, 2-axle;
- Rig<sub>3x</sub>= Rigid trucks, 3-axle;
- Art<sub>l</sub>= Articulated trucks, local/regional (semi-trailer);
- Art<sub>B2</sub>= Articulated trucks, B-double.

The fraction carried per type of vehicle was used to ‘switch on and off’ the use of some vehicles, as per set of assumptions. Hence, the following fractions were used per segment:

1. From the farm-to-pack house segment:  $X_{LCV}=0$ ;  $X_{art\_all}=0$ ,  $X_{rig\_3x}=0$  and  $X_{rig\_2x}=1$ .
2. For the pack house-DCs/MM segment:  $X_{LCV}=0$  and

$$X_{Art_{all}} + X_{Rig_{all}} = 1 \dots\dots\dots (11)$$

Where  $Art\_all$  = Fraction of F&V carried in all articulated trucks and  $Rig\_all$  = Fraction of F&V carried in all rigid trucks.

The calculation of the fraction of articulated and rigid trucks took into account that the proportion of tonnes of food carried per type of vehicle is likely to reflect the proportions found in an ABS survey:

- Light commercial vehicles = 3.1%;
- Rigid trucks = 25.5%;
- Articulated trucks = 71.7% (ABS, 2008a).

Given that LCVs are “switched off” in this segment, the percentages of rigid and articulated vehicles in long haul roads is likely to be 25 and 75 %, respectively. Therefore  $X_{Art\_all} = 0.75$  and  $X_{Rig\_all} = 0.25$ .

The calculation of the fraction per type of rigid truck (*i.e.* 2-axles and 3-axles) took into account that in 2009, 35 % of all rigid trucks registered in Victoria had a GVM<sup>26</sup> above 12 tonnes. This was interpreted as an indicative of a rigid 3-axle truck. The remaining 65%, which represented trucks with a GVM below 12 tonnes, was attributed to medium 2-axle trucks (Australian Bureau of Statistics, 2009).

Therefore, the fraction of rigid 2-axle and 3-axle trucks can be calculated as follows:

$$X_{Rig_{3ax}} = 0.65 * X_{Rig_{all}} = 0.1625 \dots\dots\dots(12)$$

$$X_{Rig_{2ax}} = 0.35 * X_{Rig_{all}} = 0.087 \dots\dots\dots(13)$$

Contradictory information about the number of B-doubles in Victoria was found, with a report indicating that there were 24,000 B-doubles in Victoria during 2009 (Pallas, 2009), while the total number of articulated trucks (including semi-trailers and B-doubles) reported by the ABS is 24,069 (Australian Bureau of Statistics, 2009). Using the latter statistics, we assumed that 14% of articulated trucks (or the percentage corresponding to a GCM<sup>27</sup> below 40 tonnes) are articulated semi-trailers, while the rest is attributed to B-doubles.

Therefore, the fraction of articulated trucks per type can be calculated as follows:

$$X_{Art_{S}} = 0.14 * X_{Art_{all}} = 0.105 \dots\dots\dots(14)$$

$$X_{Art_{B}} = 0.86 * X_{Art_{all}} = 0.645 \dots\dots\dots(15)$$

3. For the Port of Melbourne-to-DCs/MM and interstate to DCs/MM, a combination of LCVs (light and heavy), 2-axle and 3-axle rigid, semi-trailers and B-doubles is assumed.

The calculation takes into account the original percentages from ABS (2008a). Therefore:

<sup>26</sup> Gross vehicle mass. Tare weight (*i.e.* unladen weight) of the motor vehicle, plus its maximum carrying capacity excluding trailers.

<sup>27</sup> GCM = gross combination mass. Tare weight (*i.e.* unladen weight) of the motor vehicle and attached trailers, plus its maximum carrying and towing capacity. GCM is the weight measurement used for trailer towing vehicles such as articulated trucks.

$$X_{LCV}=0.03$$

$$X_{Rig\_all}=0.25$$

$$X_{Art\_all}=0.72$$

$$X_{Rig_{2ax}} = 0.65 * X_{Rig_{all}} = 0.1675 \dots\dots\dots(16)$$

$$X_{Rig_{3ax}} = 0.35 * X_{Rig_{all}} = 0.0893 \dots\dots\dots(17)$$

$$X_{Art_I} = 0.14 * X_{Art_{all}} = 0.1 \dots\dots\dots(18)$$

$$X_{Art_{B2}} = 0.86 * X_{Art_{all}} = 0.617 \dots\dots\dots(19)$$

- From MM to DCs and MM/DCs-to-stores segments, it has been assumed that a combination of LCVs (light and heavy), 2-axle and 3-axle rigid and semi-trailers are used. B-doubles are restricted to certain routes and unable to travel through many urban areas. Therefore they mainly go to freight terminals (import, export and interstate focus) but cannot be used to move large loads between DCs and stores. Therefore:

$$X_{LCV}=0.03$$

$$X_{Rig\_all}=0.25$$

$$X_{Art\_all}= X_{Art_I}=0.72$$

$$X_{B2}=0$$

$$X_{Rig_{2ax}} = 0.65 * X_{Rig_{all}} = 0.1675 \dots\dots\dots(20)$$

$$X_{Rig_{3ax}} = 0.35 * X_{Rig_{all}} = 0.0893 \dots\dots\dots(21)$$

## ***B5 Equations for fuel use during transport***

### **B.5.1 Type of fuel used in commercial transport**

According to the ABS (2009), less than 6% of LCVs use LPG or dual fuel in Victoria. Fifty percent of LCVs use petrol (unleaded) and 36% use diesel as fuels. For heavy LCVs, the emissions factor for petrol used in Marquez et al (2010) is 375 g CO<sub>2</sub>-e/km. To simplify the calculation, only this factor was used, reflecting the dominance of petrol-fuelled units.

Eighty five percent of light rigid trucks and 92% of heavy rigid trucks registered in Victoria run in diesel. Therefore, it is fair to assume that all fuel used by rigid trucks is represented by diesel emission factors. A correction for loading capacity is required, this aspects is further discussed in the next section. In terms of articulated trucks, 98% of these run in diesel. Again, it is fair to assume that all fuel used by articulated trucks is represented by diesel emission factors. A correction for loading capacity is required, this aspects is further discussed in the next section.

### **B5.2 The effect of backhauling**

In this project, a return transport (2-way) was assumed in all transport legs. That is, all transport segments are composed of a *fronthaul* (or the first leg of the truck trip that involves hauling a load to the targeted destination) and a *backhaul* (or the return run of the same truck).

The effect of loading capacity (*LC*) in the fronthaul and backhaul segments was modelled as a factor affecting the emissions factor for diesel, only. This is the approach that has been taken by DEFRA (AEA, 2008), which uses the correlations presented in Figures B5.1 and B5.2 for rigid and articulated trucks, respectively, to correct diesel emissions as a function of loading. These same correlations were used to correct the emissions factor in rigid and articulated trucks performing either fronthauls or backhauls.

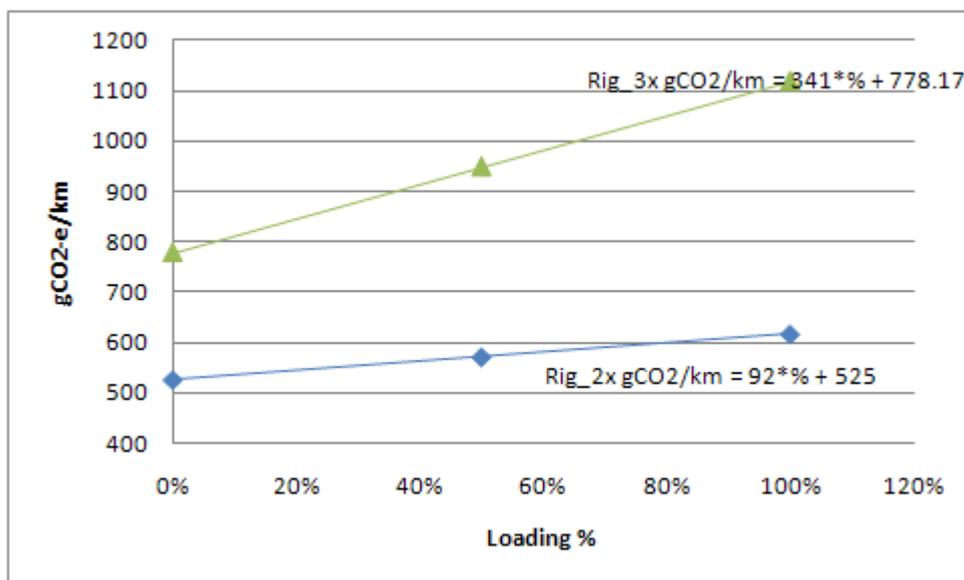


Figure B5.1. Correction of diesel emission factor for rigid trucks.

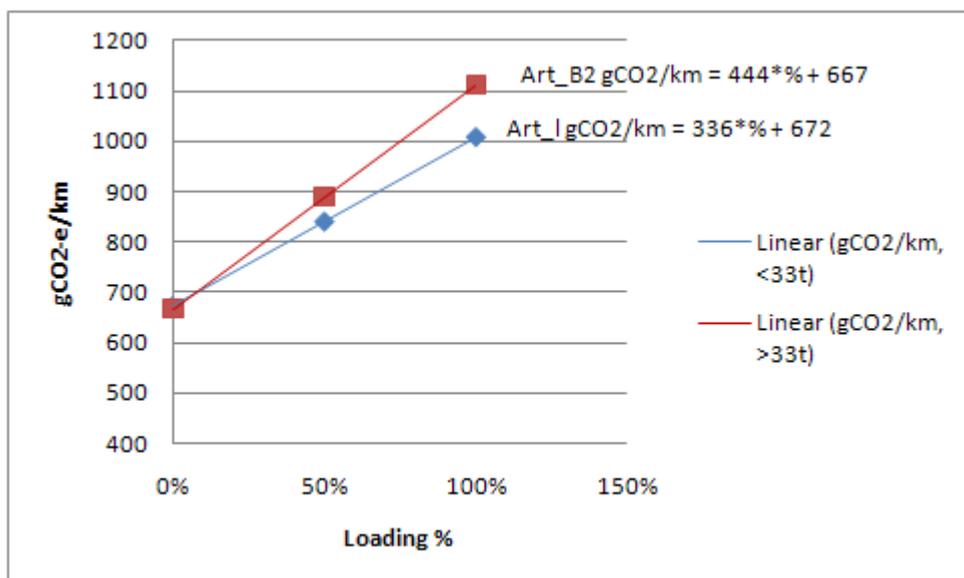


Figure B5.2. Correction of diesel emission factor for articulated trucks.

For LCVs there are no correlations based on the loading %. Therefore it was assumed that the emission factor was unaffected by loading %.

Loading percentages for fronthaul segments of rigid and articulated trucks were calculated through Eqs. (1) to (5) and the following equations:

$$\%_{fronthaul_{RGSX}} = 100 * \frac{LC_{RGSX}}{13} \dots\dots(22)$$

$$\%_{fronthaul_{RGSX}} = 100 * \frac{LC_{RGSX}}{23} \dots\dots(23)$$

$$\%_{fronthaul_{Art1}} = 100 * \frac{LC_{Art1}}{40} \dots\dots(24)$$

$$\%_{fronthaul_{Art2}} = 100 * \frac{LC_{Art2}}{55} \dots\dots(25)$$

Figures B5.1 and B5.2 indicate that fully loaded vehicles are expected to use more fuel and therefore will produce more carbon emissions.

The question on how to account for backhauling in carbon accounting of consignments is not an obvious one. Methods to account for backhauling include reallocation amongst legs according to the economic value of fronthaul and backhaul loads, for example. This type of allocation can become complex and should only be applied where one leg is, on average, considerably more valuable than a dependent leg (World Economic Forum, 2008).

In this report, our major focus is in a specific sector (fruit and vegetables). A consignment using a 3PL can carry oranges in one way and return with mangoes or packaging or other products in return. Assigning an effect of backhauling on the basis of load value can be misleading in this case, where the value of products transported in the return trip may be higher than fruit. Further, the value of a load of fruit changes for each player (a load of fruit has a higher retail value than at farm value). Finally, ownership of the backhaul trip is important: for retailers (or dedicated 3PLs outsourced to carry out retail operations), it may be critical to reduce their empty return trucks because they are the main carriers. For growers, backhauling is not important, because pricing of the transport service to growers is set independently of the backhauling achieved by the 3PL.

For the purposes of this report, two components of backhauling are distinguished: *useful backhauling*, applicable to the loaded fraction of the truck, and *wasteful backhauling*, applicable to the empty fraction of the truck in the return leg. Therefore, accounting of GHG emissions assumes that any portion not utilized in the backhaul trip will increase the overall supply chain emissions. The following diagram shows an example of backhaul attribution:

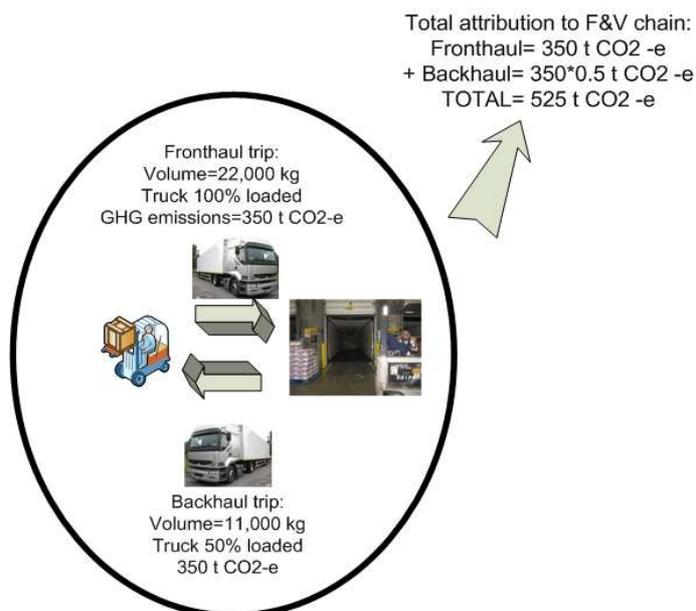


Figure B5.3. Illustration of the attribution of fronthaul and backhaul GHG emissions in the F&V modelling scenarios. The wasteful backhauling component increases the emissions from the chain.

This approach allows to penalize the chain when a low truck utilization rate occurs and decreases the penalty under high utilization rate scenarios. The carbon emissions are thus linked to the backhaul efficiency in a direct manner.

The suggested approach would need to be modified when dealing with different products. For example, the investigation of the entire food chain at state level or national level may require splitting the effect of partial loads or empty returns among all the products.

For backhaul segments, loading percentages of rigid and articulated trucks used the following assumptions:

1. From the farm to the packing house, it is likely that transport will take the form of a non-refrigerated (flat bed or side liner) truck. This segment is also likely to be covered by trucks owned by growers. The opportunities for loading in return in this segment are small. Therefore, in this segment, the loading % for all types of trucks is set to zero.
2. On the basis of the information provided in submissions to the ACCC (Australian Competition and Consumer Commission, 2008), it is thought that very few growers own long distance transport vehicles. Most growers will hire a 3PL to transport their goods to supermarkets. For the transport leg between growing regions and DCs, it is likely that trucks will be dispatched empty to collect the product from nearby depots. It is also very likely that the transport back to the growing regions will have a high backhauling component, as part of 3PLs strategies to minimize costs. On the basis of Hassall (2003), it is estimated that in rigid trucks the loading % ranges as follows:
  - For LCVs, between 25% and 50%.
  - For rigid and articulated trucks (all types), between 33% and 66%.

A Pert distribution between these values was established as follows:

$$\%_{backhaul_{LCV}} = VosePert(25,35,50) \dots\dots\dots(26)$$

$$\%_{backhaul_{Rtgsx}} = VosePert(33,50,66) \dots\dots\dots(27)$$

$$\%_{backhaul_{Rtgsx}} = VosePert(33,50,66) \dots\dots\dots(28)$$

$$\%_{backhaul_{Art_1}} = VosePert(33,50,66) \dots\dots\dots(29)$$

$$\%_{backhaul_{Art_{B_2}}} = VosePert(33,50,66) \dots\dots\dots(30)$$

3. Backhauling in this report is investigated in the context of road transport only. Therefore, imports backhauling is not analysed.
4. From Melbourne Markets to DCs and from DCs to individual stores, backhauling is considered to be minimal. Therefore, in both segments the loading % is set to zero.
5. From Melbourne Markets to greengrocers, it is reasonable to assume that 3PLs are contracted and therefore the same logic applied in (2) is valid in this case. Therefore, Eqs.(26) to (30) apply.
6. From shops to consumers' households, no loading factor applies. However, it is considered that the consumer's fronthaul (a necessary 'evil' of buying food) contributes in the same proportion than when the consumer is going back home with his/her purchase. Therefore, the amounts of GHG emissions are doubled.

### ***B6 The effect of refrigeration during commercial transport***

Finally, a correction in emissions due to refrigeration during transport is also considered. The following assumptions were used:

- *Produce that requires refrigerated transport (VIC)*

Not all produce requires refrigerated transport. For vegetables and fruit, 60% and 48% of the total vegetable tonnage produced per year in Victoria is expected to be transported under refrigeration, respectively.

To assess the effect of refrigerated transport, the fraction of refrigerated transport ( $F_{ref}$ ) for all types of vehicle was varied from 0 to 1 using a Pert distribution:

$$F_{ref} = VosePert(0,0.5,1) \dots\dots\dots(31)$$

The number of refrigerated vehicles is therefore calculated as:

$$N_{LCV,ref} = Round(N_{LCV} * F_{ref}, 0) \dots\dots\dots(32)$$

$$N_{Rtgsx,ref} = Round(N_{Rtgsx} * F_{ref}, 0) \dots\dots\dots(33)$$

$$N_{Art_1,ref} = Round(N_{Art_1} * F_{ref}, 0) \dots\dots\dots(34)$$

$$N_{Art_{B_2},ref} = Round(N_{Art_{B_2}} * F_{ref}, 0) \dots\dots\dots(35)$$

Non-refrigerated ( $F_{non-ref}$ ) vehicles are found by subtracting the refrigerated units from the total of vehicles per type.

The emissions from the use of extra diesel to power refrigeration depend on the type of operation. Table B6.1 shows the grams of CO<sub>2</sub> –e per km for different types of refrigerated transport.

Table B6.1. Emissions expected for different types of refrigerated transport, including motion fuel (Tassou et al., 2008).

g CO <sub>2</sub> -e/km	Chilled (1-drop)	Chilled (multi-drop)	Frozen (1-drop)	Frozen (multi-drop)
Rig_2x	1272	1308	1344	1380
Rig_3x	1632	1680	1728	1776
Artic_I	2318	2394	2470	2546
Artic_B2	2552	2596	2684	2772

The factors selected represent the most common operation for most segments of the fresh F&V chain (chilled, single drop). The increase from single drop to multi-drop is less than 3%. Therefore, the error introduced due to the use of different modes (e.g. during city distribution) is considered to be negligible.

For LCVs, there is a lack of information on emission factors for refrigerated vans. In this case, an assumption of an increase in 18% CO<sub>2</sub>-e with respect to non-refrigerated vehicles has been used, which seems reasonable with respect to data provided in Tassou (2008).

Further, diesel for refrigeration is only accounted in the fronthaul shipment. In backhaul trips, the refrigeration plant can be either turned off or used for other goods. In either case, the fresh fruit and vegetable shipment should not be penalized for this use.

### ***B7 The use of fuel in the ‘last mile’: consumer segment***

To assess the effect of the number of trips made by consumers to supermarkets and greengrocers, a stochastic model tested the effect of halving these trips or doubling these trips, through the following equation:

$$C_{trips,MSG} = VosePert(88.4 * 0.5, 88.4, 88.4 * 2) \dots\dots\dots(36)$$

A similar distribution was used to test the effect of greengrocer trips:

$$C_{trips,GG} = VosePert(44.2 * 0.5, 44.2, 44.2 * 2) \dots\dots\dots(37)$$

These distributions are later used to calculate the number of vehicles circulating for purchasing FV.

