

The Geographic Energy Adaptive Potential of the Farmers' Market System as Compared to the Conventional Supermarkets System

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ABSTRACT

Geographic energy adaptive potential is a quantitative assessment of the capacity of the supply chain system to deliver the same goods using less energy. Issues of oil supply and carbon emissions motivate the study of the energy adaptive potential of the Farmers' market and supermarket food distribution systems. Three key indicators are used to measure the adaptive potential of the system, 1) systems' fuel intensity and traceability of products in the supply chain, 2) potential for freight consolidation, 3) access to stores by potential customers.

A method is presented to compute the freight energy intensity using information on product origins, number and type of delivery vehicles and amount of goods delivered. A hypothetical freight logistical consolidation model is created to determine potential energy savings. Access to Farmers' markets and supermarkets by customers is calculated using Service Area analysis of ArcGIS10 and is a function of the geographic elements such as road network infrastructure and census information.

The Farmers' market system in the New Zealand setting was assessed using the three key indicators prescribed. Results of the survey conducted have shown that Farmers' markets have higher freight energy-intensity than supermarkets. The energy intensity values for the latter were obtained using figures from government-commissioned reports. Consolidation of freight in the Farmers' market could decrease the energy intensity. However given the current volumes of goods sold at the market, the Farmers' market would still be more energy-intensive than supermarkets. There is also no difference between access of customers to Farmers' markets and supermarkets.

INTRODUCTION

The peaking of world oil production is forecast to occur within the decade from 2005-2015 and before 2030 (1). Even with the later date, the fact remains that oil is a finite resource and reduction of fuel use in all sectors is a major risk management issue (2). Two mitigation strategies may address the issue of the decline in fuel supply namely, finding renewable energy sources, and demand reduction (3). One study by Krumdieck et al. has shown that alternative sources of energy will not be enough to substitute for the decline of oil production (4). Demand reduction entails a re-design of goods production and distribution system which at present relies on cheap and readily-available supply of fuel. Petroleum, which is the primary fuel for freight movements of commodities, accounts for 35% of all transport energy use (5).

Modern or conventional food distribution systems are characterised by long and complex supply chains arising from their horizontally integrated nature, with different parts of the supply chain owned and controlled by different companies (6). The supply chain links from primary producer to end-user are obscured from consumers as well as the processing technologies, freight mode, and consolidation with other goods (7). The most prevalent type of modern food systems are supermarkets, operating with monoculture food production and centralised processing (8). Supermarkets typically capitalises on economies of scale and on the comparative advantage of some countries or regions in producing food (9).

Local food systems have gained popularity due to a variety of reasons including the perception that local production offers higher-quality and organic produce. They are also frequently associated with sustainability, which is a multi-faceted issue consisting of socio-cultural and political aspects (10-12) as well as environmental, in terms of waste, carbon footprint, organic certification, and water and energy use (12, 13). Perceived environmental benefit is linked with shorter distances travelled by the goods and the removal of some links on the supply chain such as processing and packaging results in a smaller environmental impact and less reliance on fossil-fuels. According to the report published by Delphi experts, the issue of decline in fuel supply and climate change will actually encourage consumers to give high preference to locally-produced goods (14). The same study also cited that minimisation of energy consumption will have more weight over cost efficiency and speed as a criterion for the design of the supply chain (14).

One famous example of a shift from conventional systems to more local production is that of Cuba in the 1990s, when collapse of the supply chain from the former USSR caused drastic shortfalls in fuel and agro-chemical input supplies over a short time and resulted in severe food crisis (15). This kind of transition may serve as a model for the post-peak oil era.

However, Mariola argues that it is too simplistic to assume that local food systems with fewer food miles imply lower fossil fuel demand and emissions (16). Smith et al. point out that total energy consumption includes key decisions in the whole supply chain where transportation is just one aspect to be considered (17).

It is therefore necessary to provide a quantitative analysis of local food systems to determine if they are actually less reliant on fossil fuels than the conventional supermarket systems. This paper aims to take a holistic approach in developing a model measuring transport energy intensity taking account of both freight and personal transport.

PREVIOUS STUDIES

This section outlines previous studies comparing energy use of Modern/Conventional Food System and Local Food Systems. Geographical factors such as land-use patterns, transport infrastructure and socio-cultural and demographical aspects within the population may have influenced the differences in the results of the studies as well as actual methodologies used.