A second distribution was used to model the fuel consumption as a function of the type of car used by consumers. Eighty eight percent of all registered passenger cars in Victoria use petrol as the main fuel (Australian Bureau of Statistics, 2008a). However, petrol use depends on the type of car and therefore the emission factor can change as a function of car size. To account for this variation, a Pert distribution was used to model the emission factor (g CO<sub>2</sub>/km) as follows (AEA, 2008):

$$E_{consumer} = VosePert(180.9, 213.9, 295.8) \dots\dots\dots(38)$$

## B8 Calculation of emissions

The calculation of emissions ( $E$ , tonnes CO<sub>2</sub>-e) per segment was performed as follows:

### B8.1 Major supermarket chains (MSC)

A) Segment from grower to packing house (F\_PH):

This segment considers only small non-refrigerated trucks travelling the distance between harvest points and packing sheds, with % backhauling =0. A single equation for rigid 2-axes trucks was used to represent this link:

$$E_1(F_{PH}) = [1e^1(-6) ((tCO_2 - e)/(g CO_2 - e)) * [(92 * \%_{01}(Rig_{12x}) + 525((g CO_2 - e)/km)) * N_1(Rig_{12x}, nonref)]$$

This can be simplified to:

$$E_{F_{PH}} = 1e^{-6} \left( \frac{tCO_2 - e}{g CO_2 - e} \right) * (2 - \%backloading) \left( 92 * \%_{Rig_{2x}} + 525 \left( \frac{g CO_2 - e}{km} \right) \right) * N_{Rig_{2x}, nonref} * D_{F_{PH}} (km)$$

Simplified even further, we have:

$$E_{F_{PH}} = 2e^{-6} \left( \frac{tCO_2 - e}{g CO_2 - e} \right) * \left[ 92 * \%_{Rig_{2x}} + 525 \left( \frac{g CO_2 - e}{km} \right) \right] * N_{Rig_{2x}, nonref} * D_{F_{PH}} (km) \dots (39b)$$

B) Segment from packing house to DC (NRM\_DC):

$$E_1(LCV, NRM_{DC}) = [1e^1(-6) ((tCO_2 - e)/(g CO_2 - e)) * [359((g CO_2 - e)/km) * N_1(LCV_{nonref}) * D_1(NRM_{DC})]$$

$$E_1(Rig_{12x}, NRM_{DC}) = [1e^1(-6) ((tCO_2 - e)/(g CO_2 - e)) * [(92 * \%_{01}(Rig_{12x}) + 525((g CO_2 - e)/km)) * N_1(Rig_{12x}, nonref) * D_1(NRM_{DC})]$$

$$E_{Rig_{2x}, NRM_{DC}} = 1e^{-6} \left( \frac{tCO_2 - e}{g CO_2 - e} \right) * \left[ \left( 341 * \%_{Rig_{2x}} + 778.2 \left( \frac{g CO_2 - e}{km} \right) \right) * N_{Rig_{2x}, nonref} * D_{NRM_{DC}} (km) + 1,63 \right]$$

$$E_1(Art_{1L}, NRM_{DC}) = 1e^1(-6) ((tCO_2 - e)/(g CO_2 - e)) * [(336 * \%_{01}(Art_{1L}) + 672((g CO_2 - e)/km)) * N_1(Art_{1L}, nonref) * D_1(NRM_{DC})]$$

$$E_{Art_{B2}, NRM_{DC}} = 1e^{-6} \left( \frac{tCO_2 - e}{g CO_2 - e} \right) * \left[ \left( 444 * \%_{Art_{B2}} + 667 \left( \frac{g CO_2 - e}{km} \right) \right) * N_{Art_{B2}, nonref} * D_{NRM_{DC}} (km) + 2,552 \right]$$

Where  $N_{LCV_T}$ ,  $N_{Rig_{2x}_T}$ ,  $N_{Rig_{3x}_T}$ ,  $N_{Art_{1L}_T}$  and  $N_{Art_{B2}_T}$  are the total number of vehicles calculated per segment (i.e. refrigerated + non-refrigerated).

The total emissions from this segment are the sum of all the above:

$$E_{NRM_{DC}} = E_{LCV, NRM_{DC}} + E_{Rig_{12x}, NRM_{DC}} + E_{Rig_{2x}, NRM_{DC}} + E_{Art_{1L}, NRM_{DC}} + E_{Art_{B2}, NRM_{DC}} \dots (45)$$

C) Segment from imports to DC (I\_DC):

The calculation of emissions from imported goods is a complex issue and the accounting methodology for shipped goods is still under discussion.

In a nutshell, the containerized transport of perishables by ship has two components:

a) **Fuel for refrigeration.** Based on a previously developed methodology (Estrada-Flores S., 2008), the following parameters were used to calculate the imports carbon footprint due to refrigeration:

- Each 20 ft refrigerated container carries 21 tonnes of products and is powered with mobile diesel generators, which in turn use marine diesel oil (MDO).
- These units have a specific fuel consumption of 280 to 330 g/kWh. An average of 300 g/kWh was used.
- The actual power consumption (kW) used per container vary widely and according to the type of container, the type of cargo and several other factors. In order to account for these variations, a VosePert model was introduced to model this variable, using a minimum of 1 kW (typical of chilled products with minimum temperature maintenance requirements) to 9 kW (typical of tropical fruit, with high temperature maintenances requirements)<sup>28</sup>.
- The emissions factor for MDO used was 3.206 g CO<sub>2</sub>-e/g fuel (EnSys Energy & Systems Inc., 2007).
- An average speed of 20.5 knots (or 38 km/h) was considered (Stopford, 2009).

Emissions from refrigeration were calculated as:

$$E_{I_{DC}^{ref}} = \frac{V_{F&V}(t)}{21(t)} * 300 \left( \frac{g \text{ MDO}}{kWh} \right) * \frac{D_{I_{DC}}(km)}{38 \left( \frac{km}{h} \right)} * 3.206 \left( \frac{g \text{ CO}_2 - e}{g \text{ MDO}} \right) * VosePert(1,4,9)(kW) * 1e^{-6} \left( \frac{t \text{ CO}_2 - e}{g \text{ CO}_2 - e} \right)$$

b) **Fuel for motion.** In previous studies, emissions coefficient of 0.007 kg CO<sub>2</sub>/t-km were used (Saunders et al., 2006)<sup>29</sup>. In this case, we selected to use the DEFRA's values for marine freight transport (AEA, 2008), where the emissions factors for small and large container vessels are 15 and 13 g CO<sub>2</sub>-e per tonne per km. An average of 14 g CO<sub>2</sub>-e/t km was used.

There are some caveats in using this approach: Firstly, it is assumed that all imports entering the Victorian F&V chain arrive in ships. Secondly, the emission factors for maritime transport will vary according to: (i) the total weight of the vessel (*i.e.* cargo plus the weight of the ship and equipment onboard); (ii) the international lines used to transport the container (*e.g.* feeder line, ocean line) (Leonardi and Browne, 2009); and (iii) the use of bulk transport in refrigerated cargo holds, as distinct to containers<sup>30</sup>. There are currently no emission factors that take into account the loading factor of the ship and the effect of the type of ship and routes is difficult to model, because data is specific of each importer and country of origin. The value selected should be regarded as the lower limit of the emission factor. The calculation of emissions for motion is<sup>31</sup>:

$$E_{I_{DC}^{motion}} = 14 \left( \frac{g \text{ CO}_2 - e}{t * km} \right) * D_{I_{DC}} * V_{F&V} * 1e^{-6} \left( \frac{t \text{ CO}_2 - e}{g \text{ CO}_2 - e} \right) \dots \dots (47)$$

<sup>28</sup> [www.thermoking.com/aboutus/tradepubs/2040/2040summer08.pdf](http://www.thermoking.com/aboutus/tradepubs/2040/2040summer08.pdf)

<sup>29</sup>

<http://webarchive.nationalarchives.gov.uk/http://www.dft.gov.uk/pgr/freight/research/lifecyclemodellingco2emissio3225?page=4>

<sup>30</sup> The use of charter refrigerated vessels can reduce shipping times, distances and overall carbon emissions, due to loading efficiencies and the fact that no port calls are made.

<sup>31</sup> This calculation provided results within ±0.02 tonnes CO<sub>2</sub>-e of the results provided by the Marine Freight Calculator developed by Catalyst &D (<http://www.catalystnz.com/abode/carbonCalculatorAdd.do>)

The total emissions from imported goods becomes:

$$E_{I_{DC}} = E_{I_{DC}^{ref}} + E_{I_{DC}^{motion}} \dots\dots\dots(48)$$

E) Segment from MM to DCs:

Eqs.(39) to (45) apply again, using the MM volumes going into the MS chain and  $D_{MM\_DC}$  in the calculation.

F) Segment from Interstate to DCs:

Eqs.(39) to (45) apply again, using the interstate volumes going into the MSC and  $D_{INTER\_DC}$  in the calculation.

G) Segment from DCs to stores (DC\_S):

Eqs.(39) to (45) apply again, using the F&V volumes going into the stores and  $D_{DC\_S}$  in the calculation.

G) Segment from supermarket stores to consumers' households (S\_C):

The total number of consumer vehicles is calculated by multiplying the trips per household (88.4) by the total number of households (1,294,450) considered in the analysis. The result is multiplied by the distances between households and the nearest supermarket ( $D_{S\_C}$ ) and by the corresponding emissions factor. As mentioned in the backhauling section, the GHG emissions are doubled to include the travel on the 2-way travel incurred by consumers.

However, in the attribution of the 'last mile' emissions, the fact that consumers shop for a mix of products (and not only fruit and vegetables) has to be taken into account. Therefore, a factor weighting the proportion of fresh fruit and vegetables purchased by the consumer in each trip was required.

To build this factor, the contents of the Victorian healthy food basket proposed by Palermo et.al. (2007) were used to calculate a weight proportion of purchased fresh fruit and vegetables. The foods contained in the basket were based on the Queensland Healthy Food Access Basket but modified to suit Victorian purchasing trends. The authors used industry data from ACNielsen reports and ABS Household Expenditure surveys as a source of information on food consumption to arbitrarily devise the basket (Palermo et al., 2007).

Using this basket, an analysis of the consumption for four types of households (a family composed by two adults and a child; a family composed of one adult, one adolescent and a child; a single elderly pensioner and a single adult) was conducted. It was determined that all the basket comprise in average 30% of **fresh** fruit and vegetables. Therefore, the emissions in the consumer segment ( $E_{S\_C}$ ) were multiplied by a factor of 0.3, thus effectively attributing 30% of the total travel shopping emissions to fresh fruit and vegetables.

H) Sum of all MSC segments:

The total emissions for the MS chain was the sum of all the above emissions:

$$\begin{aligned}
 E_{MSC} &= E_{FPH} + E_{NRM_{DC}} + E_{I_{DC}} + E_{MM_{DC}} + E_{INTER_{DC}} + E_{DC_S} + E_{S_c} \\
 E_{MSC} &= E_{FPH} + E_{NRM_{DC}} + E_{I_{DC}} + E_{MM_{DC}} + E_{INTER_{MSC}} + E_{DC_S} + E_{S_c} \\
 E_{MSC} &= E_{FPH} + E_{NRM_{DC}} + E_{I_{DC}} + E_{MM_{DC}} + E_{INTER_S} + E_{DC_S} + E_{S_c} \\
 E_{MSC} &= E_{FPH} + E_{NRM_{DC}} + E_{I_{DC}} + E_{MM_{DC}} + E_{DC_S} + E_{S_c} \dots\dots(49)
 \end{aligned}$$

## B8.2 Melbourne Markets-Greengrocer chains (MM)

### A) Segment from grower to packing house (F\_PH):

This segment was treated as discussed in the MSC model, adjusting the corresponding volumes to reflect MM conditions.

### B) Segment from packing house to MM (NRM\_MM):

This segment was treated as described in Section B of the MSC model. Eqs. (39) to (45) were used, changing the volumes and distances ( $D_{PH_{MM}}$ ) to reflect the conditions in the MM chain.

### C) Segment from import to MM (I\_MM)

This segment was treated as described in Section C of the MSC model, changing the F&V imported volume for MM and the distances ( $D_{I_{MM}}$ , which are essentially the same as for I\_DC) to reflect the MM conditions in this segment.

### E) Segment from Interstate to MM:

Eqs.(34) to (39) apply again, using the interstate volumes going into the MM and  $D_{INTER_{MM}}$  in the calculation.

### D) Segment from MM to greengrocers (MM\_GG):

This segment was treated through Eqs.(34) to (39), using the F&V volumes going into the greengrocers and  $D_{MM_{GG}}$  in the calculation.

### E) Segment from GG to consumers (GG\_C):

The total number of consumer vehicles is calculated by multiplying the trips per household (44.2 or half the shopping trips to supermarkets, according to data from Metcash, 2008) by the total number of households (1,294,450) considered in the analysis (Marquez et al., 2010). The result is multiplied by the distances between households and the nearest greengrocer ( $D_{GG_C}$ ) and by the emissions factor resulting of Eq. (32).The same criteria of doubling GHG emissions to account for the contribution of “empty fronthaul” used in MSC was applied in MM.

In regards to the percentage attributable to fresh fruit and vegetables in the greengrocer chain, it could be argued that trips to greengrocers are of a different nature than in the case of supermarkets, e.g. consumers may make specific trips to greengrocers and do not purchase other products; consumers can find a range of products in supermarkets that they would not find in greengrocers and they may need to supplement their greengrocer trip with other side trips to the butcher, deli and so on. Further, there is evidence that during the recent financial recession,

US consumers increased their shopping trips and these seem to be directed to grocery stores rather than to retail stores<sup>32</sup>.

The authors were unable to find a study that covers the shopping habits of consumers in detail to draw specific conclusions on the split of purchases when consumers shop for groceries. Therefore, it was decided to apply the same weighting factor of 0.3 for greengrocers trips, using the same rationale than for supermarket trips.

F) Sum of all MM segments:

The total emissions for the MS chains is the sum of all the above emissions:

$$E_{MM} = E_{FPH} + E_{NRM_{MM}} + E_{I_{MM}} + E_{INTER_{MM}} + E_{MM_{GG}} + E_{GG_c}$$
$$E_{MM} = E_{FPH} + E_{NRM_{MM}} + E_{I_{MM}} + E_{MM_{GG}} + E_{GG_c} \dots\dots(50)$$

---

<sup>32</sup> [http://www.progressivegrocer.com/progressivegrocer/content\\_display/supermarket-industry-news/e3i3ecdc15bacc281d2da09869bd95f82ff](http://www.progressivegrocer.com/progressivegrocer/content_display/supermarket-industry-news/e3i3ecdc15bacc281d2da09869bd95f82ff)

## Appendix C. Detailed GHG emission profiles for MSC and MM segments.

### C1. Major supermarket chains

The GHG emission values representing 80% of the data simulated are presented in red (low value) and blue (high value).

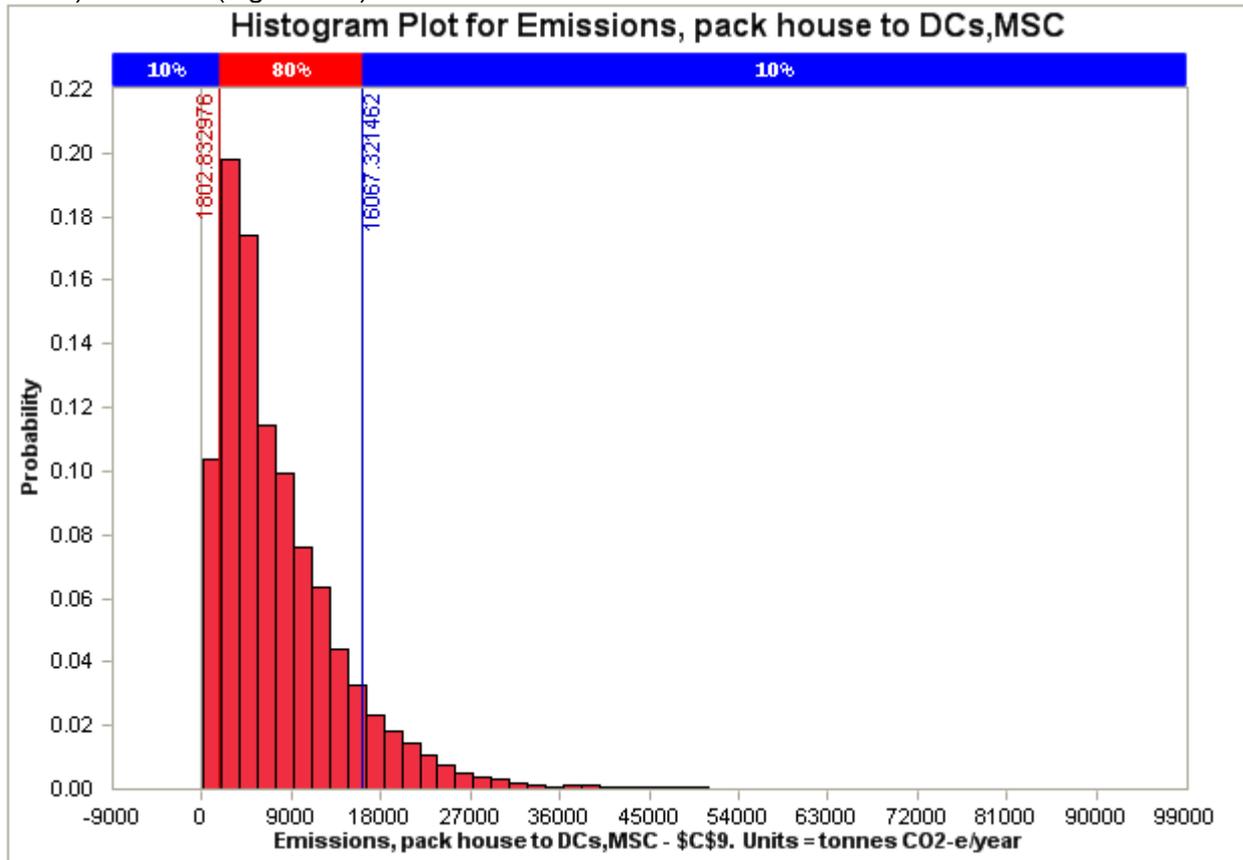


Figure C1.1 Distribution of GHG emissions arising from the F&V transport between farms and packing houses.

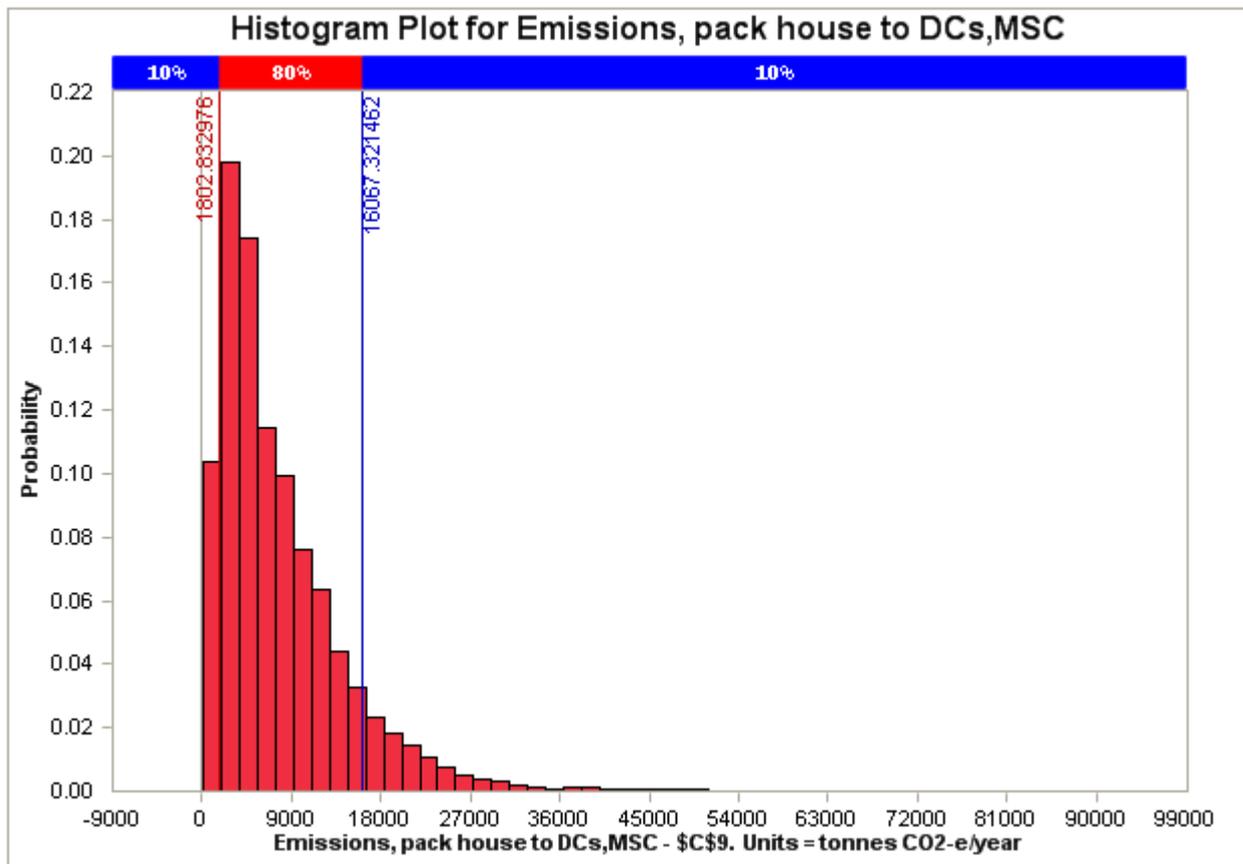


Figure C1.2. Distribution of GHG emissions arising from the F&V transport between packing houses and MSC DCs.

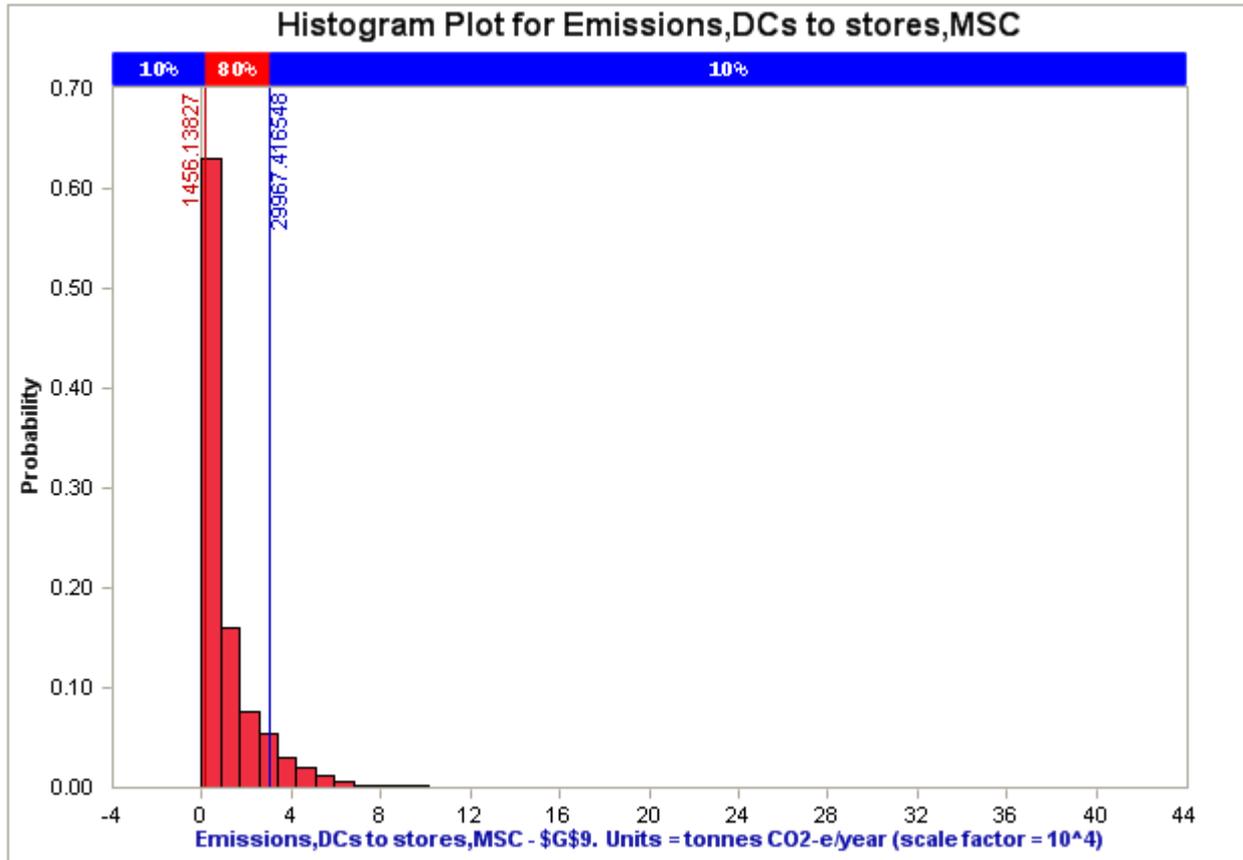


Figure C1.3. Distribution of GHG emissions arising from the F&V transport between MSC DCs and MSC stores.

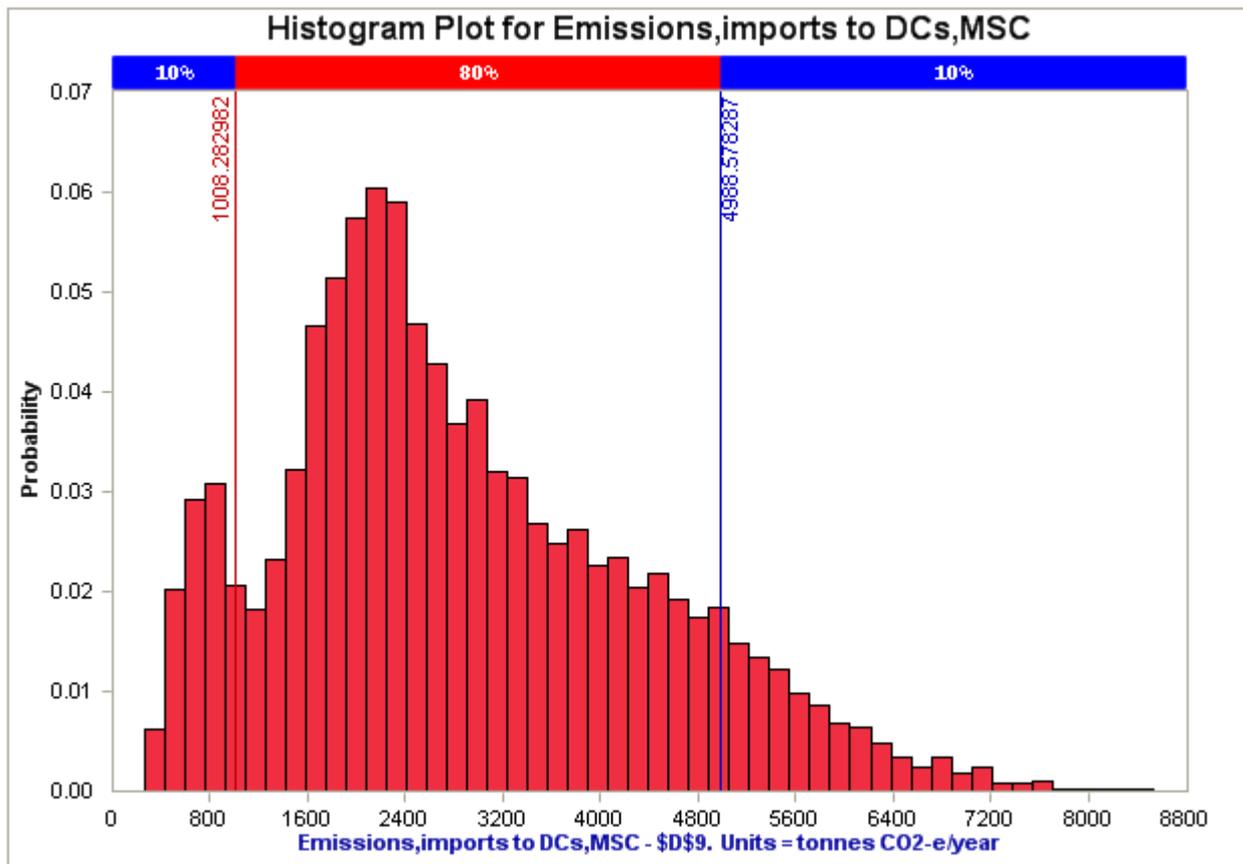


Figure C1.4. Distribution of GHG emissions arising from the imported F&V transported between the country of origin and MSC DCs.

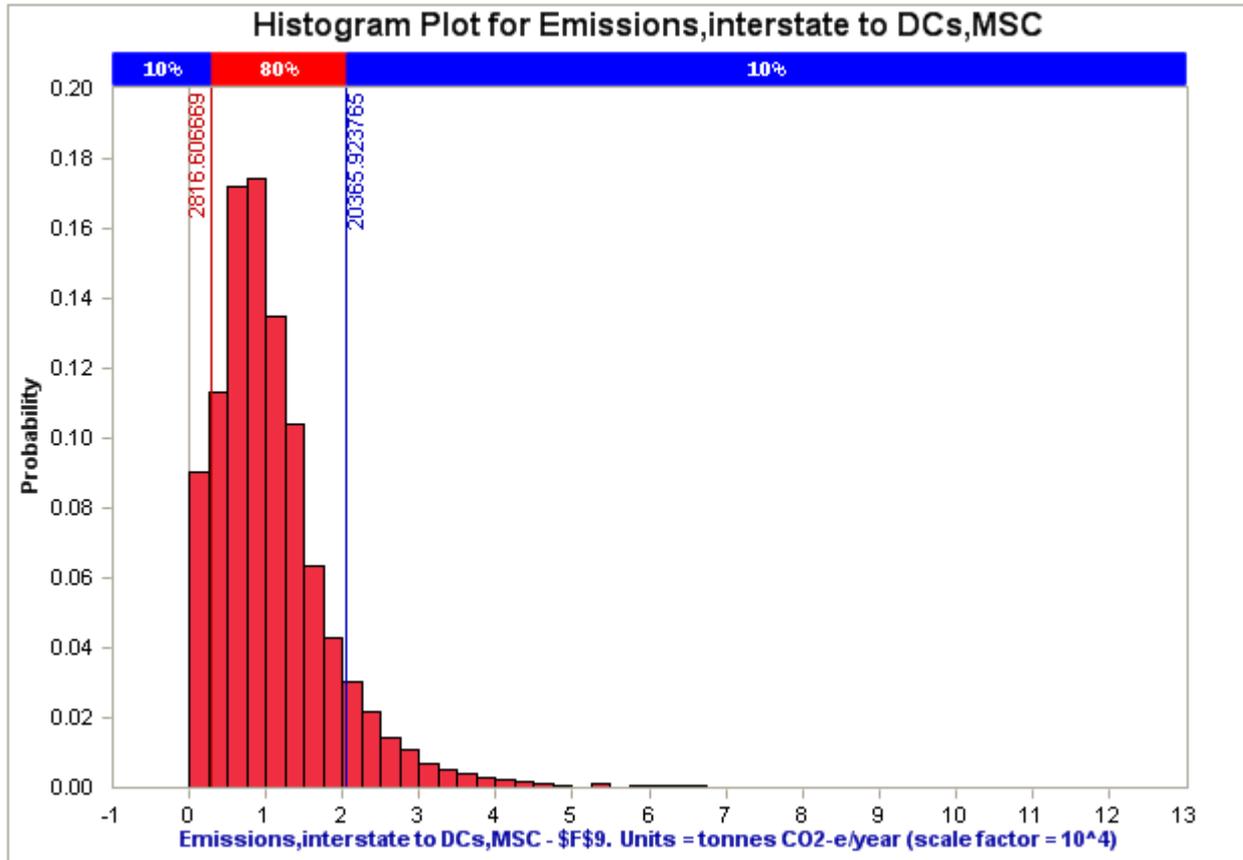


Figure C1.5. Distribution of GHG emissions arising from the interstate-sourced F&V transported between the Victorian point of entry and MSC DCs.

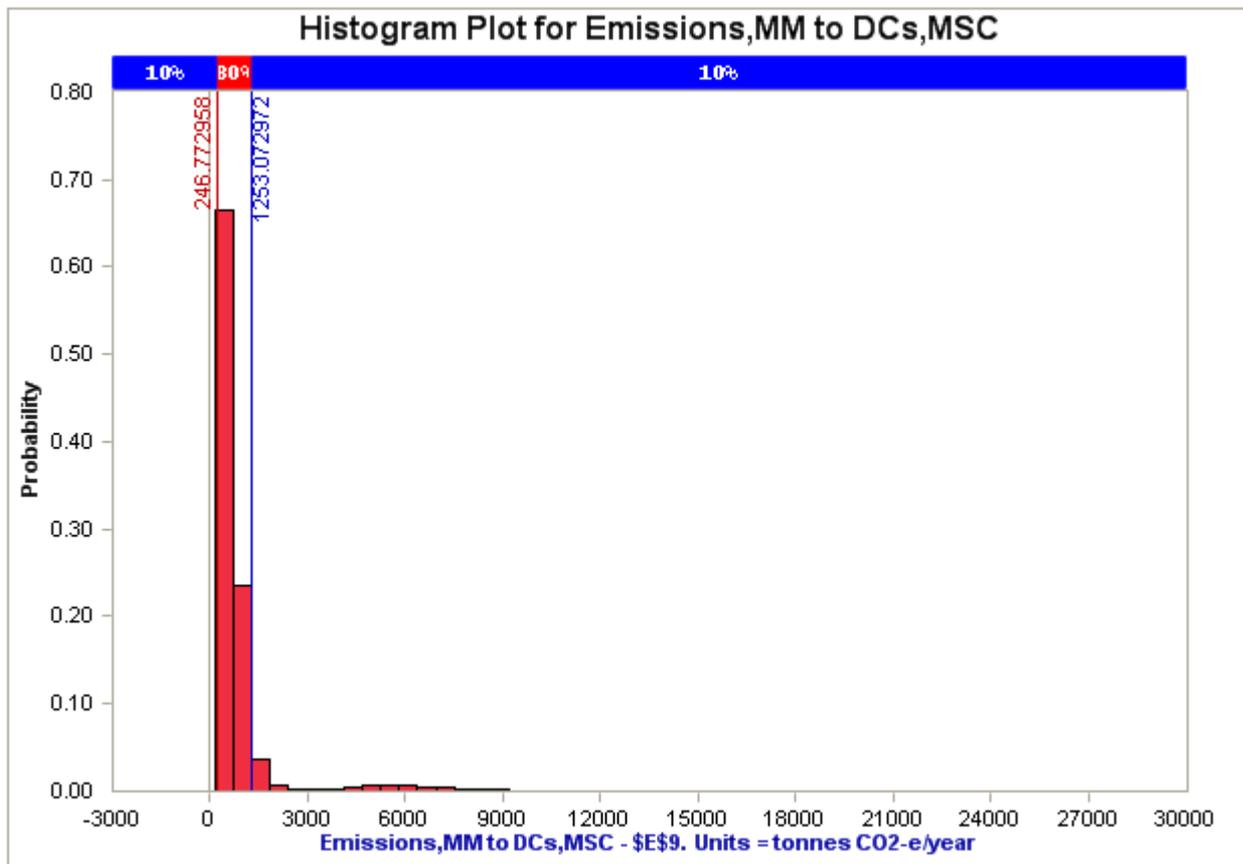


Figure C1.6. Distribution of GHG emissions arising from the F&V transport between Melbourne Markets (MM) and MSC DCs.

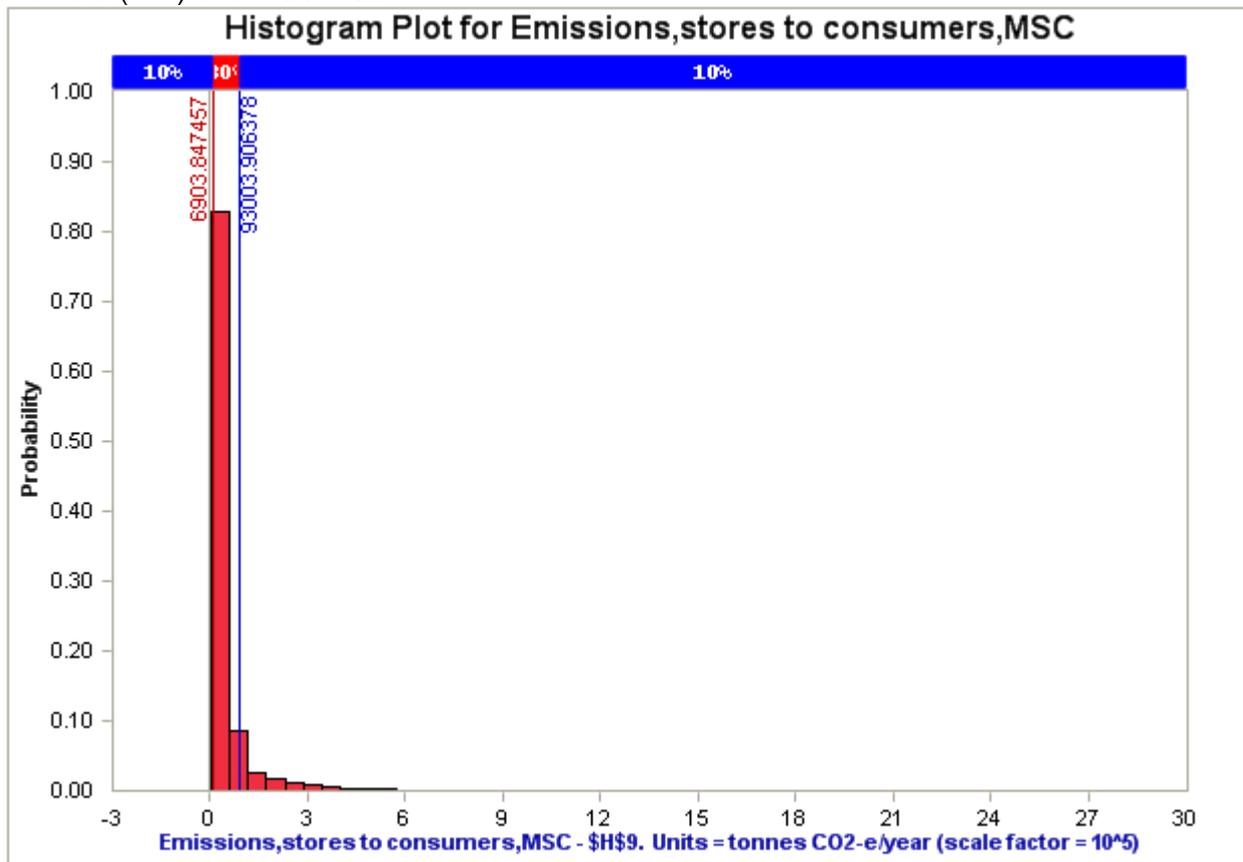


Figure C1.7. Distribution of GHG emissions arising from the F&V transport between MSC stores and consumers.