The study of Pirog et. al compared the food miles for the local, Iowa-based region and the conventional/national system by examining distances from producers to food retailers. It found that the conventional system used 4 to 17 times more fuel than the regional and local systems (18). A Montana-based study yielded similar results with higher fuel consumption and carbon dioxide emissions for food purchased at the conventional supermarket systems and also emphasised the lack of transparency of the actual products origins (7).

In contrast, the study of Van Hauwermeiren et. al in Belgium showed that local food systems actually use slightly more energy than the conventional supermarket system. The study simulates one full summer season using data from interviews with suppliers of food and accounts for the total energy used for transport, processing and storage (19). A study in New Zealand using lifecycle analysis demonstrated that the total energy and greenhouse gas emissions of New Zealand exports to the United Kingdom are actually lower than those produced in the United Kingdom. This was found for agricultural products such as fruit and vegetables, lamb and dairy (20). A study in Sweden found no significant differences in energy use for transport to Farmer's markets compared with the supermarket system due to the high loading capacities of the vehicles that delivers to the latter (21).

The ability of the Farmers' market system to reduce fuel consumption, hence forth referred to as the "geographic adaptive potential" should also incorporate the customers' access to the stores. In fact, the transport energy intensity of the customers has a high impact on the total energy consumption and probably is the most energy-intensive link in the supply chain (22). One of the main criticisms on the Farmers' market system is that most of its customers drive to the market (16).

The results of the study conducted by Coley et. al in the United Kingdom suggest that if a consumer drives a round-trip distance of more than 6.7 km in order to purchase organic vegetables, their carbon emissions (which is a direct factor of energy consumption) are likely to be greater than the emissions from the system of cold storage, packing, transport to a regional hub and final transport to customers used by large-scale vegetable suppliers (23).

Local shopping may reduce automobile dependence as it encourages the use of active modes such as walking or biking. Meanwhile, the geographical location of the store is cited as the primary reason for not shopping at Farmers' market (24, 25). However, geographical distance is not the only factor for shoppers to walk to the stores but more importantly the design and infrastructure of an urban form (26, 27) .

DATA AND METHODOLOGY

The geographic energy adaptive potential of the Farmers' market system is measured in terms of 3 key indicators namely:

- 1) Traceability of products along the supply chain and low energy intensity,
- 2) Potential to reduce the energy intensity through logistical strategies such as freight consolidation and trip chaining,
- 3) The facility is in a location where customers have active mode access to it.

The chosen level of geographical detail of the models in this paper will be the Territorial Authority units (or TAs). In New Zealand, TAs are defined as the second biggest area classification after the regional councils. A metric for classifying TAs according to population density is prescribed in Table 1. In general New Zealand TAs (cities or towns) have population densities less than 1000 people/km² except for Auckland and Waikato city. Christchurch, the biggest city in the South island has a population density of 753 people/km² (28).

TABLE 1 Classification of New Zealand Territorial Authorities

Classification	Density (people/km ²)	Number of TAs in New Zealand
High Density	> 500	8
Medium Density	50 – 500	10
Low Density	< 50	65

Farmers' Market in New Zealand:

In New Zealand, Farmers' market normally operates 1 day a week for around 3-4 hours. The number of stalls and the type of goods being sold varies seasonally in contrast to the supermarkets (29). Another purpose of the market is it serves as weekend community gathering location hence some stalls usually carry hot foods which are cooked onsite (30).

A) Evaluation of Fuel Intensity and Traceability in the Supply Chain.

As mentioned in the literature review, the processes in the supply chain of the conventional supermarket system are obscured and hence there is lack of traceability of the products from primary producer to end-consumer. This section aims to determine whether the same scenario holds true for Farmers market and using the data collected from the survey, perform a freight transport energy audit of the system then calculate the energy intensity.

The standard comparative model of local food systems with modern food systems is to evaluate and compare the energy intensities of different products (19-21). This research explores a system-wide assessment of the energy intensity by providing a distinction on products which lacks the traceability factor from the main suppliers to the market. Products in the Farmers' markets are distinguished using this traceability factor in which produced, meat, eggs, fish, honey are easily traceable while bread, pastries and hot foods are difficult to trace, and in which case there is a need to identify the origins of the products' ingredients.