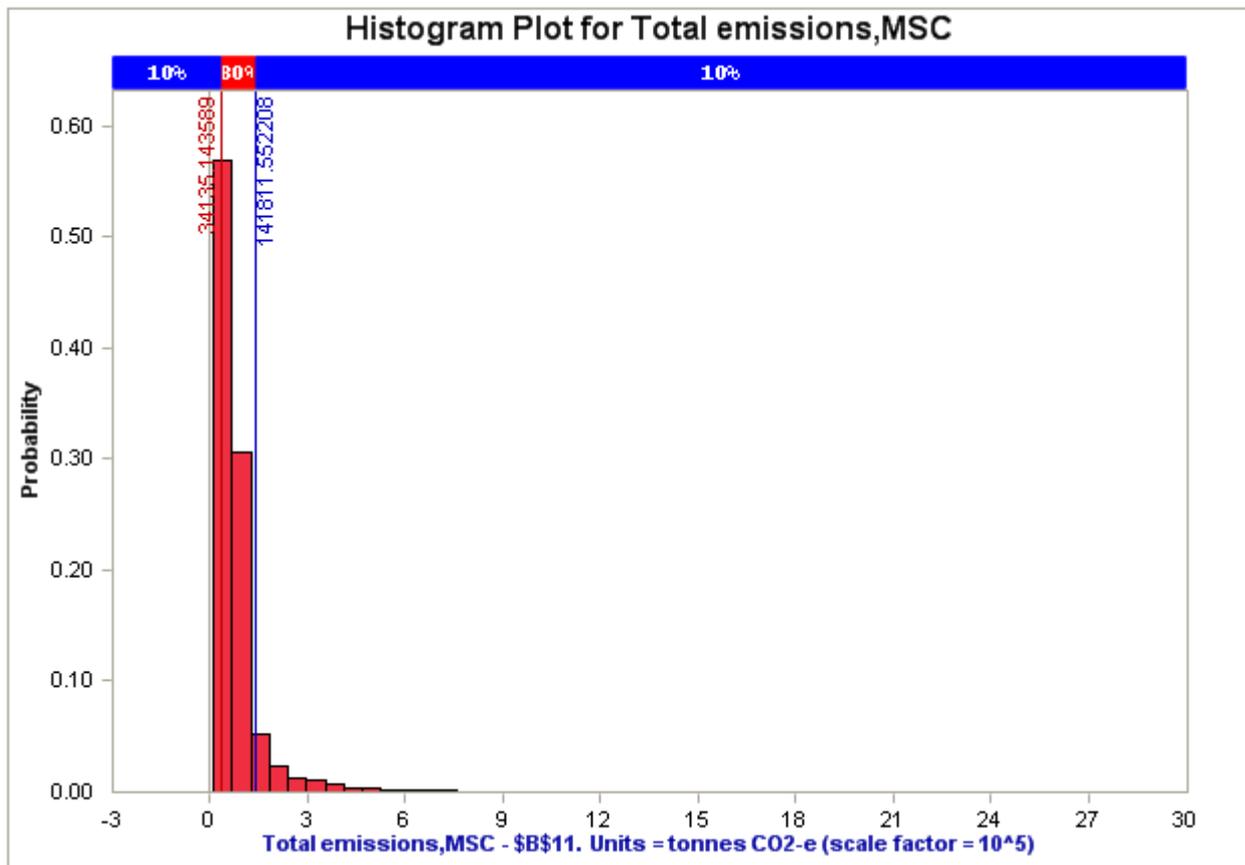


Figure C1.8. Distribution of GHG emissions arising from the farm to fork F&V transport, MSC case.

## ***C2. Melbourne Market-greengrocers***

The GHG emission values representing 80% of the data simulated are presented in red (low value) and blue (high value).

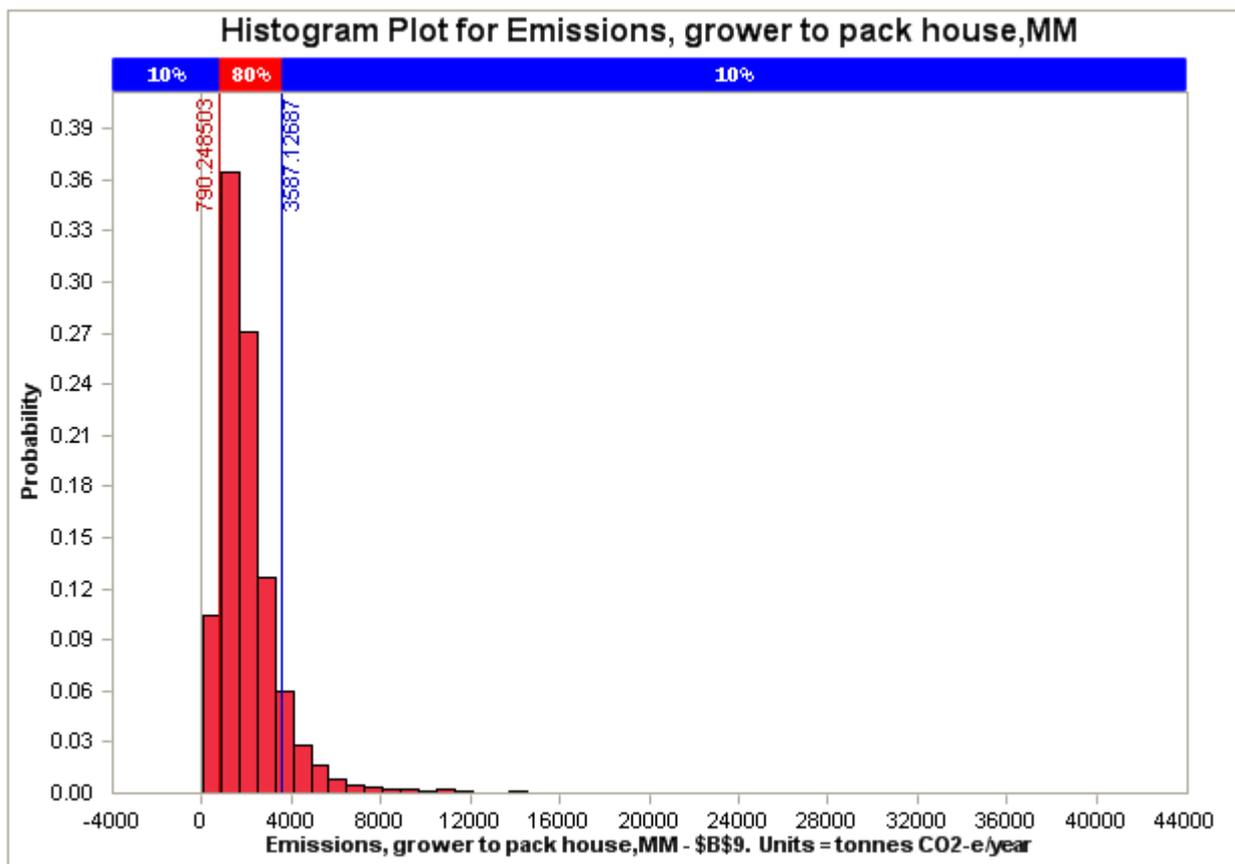


Figure C.2.1. Distribution of GHG emissions arising from the F&V transport between farms and packing houses.

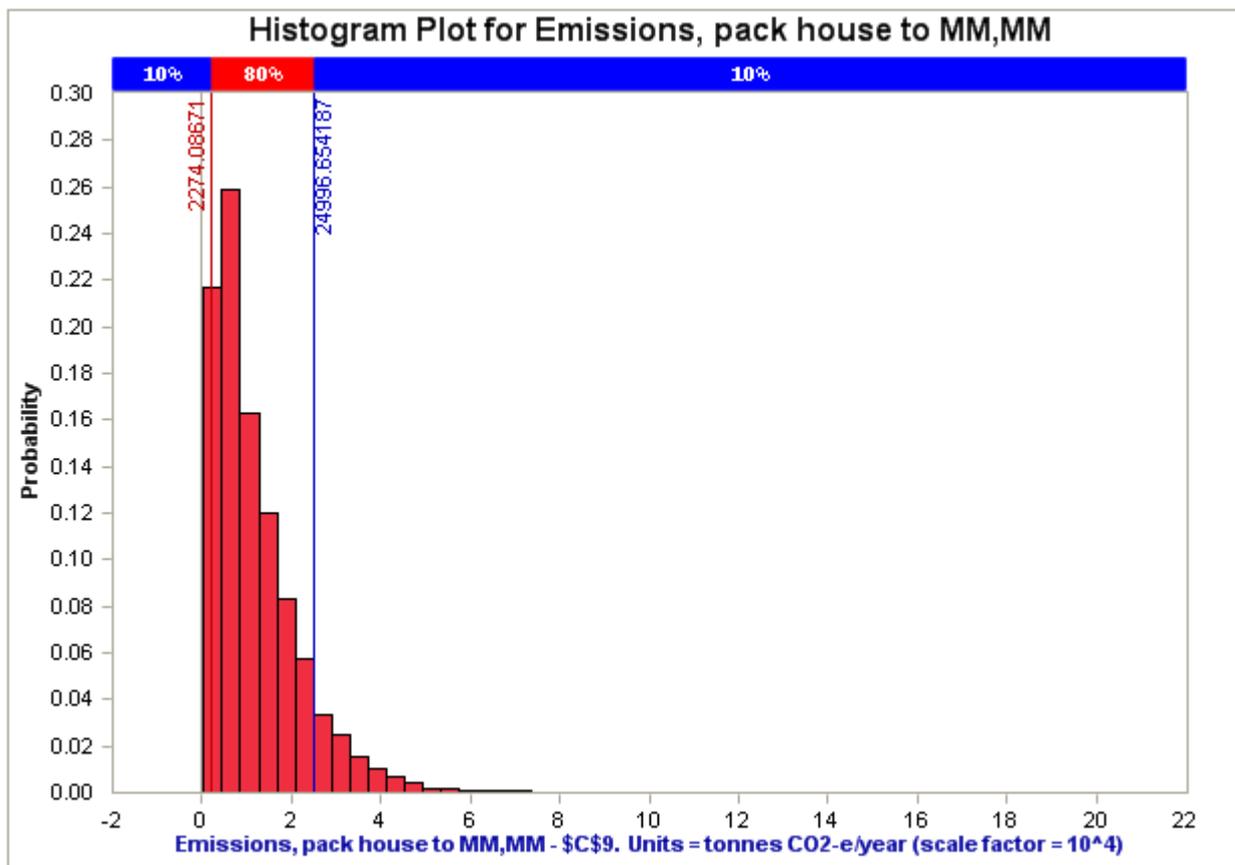


Figure C.2.2. Distribution of GHG emissions arising from the F&V transport between packing houses and MM.

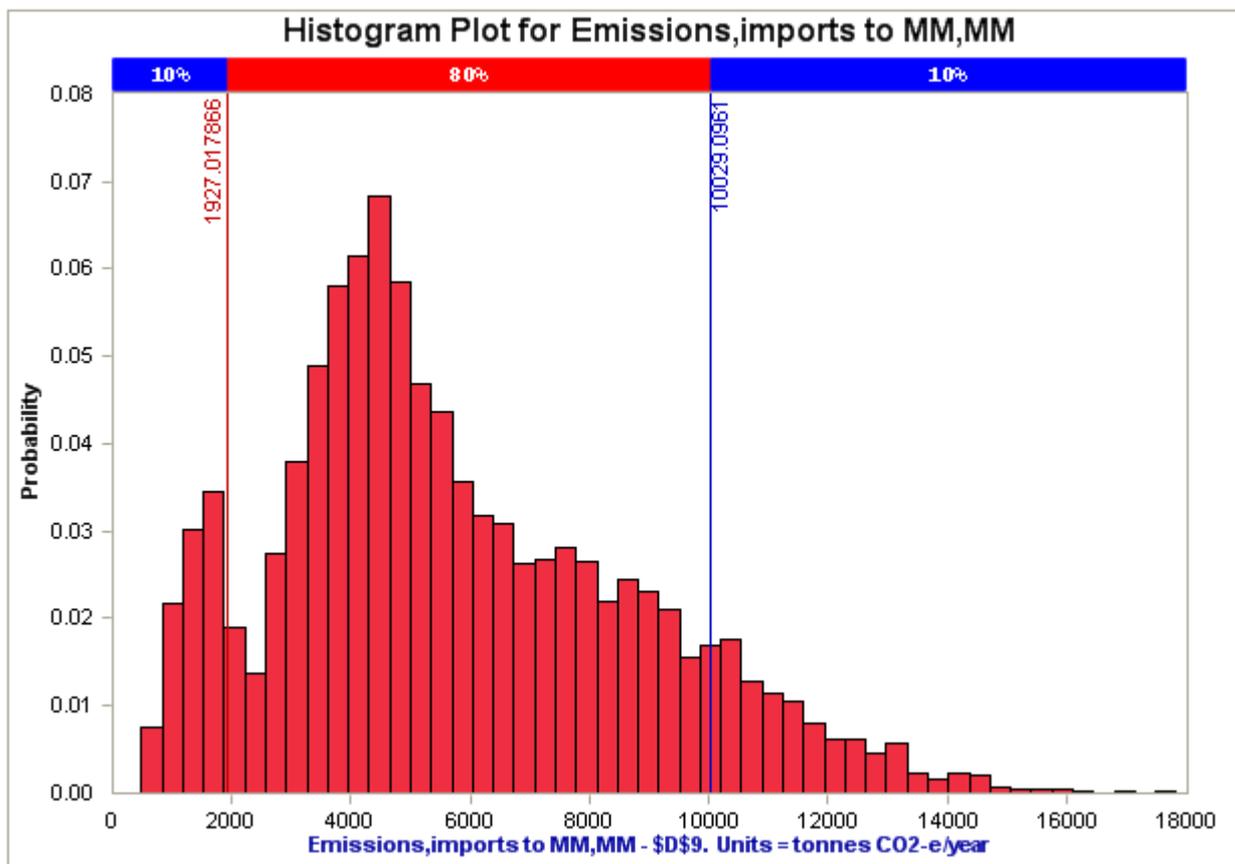


Figure C.2.3. Distribution of GHG emissions arising from the imported F&V transported between the country of origin and MM.

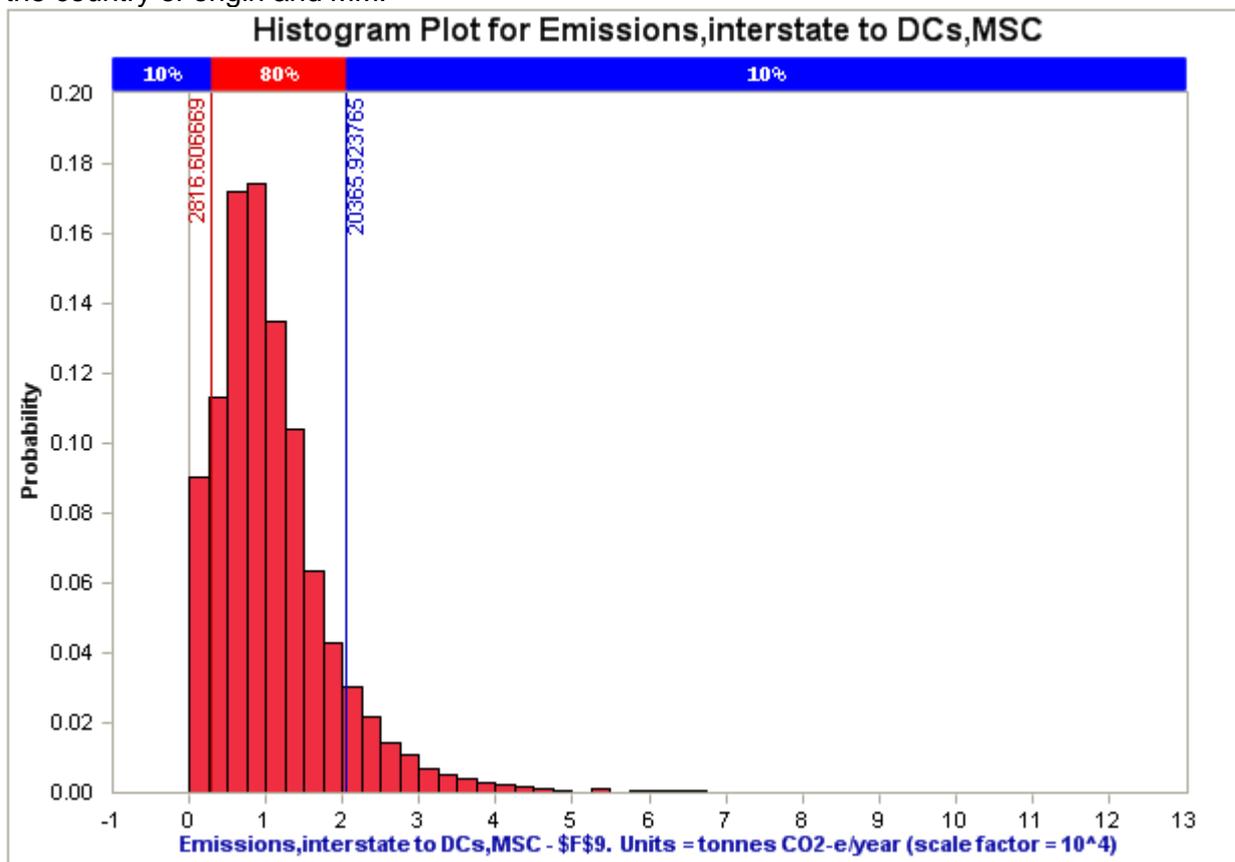


Figure C2.4. Distribution of GHG emissions arising from the interstate-sourced F&V transported between the Victorian point of entry and MM.

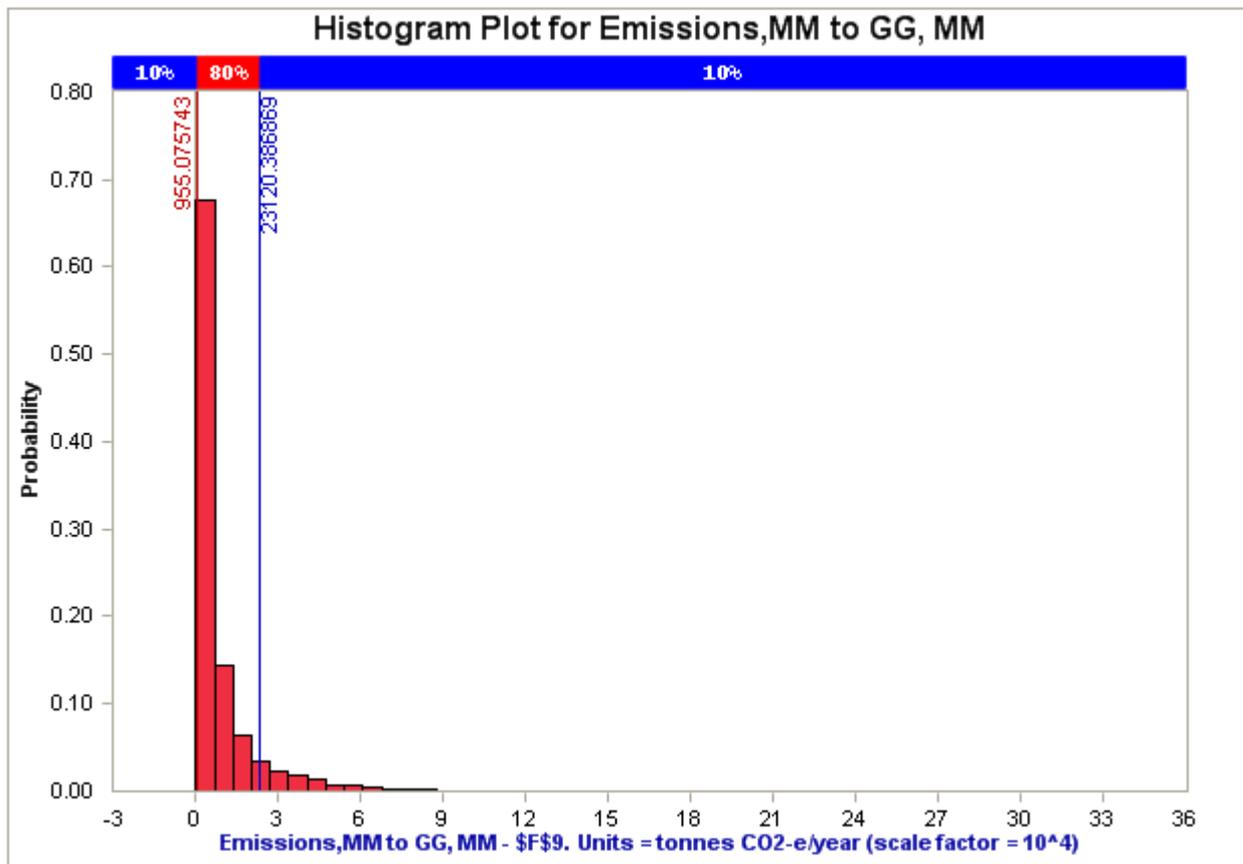


Figure C.2.5. Distribution of GHG emissions arising from the F&V transport between MM and greengrocers (GG).