The survey was conducted in 5 Farmers' markets in New Zealand (participants name, location and vendors' information are withheld for privacy and confidentiality reasons). Each vendor in the market brings several products p_i 's and normally use a single vehicle v .

The origin is denoted by O , which could be farm/kitchen/bakery/butcher or the location where the food is loaded into the vehicle v . The destination D is the Farmers' market.

The energy use for freight transport $E_{p,v}$ is given by the formula:

$$E_{p,v} = 2d_{p,v} \times f_v \times c_f \quad (\text{in MJ}) \quad (\text{Equation 1})$$

where

$d_{p,v}$ = network distance between origin O and D . This is the estimated distance travelled by the vehicle v to deliver product p from O to D (in km). The 2-factor accounts for the return trip which is expected to be empty running.

f_v = fuel economy of the vehicle v (in litres/km)

c_f = energy content of the fuel type (either petrol or diesel) (in MJ/litre)

Note that:

$$C_{Petrol} = 31.39 \text{ MJ/litre} \quad \text{and} \quad C_{Diesel} = 35.86 \text{ MJ/litre}$$

The freight transport energy intensity E_{int} (in MJ/kg) is a measure of the energy used to transport 1 kg of food to the Farmers' market given by:

$$E_{int} = \frac{\sum_{p,v} E_{p,v}}{\sum_p q} \quad (\text{in MJ/kg}) \quad (\text{Equation 2})$$

where

q_p = Amount in kg of product p transported from O to D .

Survey Description

A list of Farmers' markets in New Zealand is given in the organisations' website (30). Eight Farmers' market were contacted via e-mail to participate in the study and 5 markets agreed to participate. The participants are denoted as FM1, FM2, FM3, FM4, and FM5. A list of the participants, number of registered vendors (30) and TA location class are listed in Table 2a.

For FM1, FM2 and FM5, an onsite survey of the vendors was conducted. For FM3 and FM4, the market manager sent a list of the contact details of each vendor and each one was contacted and asked to answer the survey. There are advantages and disadvantages for each data collection method. Onsite survey allows the surveyors to have personal interaction with the vendors and also obtain a better estimate of the amount of goods brought to the site. However, since the markets only operate for 4 hours maximum, some vendors opted out of the survey to accommodate their customers. Phone surveys to the vendors require less resource but could take several days to be able to reach each one of them and some were also apprehensive to participate. Table 2b summarises the information asked to each vendor and how each information is used in the calculations.

TABLE 2a List of Survey Participants

Participant Number	Number of registered stallholders	TA location class
FM1	50	High Density
FM2	31	Low Density
FM3	27	Medium Density
FM4	35	High Density
FM5	37	Low Density

TABLE 2b Survey Questions for the Vendors of the Farmers' Markets

Questions for the vendors	Data usage	Problems Encountered
Product type being sold	Classifying the products allows the distinction between easily traceable items with those containing several ingredients.	Some vendors sell a variety of products, in particular those who are selling "hot foods."
Estimated quantity of products brought to the market	Used in Equation 2.	Most vendors only have a very rough estimate of the quantity of products they are selling however they are able to describe a corresponding volumetric measure for them.
Number and type of vehicles used (specify fuel type)	The number and type of vehicles are used to obtain the fuel economy and fuel consumption and are used in Equation 1.	None.
Origin O (Farm, bakery, kitchen, butcher) location	The origin O is used to calculate the network distance travelled by the	Some vendors were not specific about the actual locations and the surveyors

	vehicle using ArcGIS 10 and used in Equation 1.	were required to confirm the information.
Specify if products require certain ingredients and state where the ingredients are obtained (if known)	This is the traceability factor of the products in which some goods may be locally made or cooked in the market itself but contains ingredients from a distant region.	Some products require many ingredients and with the time-constraints facing both vendors and surveyors, details on minor ingredients have been omitted.

The survey was conducted during the winter season and it was expected that there are not only fewer vendors but also lower volume of products sold. Hence the computation of the freight energy intensity for the Farmers' markets in New Zealand may vary and may even be lower if the survey is done during the summer season. A summary of the data gathered from interviews with the vendors of the 5 markets is given in Table 3.