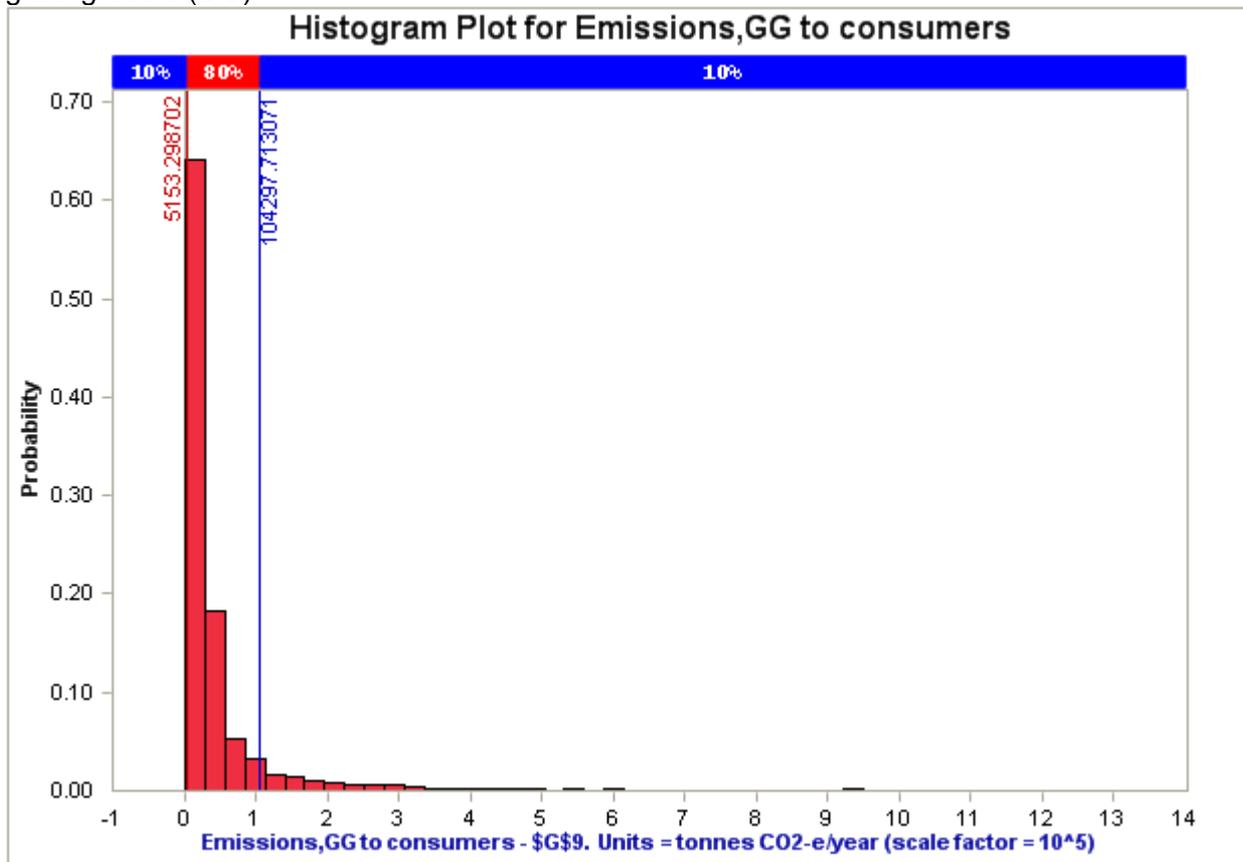


Figure C.2.6. Distribution of GHG emissions arising from the F&V transport between GG stores and consumers.

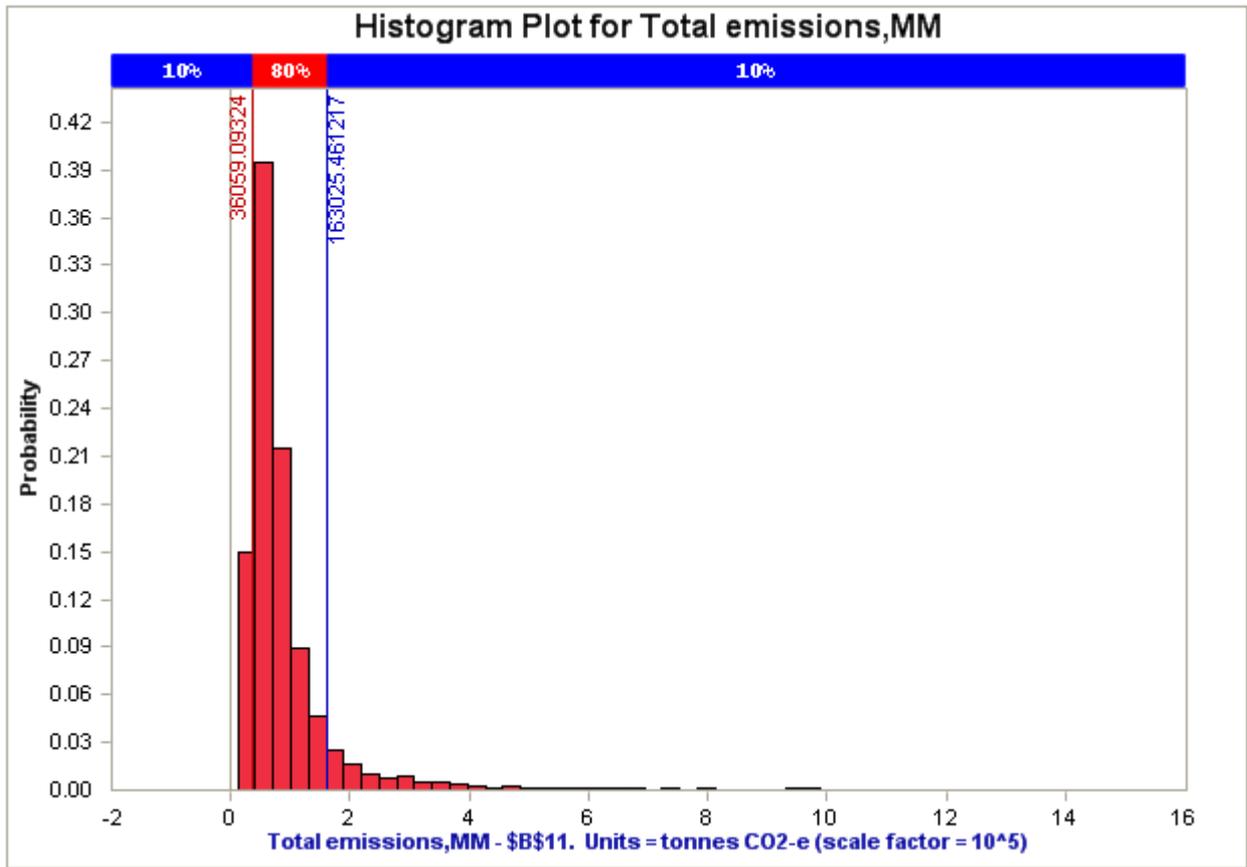


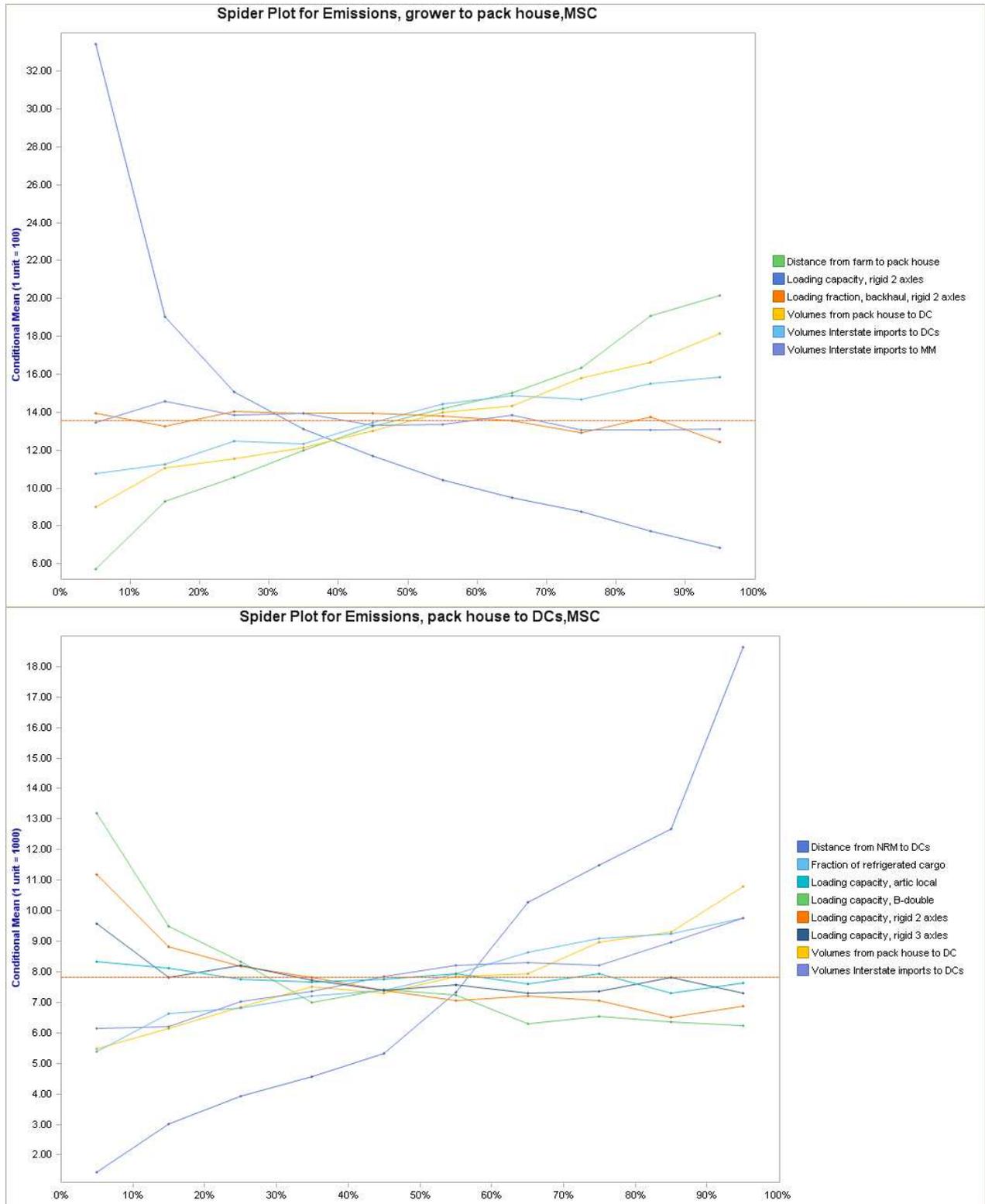
Figure 2.7. Distribution of GHG emissions arising from the fark to fork F&V transport, MM chains.

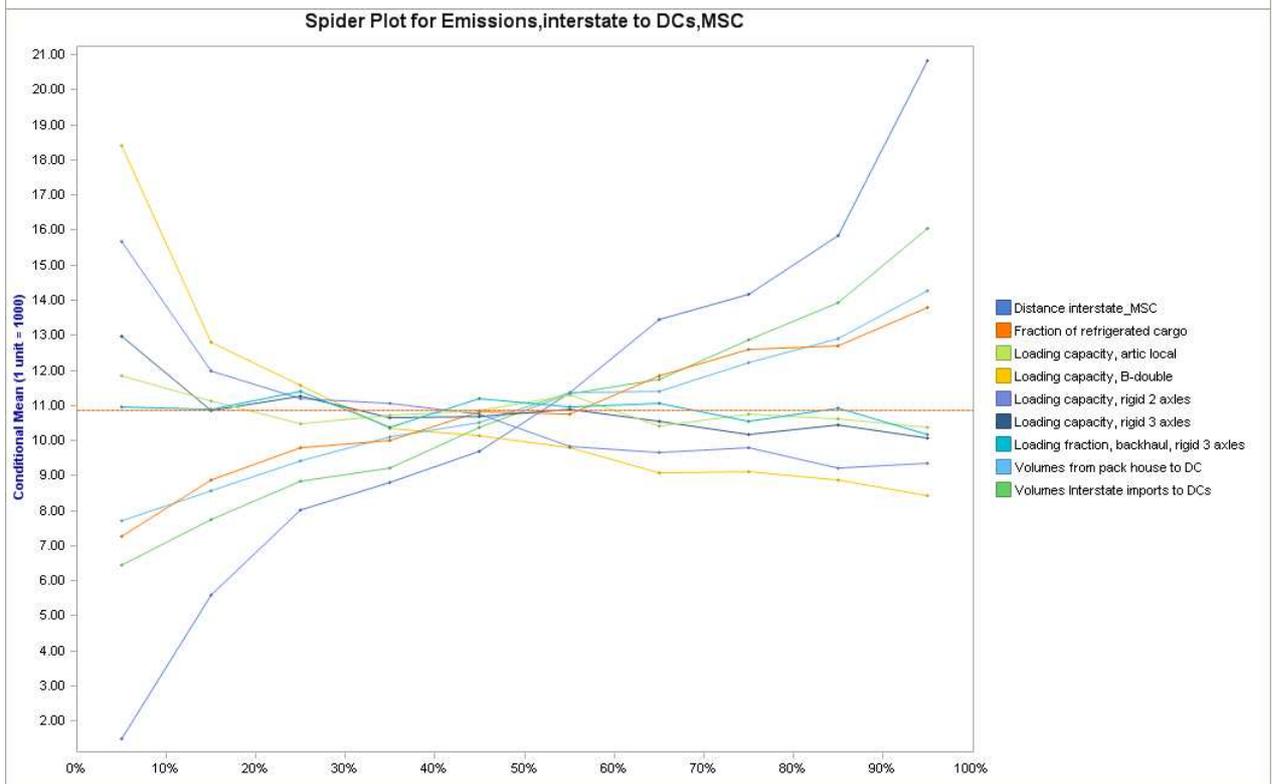
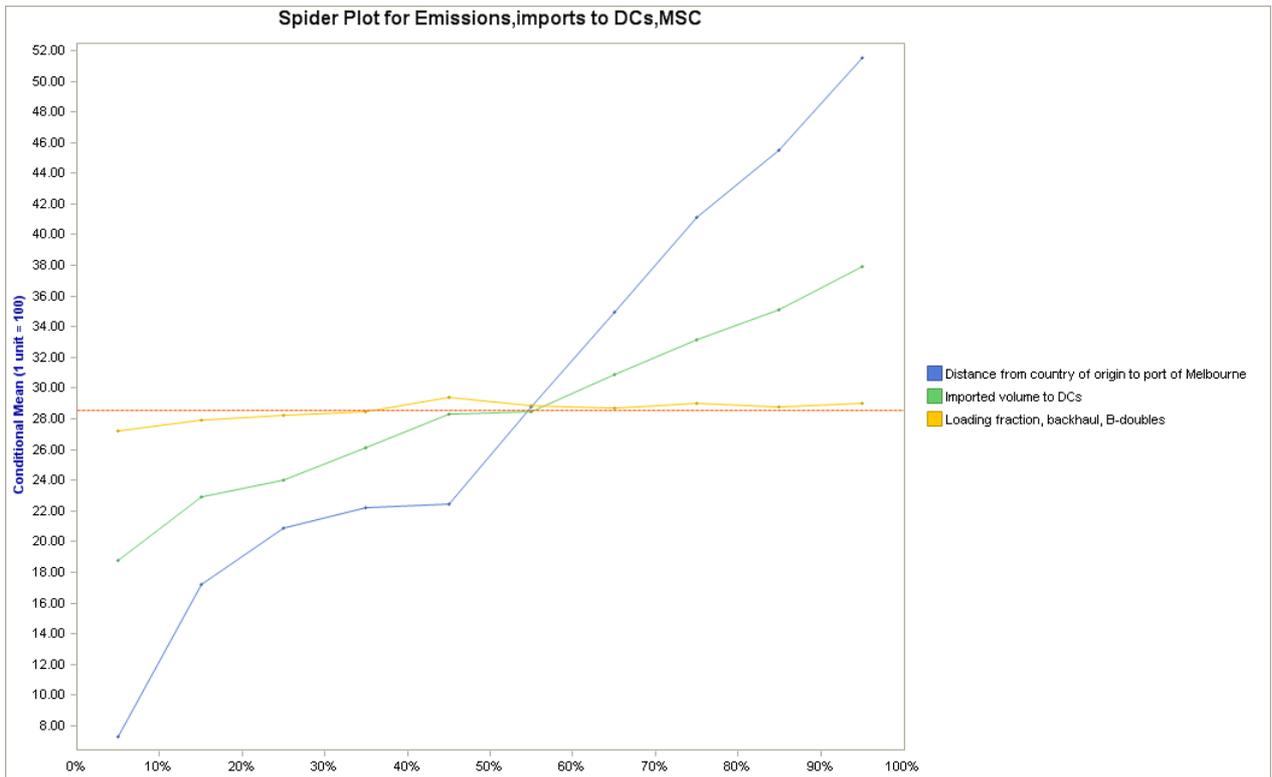
# Appendix D. Spider plots for MSC and MM segments, farm to fork.

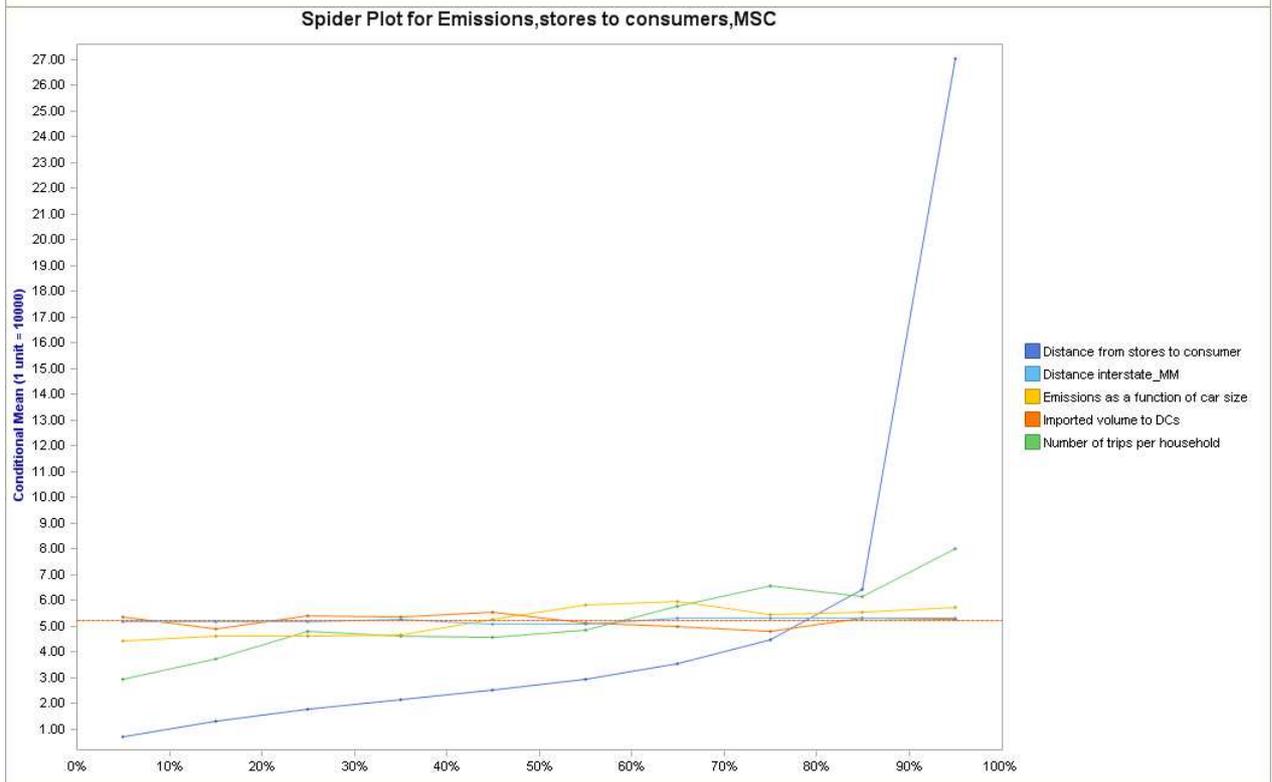
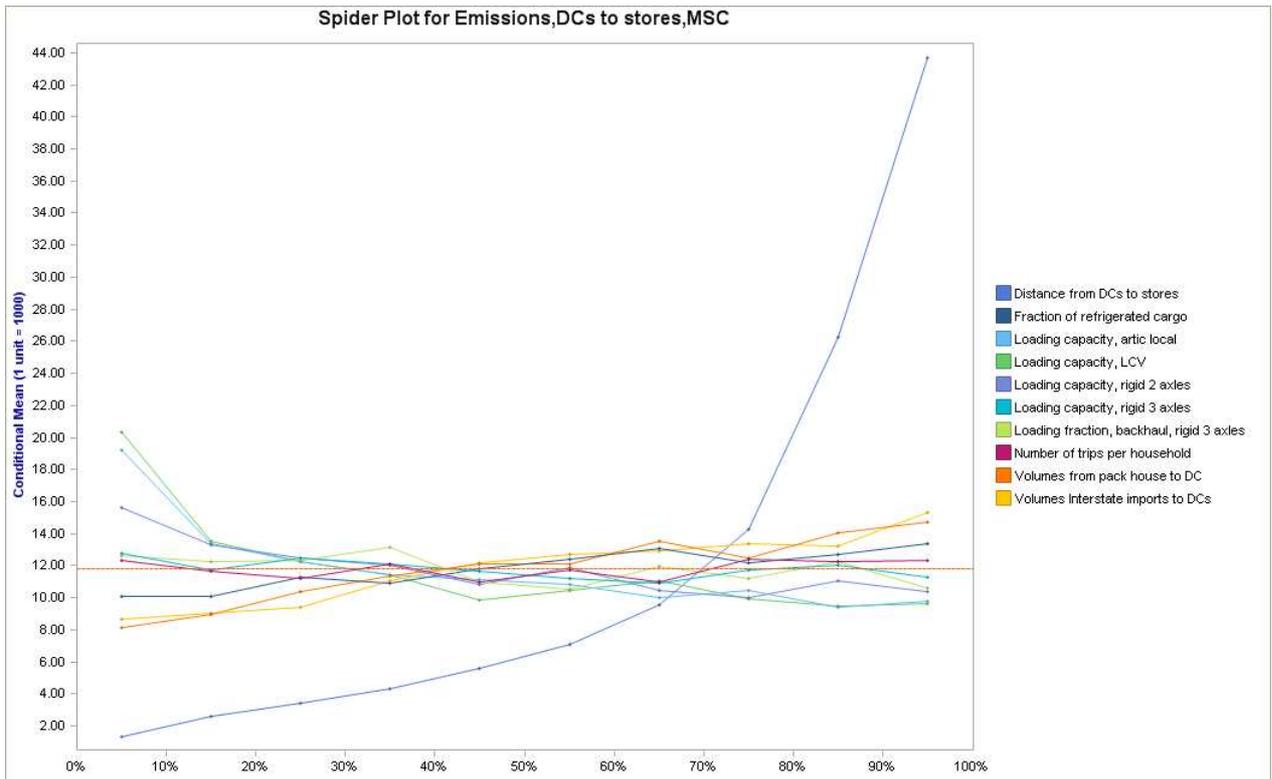


## D1. Major supermarket chains

Conditional mean= Average GHG emissions, tonnes CO2-e.

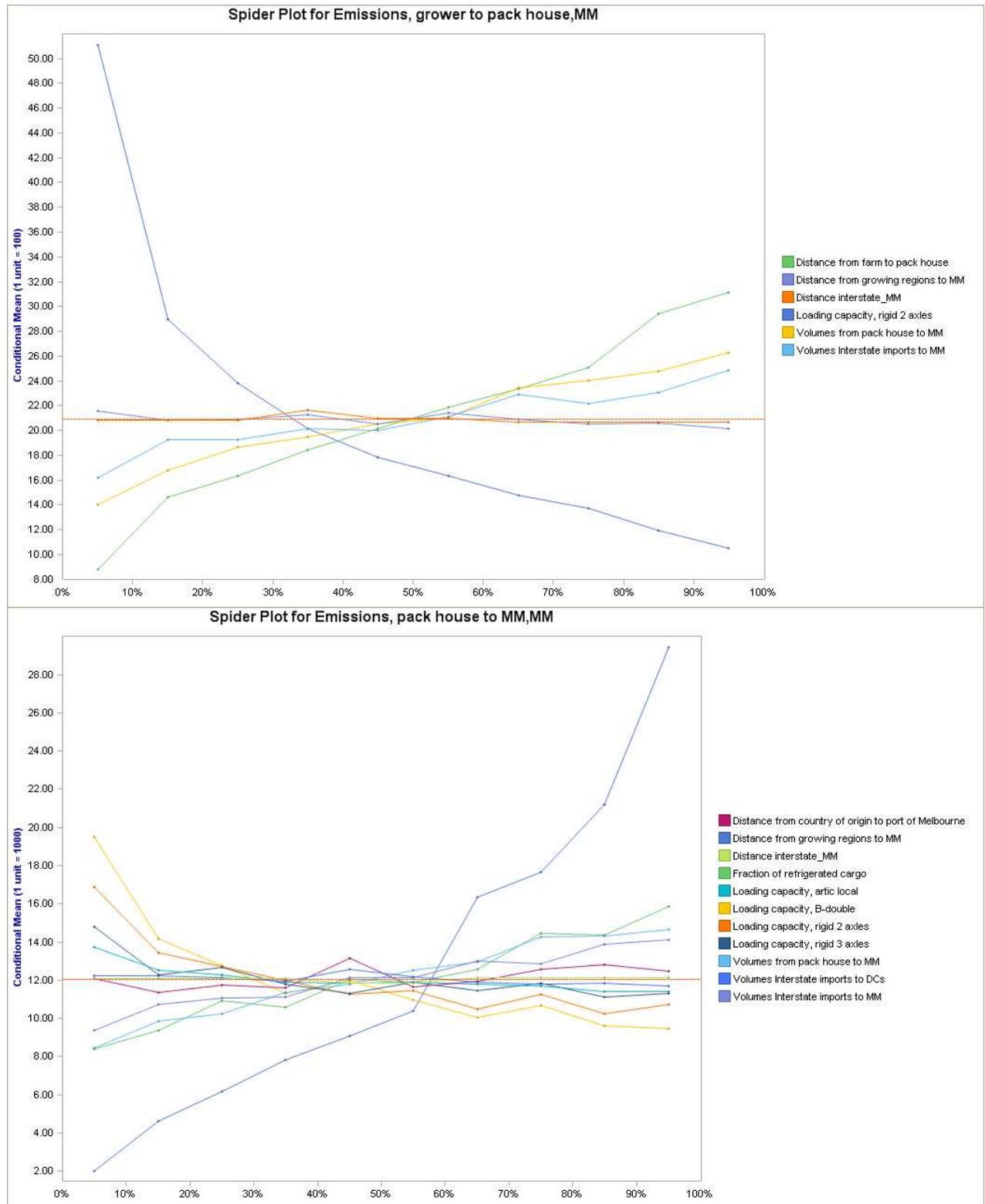


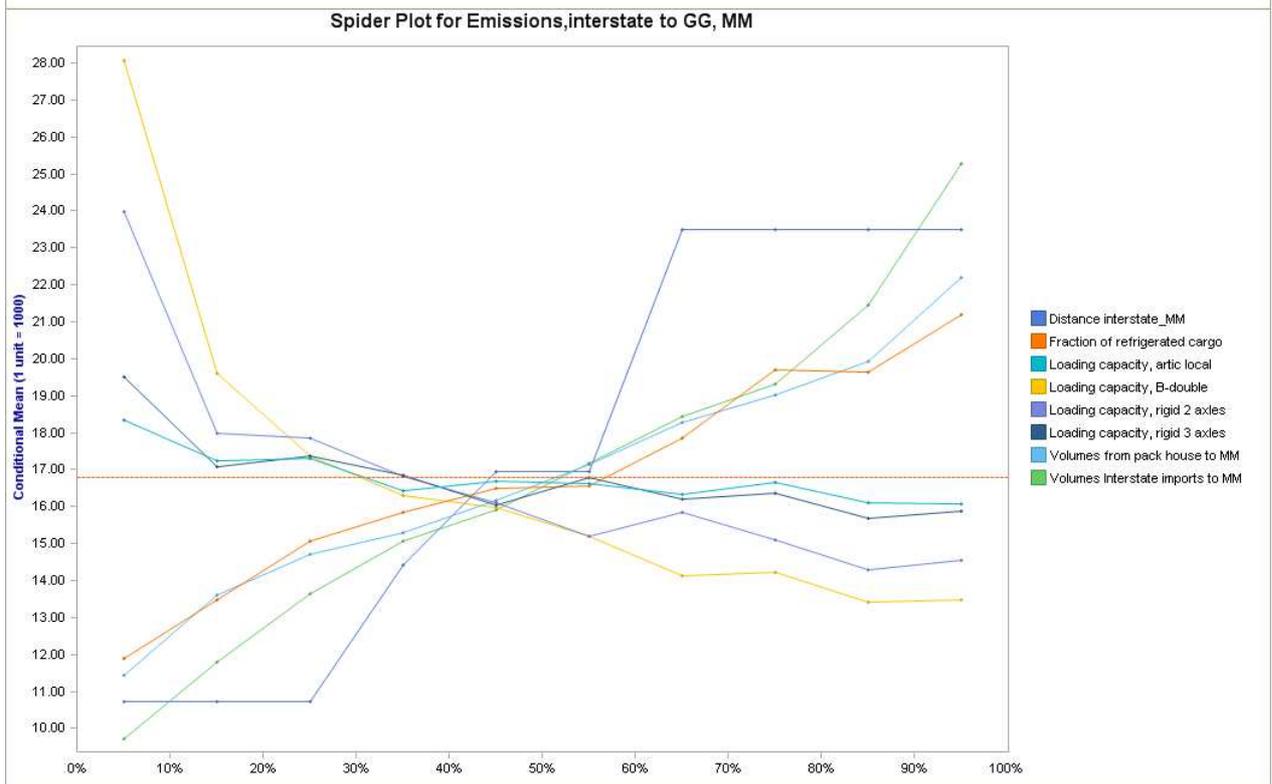
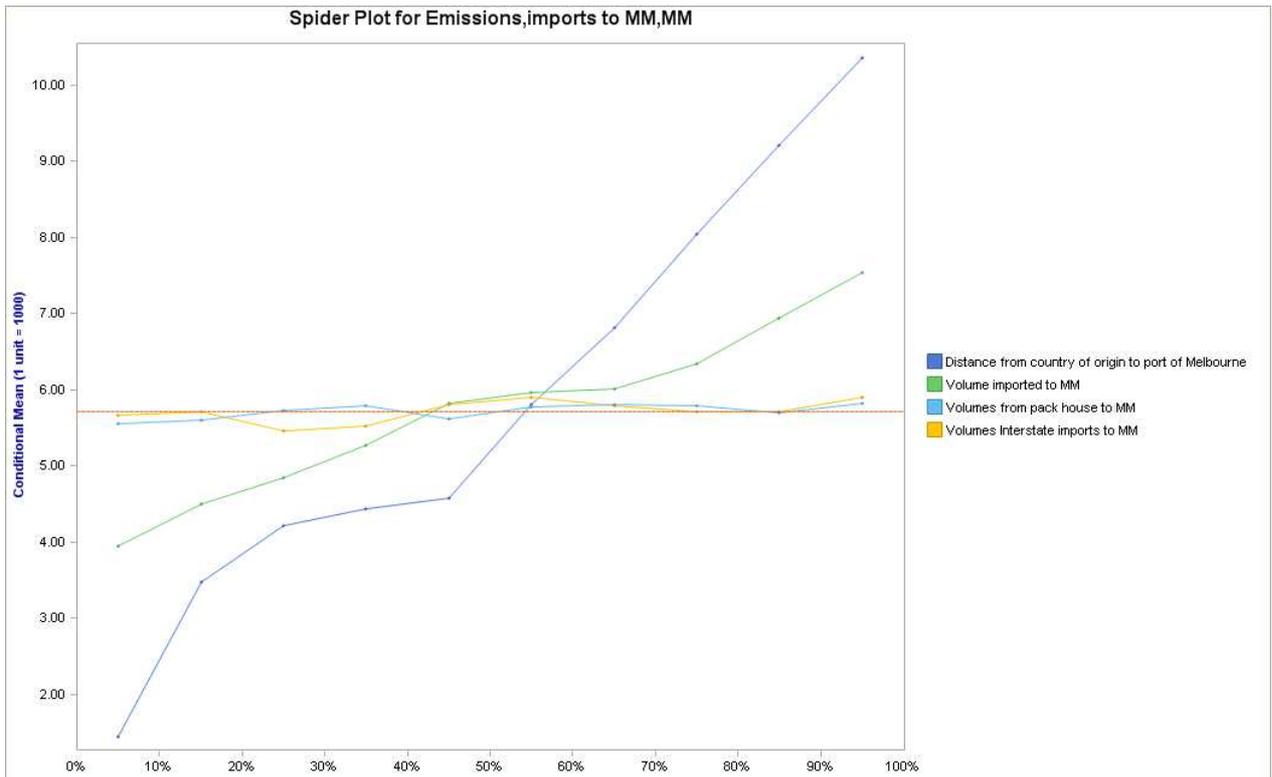


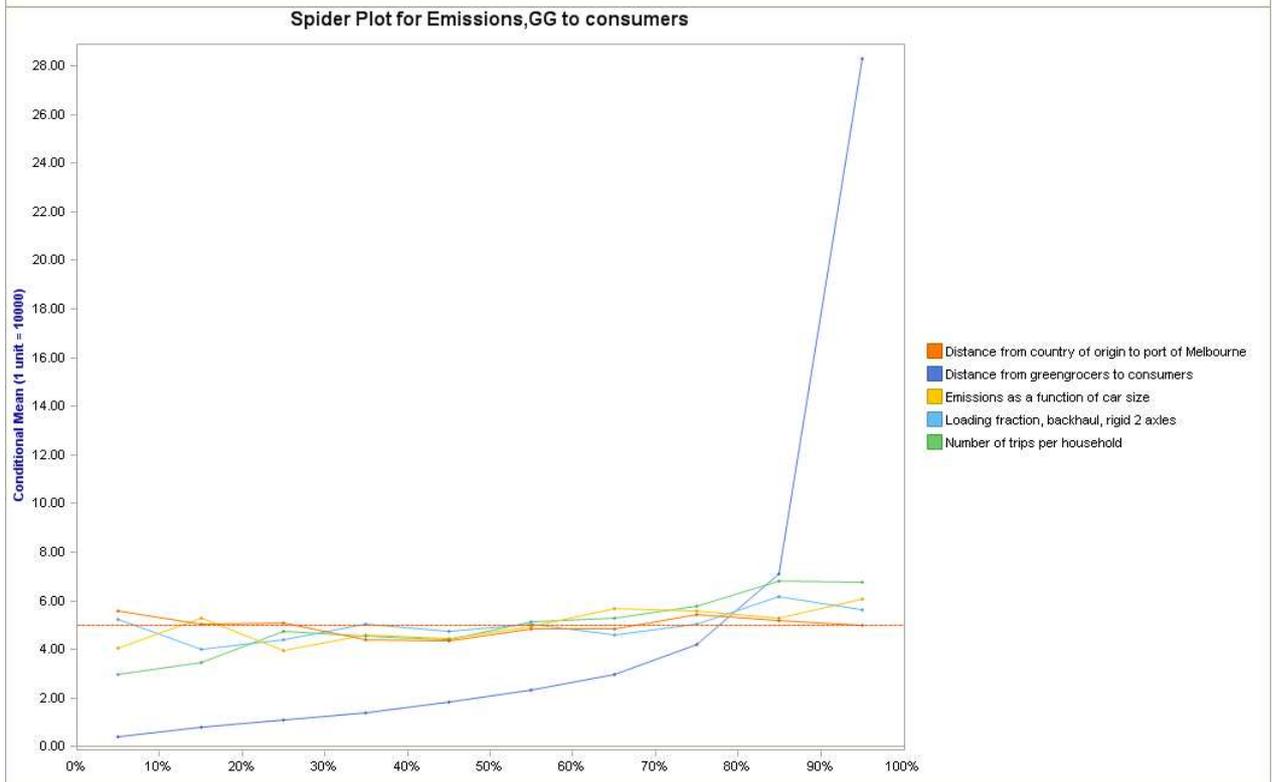
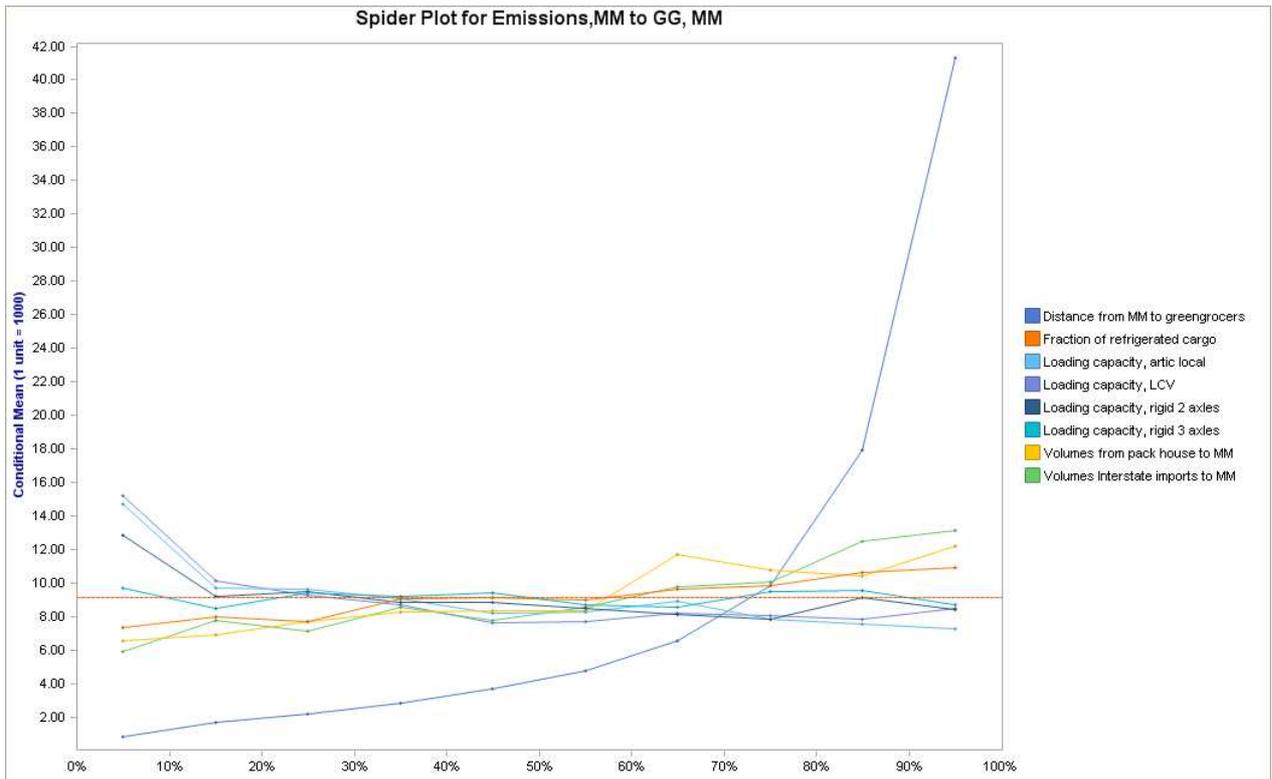


## D2. Melbourne Markets-Greengrocers

Conditional mean= Average GHG emissions, tonnes CO2-e.







## Appendix E. Discussion Paper on The ‘Last Mile’: Victorian consumers travelling to supermarkets.

The following analyses emphasise the importance of the ‘last mile’ from supermarkets to consumers. The impact of consumer transport is a significant component of the food distribution systems for F&V. In the UK, the combined GHG emissions of the nation’s weekly supermarket shop are equivalent to the impacts from road freighting food (Smith, 2005). In Melbourne, 69% of land transport emissions are from cars (Loader, 2008).

We acknowledge that other outlets (e.g. greengrocers, foodservice, farmers’ markets) contribute significantly to the overall carbon footprints of F&V and the accessibility of Victorian population to these products. Our focus on supermarkets and larger grocery stores in this section is likely to underestimate both indicators. However, independent and chain supermarkets are considered to be the best proxies of fresh and processed fruit and vegetable outlets because:

- Supermarkets are the most common food purchase place for the majority of Victorian population (Metcash, 2008). Figure E.1 shows the types of stores visited by Australian consumers in a week.

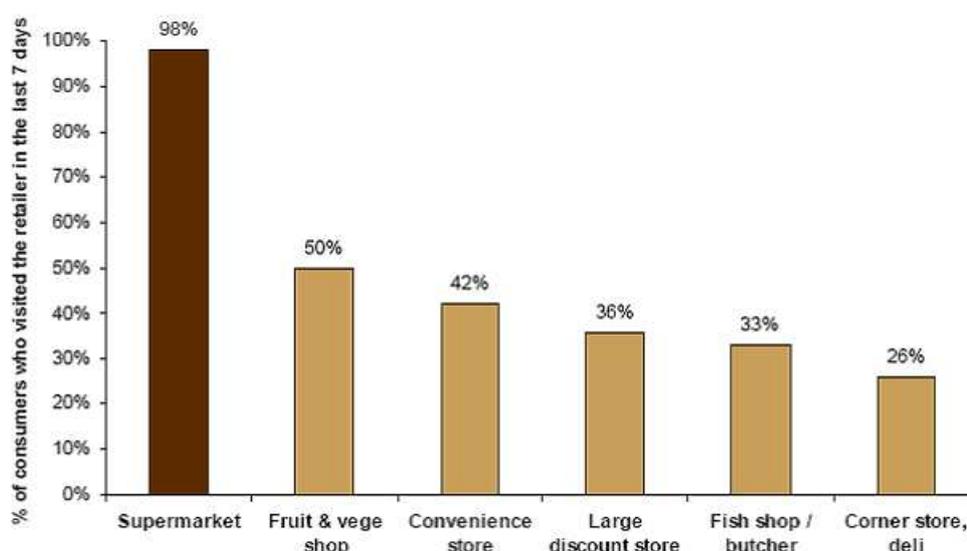


Figure E.1. Type of stores visited by Australian consumers in a week. Source: AC Nielsen, Shopper Trends 2008 as cited by (Metcash, 2008).

- Small retailers account for about 20% of total fruit and vegetable retailing with the remaining 80% of revenue derived from sales by other retailers (Burgio-Ficca, 2010). In its public submission to the ACCC Grocery inquiry, Woolworths estimated market share values for take-home food and grocery of 30.1% for Woolworths (26.2% in the fresh F&V category), 22.8% for Coles/BiLo, 16.7% for Metcash, 2.8 % for ALDI and 24.3% for other retailers<sup>33</sup>. This is congruent with IBIS estimates. Therefore, capturing outlet locations for all Woolworths, Coles, IGA, Foodworks and ALDI stores in Victoria should reflect nearly 80% of the fresh and processed F&V market.
- Foodservice is in a different (higher) price bracket than supermarkets, due to the additional labour on preparation, local rent and profits in the sector.

<sup>33</sup> Excludes take away and restaurants.

- Farmers' Markets do not offer an equivalent alternative to supermarkets, because the frequency of these varies from 1 to 4 weeks. Thus, food availability from FM is restricted.
- It can be argued that independent stores are also in a higher price bracket than large supermarket chains. In 2004, Burns et al. found a trend for cheaper prices being provided by large chain stores in rural Victorian towns (although differences among stores were not statistically significant). A more recent survey that analysed 34 stores across 18 towns in rural Victoria (Palermo, 2008) found that the cost of a food basket purchased at an independent store was significantly higher than the same basket purchased in a supermarket chain (median cost \$406.66 versus \$394.93, for an independent store purchase and a supermarket purchase, respectively). Unfortunately, Palermo et al did not distinguish between organized independent retailers (e.g. Foodworks, IGA) and small grocers (e.g. greengrocers). However, it is reasonable to assume that higher prices would be paid in stores that can't achieve the supply chain efficiencies typical of organized mass sourcing and distribution. For example, IBISWorld reports that small fruit and vegetable grocery stores source their products from Melbourne Markets and other wholesalers, which they visit a number of times per week (Burgio-Ficca, 2010).
- Similarly to large retailers, the location of fruit and vegetable stores is broadly linked to population levels and density. Like other retailers, industry operators aim to position themselves where they are able to maximise consumer traffic (Burgio-Ficca, 2010).

Therefore, the following analyses consider only supermarket chains (both independent and large chains) as proxies of fruit and vegetable outlets.

## Victorian consumers

To visualise the density of major F&V outlets (*i.e.* supermarkets, farmers' markets and Melbourne Markets) in relation to the Victorian population, a depiction showing the 79 councils is presented in Figure E.2.

Table E.1 presents an analysis of F&V outlets distribution through the calculation of densities (ratios) of FFV outlets per area and per population. In this case, the 115 stores located in the Melbourne Markets have not been considered, as these are not open to the general public (only for FFV traders).

The following observations can be drawn from Table E.1:

- As expected, the number of F&V outlets is significantly correlated to the population existent in each Section analysed.
- The number of outlets is not significantly correlated to the area of each Section.
- The Sections with the lowest density of stores per 1,000 persons (*i.e.* below the State average) are Sections 7, 8 and 6 (in increasing order), which correspond to Western, North Western and Metropolitan Melbourne. In contrast, these Sections have the highest outlet densities per area. This reflects the high density of population per area in those Sections.
- The Sections with the highest density per 1,000 persons (*i.e.* above the State average) are Sections 1 and 11 (in decreasing order), which correspond to Northern and North Western Victoria. In contrast, Sections 1 and 11 have some of the lowest densities of stores per area. This reflects the low density of population per area in those Sections.
- While in terms of density of F&V outlets per population there are no significant differences between sections, the density of F&V outlets per area are significantly different. In

particular, Section 6 (Metropolitan Melbourne) has the highest outlet density per area, which is about 500 times higher than the lowest value (*i.e.* Section 1). Metropolitan Melbourne also presents the highest density of population per area.

- From a supply chain perspective, the F&V outlets in suburban and metropolitan Melbourne are located at close distances of each other. They are also close to the major supermarket DCs and these outlets are likely to be replenished frequently. This suggests that Melbourne has a robust F&V supply network from DCs to consumers.

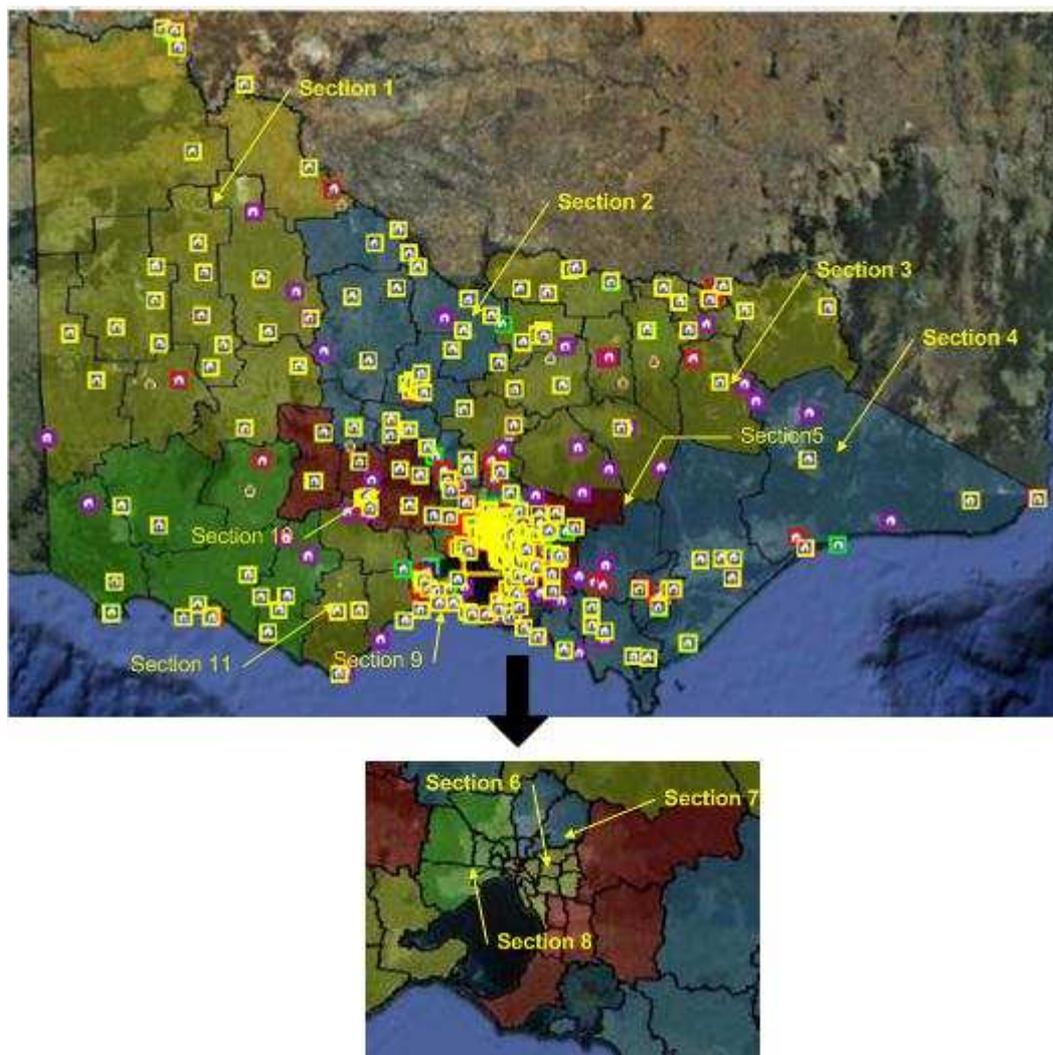


Figure E.2. Geographical distribution of major F&V outlets (*i.e.* supermarkets, farmers' markets and Melbourne Markets) in the 79 Victorian councils<sup>47</sup>. (a) The yellow squares represent IGA/Metcash stores; (b) the green squares represent Woolworths stores (including the former Safeway stores); (c) the red squares represent Coles supermarkets, BiLo and Coles Express stores; (d) the blue squares represent Aldi stores; (e) the purple squares represent Foodworks stores. Data obtained from: (a) the Metcash supplier information webpage ([http://www.metcash.com/index.cfm?page\\_id=2137](http://www.metcash.com/index.cfm?page_id=2137)); (b) the Woolworths vendors website ([www.wowlink.com](http://www.wowlink.com)); (c) the Coles Supplier website (<http://supplier.coles.com.au>); (d) the GPS Data Team provider (<http://www.gps-data-team.info/poi/australia/shopping/>); (e) the Foodworks store locator (<http://www.foodworks.com.au/store-locator?region=5&postcode=>). All accessed in Jan 2010.

Table E.1. Analysis of the density of FFV outlets (*i.e.* supermarket stores, farmers' markets and MM stores) as a function of area and population.

Section	Councils	Number of outlets	Density of FFV outlets	
			Per 1000 persons	Per 1000 km <sup>2</sup>
1	Mildura, Swan Hill, Buloke, West Wimmera, Hindmarsh, Yarriambiack, Horsham, Northern Grampians	42	0.32	0.60
2	Ganawarra, Loddon, Campaspe, Greater Bendigo, Central Goldfields, Mount Alexander, Macedon Ranges	48	0.21	2.11
3	Moira, Greater Shepparton, Strathbogie, Mitchell, Murrindindi, Mansfield, Benalla, Wangaratta, Indigo, Wodonga, Towong, Alpine	80	0.30	1.99
4	East Gippsland, Wellington, Baw Baw, Latrobe, South Gippsland, Bass Coast	73	0.29	1.76
5	Yarra Ranges, Cardinia, Casey, Greater Dandenong, Frankston, Mornington Peninsula	162	0.19	29.22
6	Melbourne, Port Phillip, Yarra, Boroondara, Stonnington, Glen Eira, Bayside, Manningham, Maroondah, Knox, Whitehorse, Monash, Kingston	230	0.14	301.44
7	Whittlesea, Nillumbik, Banyule, Darebin	47	0.10	45.28
8	Moreland, Hume, Melton, Wyndham, Hobsons Bay, Brimbank, Moonee Valley, Maribyrnong	136	0.14	72.11
9	Golden Plains, Colac Otway, Surf Coast, Greater Geelong	54	0.20	6.04
10	Pyrenees, Ballarat, Hepburn, Moorabool	34	0.24	4.40
11	Gleneg, Southern Grampians, Ararat, Moyne, Corangamite, Warrnambool	35	0.30	1.29
		<b>TOTAL =941</b>	<b>AVG=0.23</b>	<b>AVG=56.09</b>

Melbourne concentrates the majority of Victoria's population (73% or 3.74 million). In regional Victoria, Geelong, Ballarat, Bendigo and the Latrobe Valley all have major population cores, as well as some coastal regions and parts of the Murray River.

As discussed in Chapter 5, the analysis of consumer access to the nearest retail outlet offering fresh fruit and vegetables was performed by using data from 9,298 collection districts in Victoria<sup>34</sup>. Each collection district represents 552 consumers<sup>35</sup> or an average of 212 households<sup>36</sup>. Specific data on the number of households per collection district is used later in this report.

## Distances to the nearest supermarket stores

<sup>34</sup> The Census Collection District (CD) is the smallest geographic area defined in the Australian Standard Geographical Classification (ASGC).

<sup>35</sup> Using the Victorian population estimate of 5.13 million in 2006.

<sup>36</sup> Assuming an average household size for Victoria of 2.6 persons. ABS, 2006. <http://www.abs.gov.au>

In this section, supermarkets are used as a proxy of fruit and vegetables outlets and collection districts are used as a proxy of consumer households.

Figure 5.7 (Chapter 5) shows a gradient map<sup>37</sup> that illustrates the ranges of distances to the nearest supermarket store (i.e. Coles, Woolworths, ALDI, Foodworks or IGA/Metcash) that Victorians need to travel. This figure indicates that about 85% of the total number of the selected consumer locations are at less than 5 km away from the nearest F&V outlet. A further 10% of consumer locations are within 5 km and 20 km of distance to the nearest supermarket store. The remaining 330 locations are over 20 km away from the nearest store. About 56 locations are 60 km away from the nearest supermarket. Figure E.3 identifies some of the locations that have the least accessibility to a supermarket store.

In terms of Melbourne and surroundings, the observations from Figure E.4 generally agree with a previously published study that investigated the spatial distribution of the three major supermarkets in the City of Casey, a municipality located in a growth corridor in South East Melbourne (Burns and Inglis, 2007). The aforementioned study found that more than 80% of Casey residents need to travel a maximum of 10 minutes by car to reach a supermarket.

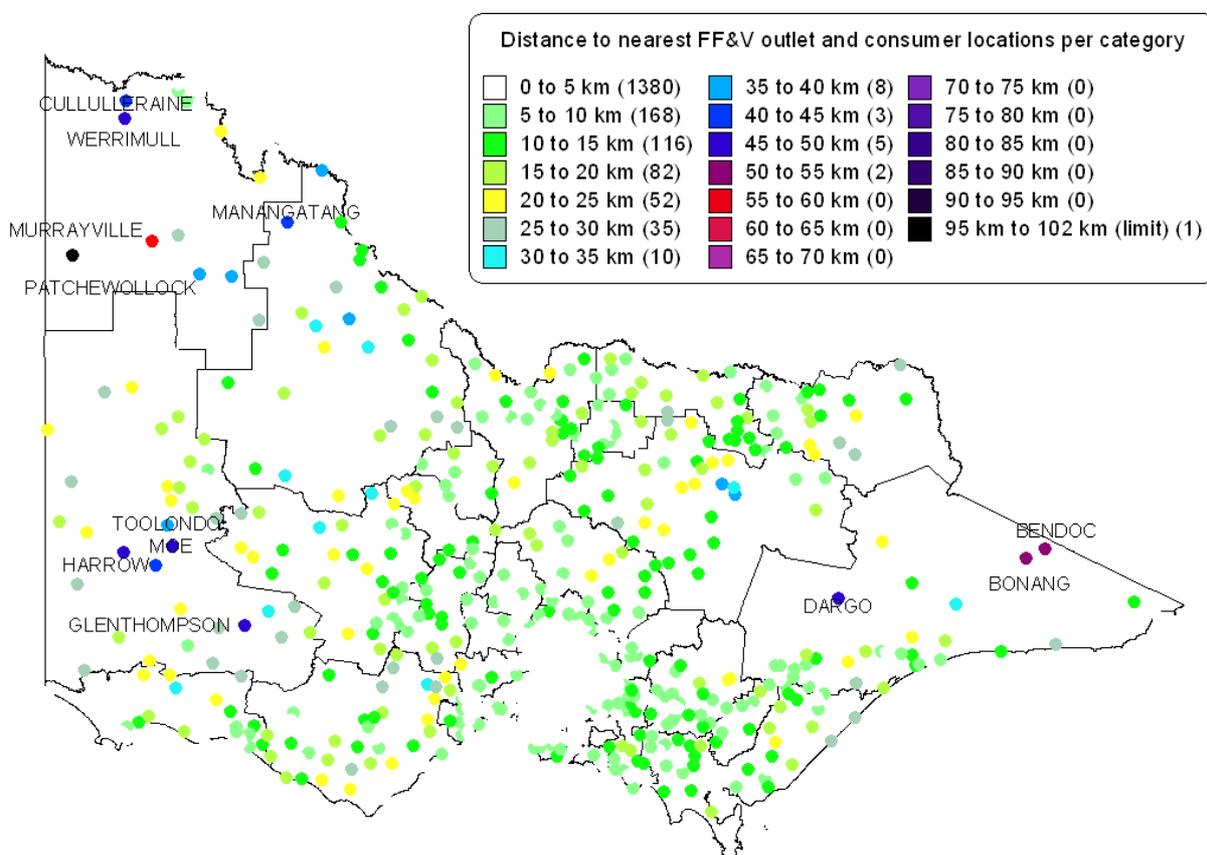


Figure E.3. Map showing some locations where consumers have to travel over 40 km to reach the nearest supermarket store.

It is worth noticing that these depictions take into account only those supermarket stores within the Victorian borders. For example, Murrayville is located near the border with South Australia and 28 km away from the town of Pinnaroo, which has an independent supermarket. However, places such as Dargo and Glenthompson are over 40 km and 50 km away from a supermarket store, respectively. Consumers rely on small grocery retailers located in town to purchase fresh and processed fruit and vegetables.

<sup>37</sup> Map created in MapViewer v.7.4.2986, Nov 2009. Golden Software Inc.

## Shopping travel intensity

In the previous analyses, the concentration of population per collection district is not taken into account, although it would be fair to assume that the distances to supermarkets are an indication of household concentration at each district.

A second gradient map (Figure E.4) was created to account for the number of households in the calculation of travel intensity per collection district. The travel intensity was calculated as the product of the average weekly shopping trip per Australian household (1.7 in 2007, according to AC Nielsen as cited in Metcash, 2008) multiplied by the number of households at each collection district and the distance travelled to the nearest supermarket computed for each collection district (Figure E.6). The results indicate that 92% of the Victorian collection districts analysed encompass consumer households travelling between 0 and 200,000 km each year.

These analyses take into account the return distance (2-way trip) from household to supermarkets. That is, attribution of distances considers consumer travel to the shops and back.

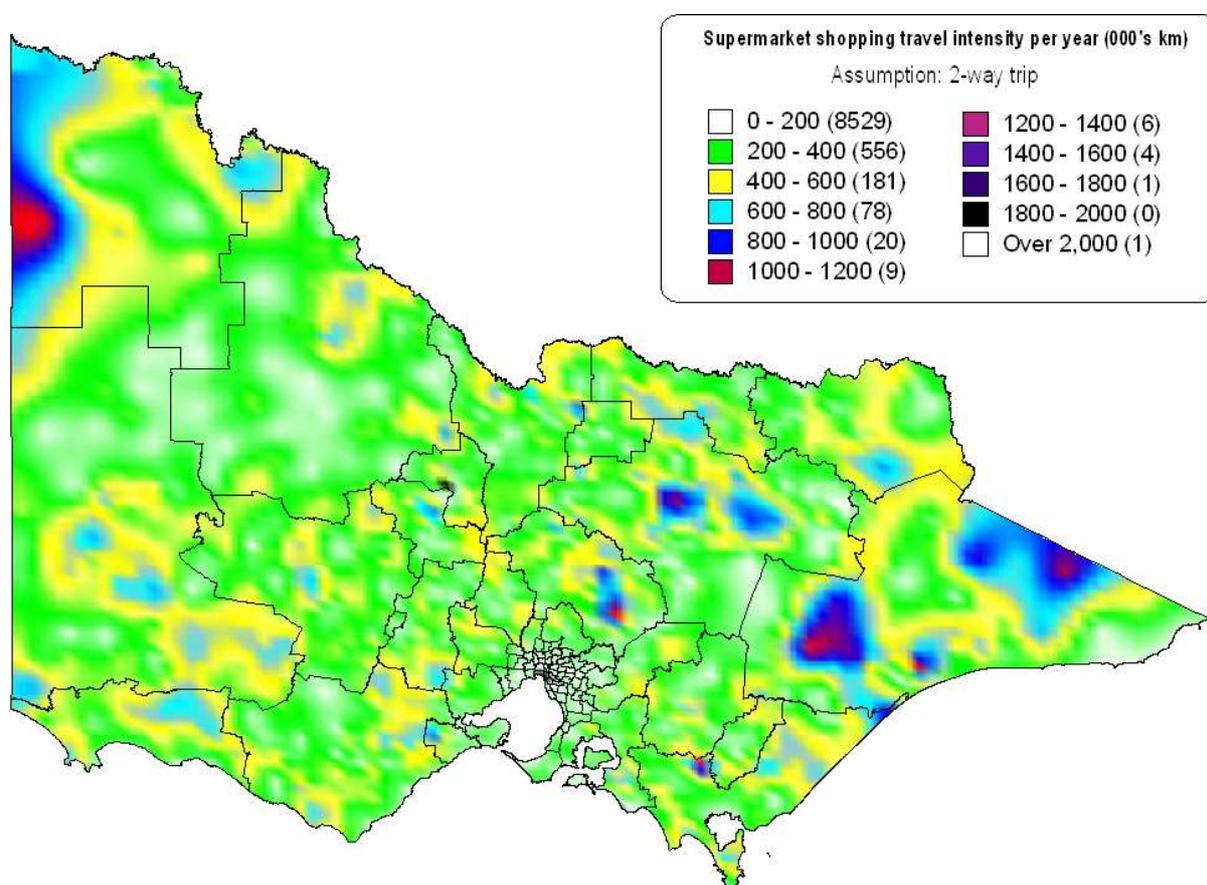


Figure E.4. Gradient map indicating the annual travel intensity of supermarket shopping by consumers in Victoria, assuming that all trips from households are to the nearest supermarket store. A two-way trip (*i.e.* from to store and back) has also been assumed.

In total, an estimated number of 1,294,450 Victorian households are expected to make 114,429,380 annual trips to the supermarket. Assuming a fixed annual number of trips of 88.4, the distances travelled by Victorian households to supermarkets amount to 734,512,617 km. This would lead to 143,280 tonnes CO<sub>2</sub> –e per year. The latter value was calculated assuming that 95% of the Victorian population uses a car<sup>38</sup> as shopping transport mode and 5% of shoppers

<sup>38</sup> Light, medium and heavy cars have an average emissions factor of 0.2024 kg CO<sub>2</sub> –e/km

use public transport (*i.e.* buses<sup>39</sup>). An average emission factor of 0.1950 kg CO<sub>2</sub> –e per km is obtained using these assumptions.

After considering the number of households per district, “hot spots” in terms of travel intensity persist, with 18,125 households in 136 collection districts travelling over 555,000 km/year to reach their nearest supermarket. This represents 1.5% of the total districts investigated in Victoria. Assuming that consumers in these ‘hot spots’ shop with the same frequency than consumers in other locations (*i.e.* 1.7 trips per week), these households would generate 15% of the carbon footprint of consumer food shopping travel in Victoria, or 20,894 tonnes CO<sub>2</sub>-e/year. Using the same assumptions about frequency of food shopping per week and vehicles emission factors, further analyses of the Victorian ‘last mile’ were performed to provide more insights about the effect of accessibility to fruit and vegetables, as represented by distances from consumer households to their nearest supermarket:

- 1) Figure E.5 shows that, in 80% of the household districts analysed, an average consumer travels between 5,000 km and 100,000 km annually for food shopping purposes.
- 2) Figure E.6 shows that the distances above translate into an average carbon footprint ranging from 2,026 to 5,360 tonnes CO<sub>2</sub> –e/year per consumer (household).
- 3) Figure E.7 shows a comparison of carbon footprints for a selection of urban and rural consumers. One list encompassing collection districts defined as “Melbourne” and one list of districts defined as “rural balance” were generated from ABS data. ABS defines “rural balance” as those districts with a population below 200 people. The results indicate that, while Melbourne collection districts account for 68% of the Victorian households, they account for only 37% of the carbon footprint generated by consumers’ travel to their nearest supermarket shop.
- 4) In contrast, supermarket shopping travel by consumers living in “rural balance” districts accounts for 41% of the travel carbon footprint, yet they encompass only 9% of the Victorian households. This disparity between population and carbon footprint arises from the fact that rural households need to travel longer to reach their nearest supermarket, as illustrated by the extended right hand side tail of the rural frequency distribution in Figure E.7.
- 5) These analyses assume that all consumer households shop with the same average frequency (1.7 times per week). This factor presumably takes into account the extreme values (*i.e.* highest shopping frequencies and lowest shopping frequencies) and therefore can be used with confidence to infer average contributions of Melbourne and rural districts. However, it would be fair to ask what would happen if the shopping frequency in rural households is less than in city districts.

Figure E.9 also presents the scenario expected if we assume that “rural balance” households shop with half the frequency of Melbourne-based households. The results indicate that the contribution of “rural balance” households to a recalculated total Victorian carbon footprint of 113,836 tonnes CO<sub>2</sub> –e/year drops to 26%. Nevertheless, this percentage remains significant, against a backdrop of “rural balance” households representing only 9% of the total number of Victorian households. These results indicate that emissions in this case are more influenced by distances to nearest shops than by shopping frequency.

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<sup>39</sup> Bus transportation has an average emission factor of 0.6567 kg CO<sub>2</sub> –e/km; however, this factor is reduced to 0.05 CO<sub>2</sub> –e kg per km per passenger, when the number of passengers is introduced as a factor.

In-depth understanding of the ‘last mile’ effect on food distribution systems can set the basis for “What if?” analyses, where factors such as optimization of store location can be used to assess their impact on the ‘last mile’ carbon footprint. For example:

- *How do the ‘last mile’ emissions compare with the transport emissions from the rest of the fruit and vegetables supply chain?* From the results of the stochastic analysis in Chapter 9, we learned that this component is the factor of greatest influence on the total GHG emissions of supermarket chains and greengrocers. However, is this the same for other product types?
- *Given the significant contribution of rural households on the overall carbon footprint generated by consumers’ travel to their nearest supermarket shop, what innovative food distribution systems can be more effective in decreasing the ‘last mile’ to rural households?* This question remains unanswered. Mostly, because it is difficult to compare systems that handle different volumes and have different supply chain efficiencies. However, substantial decreases in emissions in the consumer transport segment will only be possible if the transport distances from households located in “food desert” areas are tackled.
- *What would be the impact of adding more food outlets to decrease consumers’ travel intensity?* This relates to the point previously made. The commercial realities of mass distribution may inhibit this solution in rural areas. However, the transport of food by supermarkets to households was a potential solution offered by Estrada-Flores and Larsen (2010).
- *If increasing the number of food outlets is an option to decrease the impact of the Victorian ‘last mile’, how these improvements compare with the increase in upstream distribution operations required to supply the extra stores?* The stochastic analysis (Figure 9.3 in Chapter 9) showed that commercial distribution segments in general have a smaller carbon footprint than consumer travel, under the assumptions tested in the model. However, the commercial chain activities still contribute with 40% to 50% of the total carbon footprint. On this basis, increasing the distribution activities prior to reaching the stores would have an impact on overall GHG emissions. However, this only holds true for the fresh F&V. Mapping the entire food chain of products offered in supermarkets represents an enormous challenge that remains to be tackled. Further, trends for other products cannot be inferred by assuming that seafood or cereals would show similar trends than distribution operations for F&V.

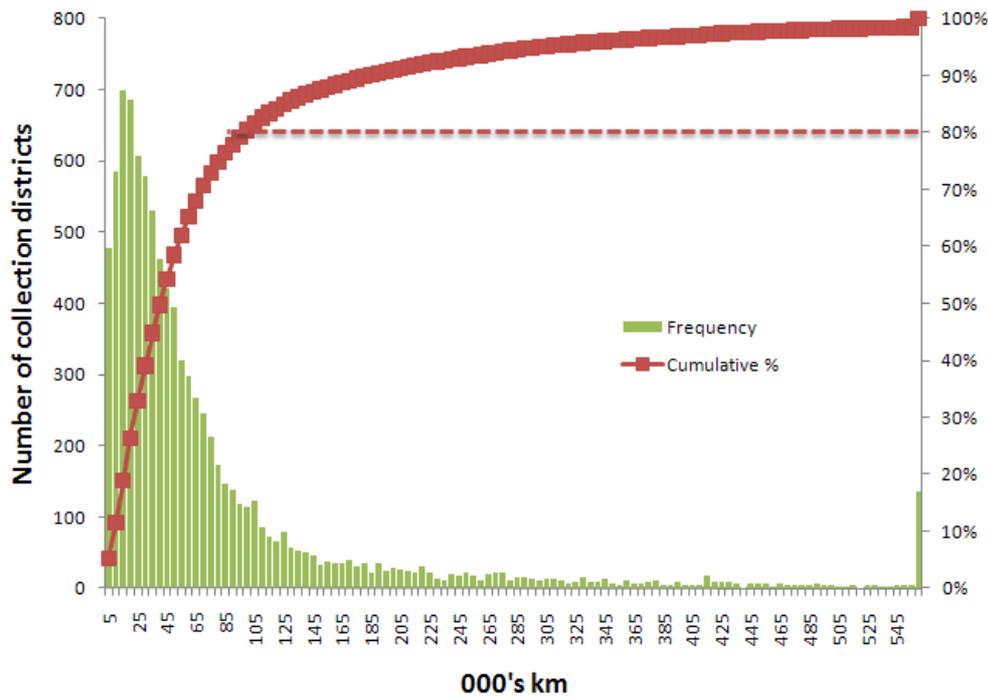


Figure E.5. Histogram showing the estimated annual travel (in thousands of kilometers) from consumers' travel to their nearest supermarket shop in Victoria, as a function of the number of collection districts. The red dotted line represents 80% of the total number of districts.

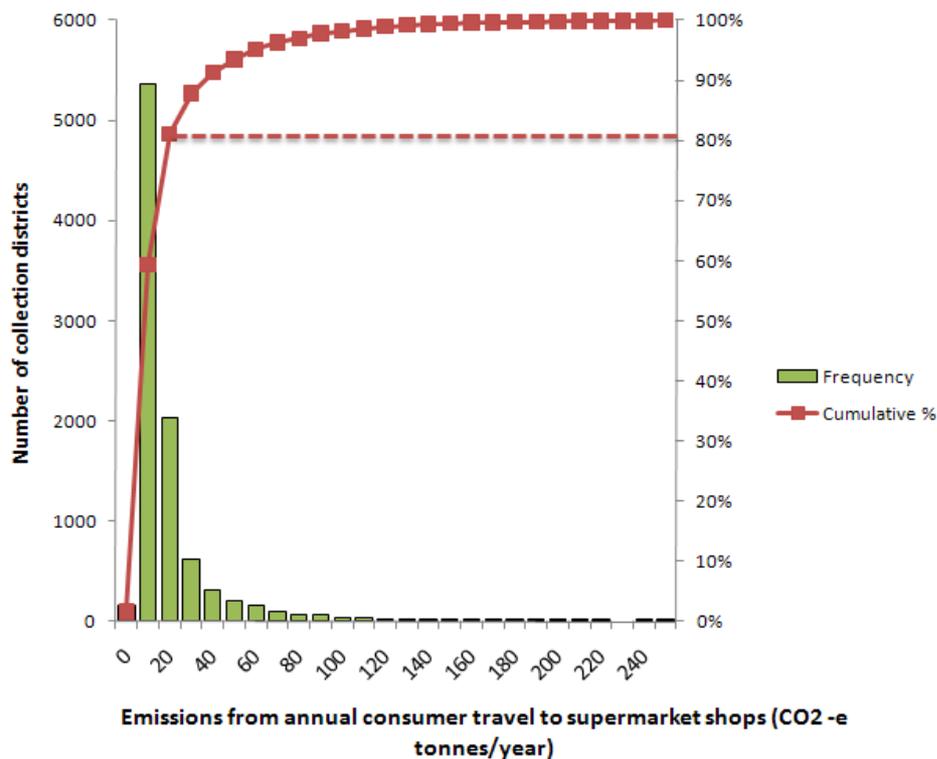


Figure E.6. Histogram showing the estimated annual emissions due to consumers' travel to their nearest supermarket shop in Victoria, as a function of the number of collection districts.

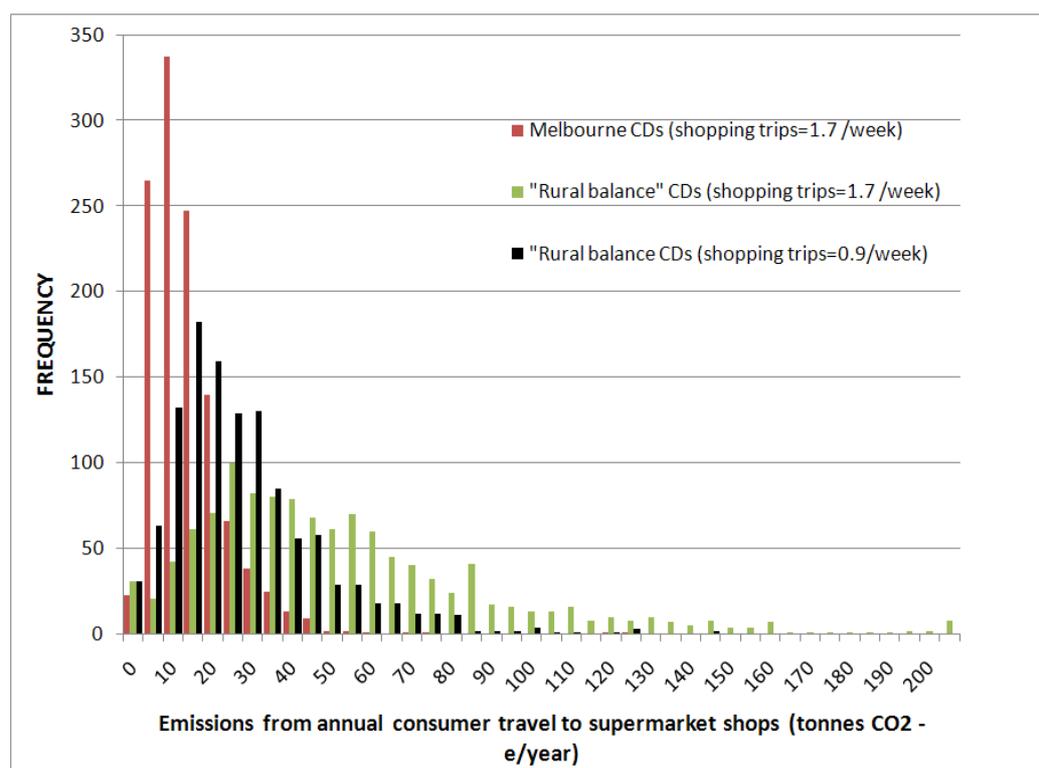


Figure E.7. Histogram showing a sample of 1170 Victorian urban and rural CDs and the estimated annual emissions due to consumer travel to supermarket shops.

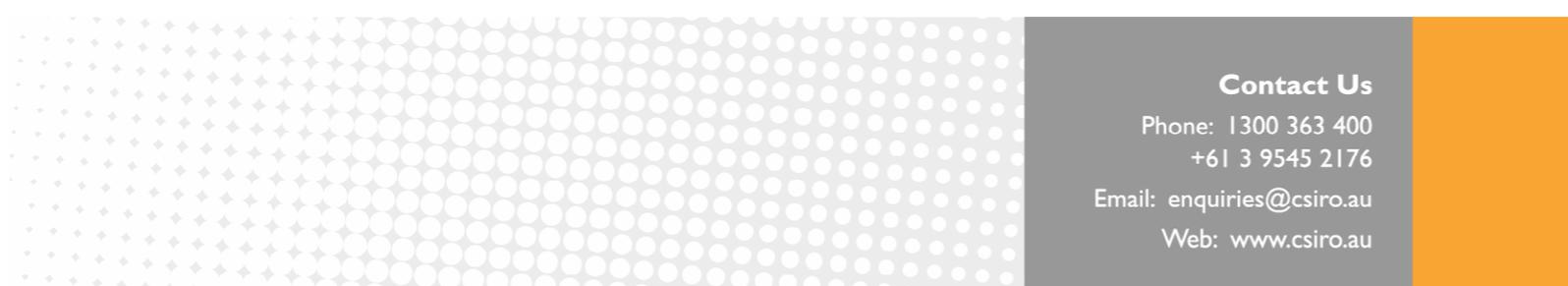
### Other issues related to accessibility to fruit and vegetable outlets

While this study does not focus on the barriers to healthy eating and the complete concept of food security, it is important to recognise that a national best practice food distribution system must include these considerations. Studies that investigate the access to affordable and nutritious food consider that areas that are 16 km away from a supermarket store constitute a “food desert” (Blanchard and Lyson, 2006, Morton and Blanchard, 2007, United States Department of Agriculture, 2009) . Using this strict definition, about 4% of all Victorian households would be living in “food deserts”.

These results need to be tempered with the fact that there is no clear association between fruit and vegetable consumption and distances to supermarkets. American studies have positively correlated the distance between supermarkets, diet quality and fruit and vegetable intake in the United States (Morland et al., 2002, Laraia et al., 2004, Rose and Richards, 2004). However, British, New Zealand, Japanese and Australian studies suggest that a lack of locally available supermarkets does not influence fruit or vegetable intake (Pearson et al., 2005, Pearce et al., 2008, Murakami et al., 2009, Timperio et al., 2008).

A survey in rural Victoria found that a complete Healthy Food Access Basket is more likely to be found in a town with a chain-owned store, and less likely to be available from an independently owned store in a town with only one grocery shop (Burns, 2004). It has been previously discussed that, while the presence of supermarket chains have a positive effect on the average cost paid for a food basket, supermarkets are present only when there is a population of consumers that guarantees a minimum profit. In the absence of supermarkets in some rural towns, independent grocery businesses act as proxies of fruit and vegetable outlets, but the prices paid are in average higher than in a supermarket (Palermo, 2008).

It is not known whether the presence of farmer-led initiatives (e.g. farmers' markets) counteracts high prices paid in Australian towns that have only independent grocery stores. However, international studies indicate that this may be the case: a UK study found that the introduction of a farmers' market in a food desert increased the availability of healthy food and lowered the overall food costs for households in the neighbourhood (Larsen and Gilliland, 2009). While farmers' markets are unlikely to replace supermarkets or grocery stores, they may act as a genuine competitive force and promote cost-savings in populations lacking supermarkets. This is an interesting area of research: most food desert studies have examined access to supermarkets, but few have identified how other food outlets can influence food availability and prices in a food desert.



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