TABLE 3 Summary of Data Gathered from 5 Farmers' Market Locations in New Zealand

Participant Number	Number of vendors interviewed	Number of vendors selling products without "other ingredients"	Total cumulative 2-way distance travelled by the vendors (km)	Average 2-way distance (km)	Estimated Energy Usage (MJ)	Estimated amount of food brought to the market (kg)	Estimated transport energy intensity (MJ/kg)
FM1	22	11	2954	134	10470	4351	2.41
FM2	12	8	704	59	2689	3910	0.69
FM3	9	6	438	44	1727	2555	0.68
FM4	11	8	1128	103	5421	1278	4.24
FM5	9	5	705	78	2703	2100	1.30

Discussion of Results

Survey results showed that 38 out of 63 surveyed vendors (or 60%) are selling items which do not contain other ingredients. However, some of these vendors have mentioned that they bought their raw ingredients from other vendors located in the same market yielding high traceability of the products in the market. For products which are easily traceable, the computation of the energy intensity is direct from the use of Equations 1 and 2, but for those that contain ingredients, the location of the ingredients are first determined (when possible) before plugging into the equations.

It is also worthwhile to note that the FM3 with the lowest average 2-way distance travelled by the vendors also yielded the lowest freight energy intensity, but the small number of participants in the study may not make this a statistically relevant conclusion.

The energy intensities of New Zealand's Farmers' markets are comparable to the values obtained in studies in other countries. In Belgium the average of 7 raw products yields a transport energy intensity of 5.25 MJ/kg (19). In Sweden, 21 producers of 1 Farmers' market have an average of 2.8 MJ/kg (21).

Computation of the corresponding transport energy intensity for supermarkets using the method described above is a highly complicated task owing to the lack of information and obscurity along the supply chain. To determine the energy intensity of the New Zealand supermarket system, aggregated data from government-commissioned reports will be used instead. The annual freight tonnes moved for retail food industry is given in the report of Paling (31). In addition, values for the energy consumption for road freight transport of food sectors using both petrol and diesel fuel is provided in the EECA Energy Ends Use database (32). Paling also provides a coarse level of

disaggregation between supermarkets with “other retail food” industry wherein 76% of total sales for retail food belong to the supermarkets (31). Using this estimate, we obtain the following:

Estimated tonnes moved by supermarkets (31) :

$$(7,400,000 \text{ tonnes} \times 0.76) = 5,624,000 \text{ tonnes}$$

Estimated road freight energy used by supermarkets (33):

$$(605,236,000 + 473,766,000) \times 0.76 = 820,041,520 \text{ MJ}$$

Converting from tonnes to kg and applying the Equation 2 yields:

$$E_{\text{int}} = E/q = 0.15 \text{ MJ/kg}$$

This value for the energy intensity of supermarkets in New Zealand is much lower than the energy intensities of the surveyed Farmers’ markets. The underlying reason for this is probably due to the higher volumes of goods moved and the efficient logistical strategies such as the use of distribution centres and freight consolidation which is the second key indicator in the study.

B) Potential for Freight Consolidation

This section looks at a hypothetical simulation of freight consolidation in the local level. It is a framework to investigate ways for the Farmers’ market system to be more efficient and apply the logistical strategies of the conventional system while preserving the small scale and independent nature of the farms and the market (34).

Assume 20 vendors selling 200kg of food. From Table 3, the average 2-way distance travelled by the vendors to the market is 94km. The model randomly populates a map with 20 food locations such that the average 2-way distance of these locations to the market is 94km. Simulate the use of 1 van for each delivery with fuel economy $f_v = 10\text{L}/100\text{km} = 0.1\text{L}/\text{km}$ and running on diesel. The values obtained in this model run are summarised in Table 4a.

The trip chaining model is as follows: Instead of having each vendor drive from their respective origins O to the market, the model simulates the use of 3 light lorries/trucks with an average payload of 8.5 tonnes, $f_v = 20 \text{ litres}/100\text{km} = 0.2\text{L}/\text{km}$, also running on diesel. The goal is to find the most optimal trip chain for the trucks loading from the farm locations. Apply the classical vehicle routing problem (VRP) (35) and implement the model using ArcGIS 10 with the Farmers’ market as the starting and ending points of each truck as illustrated in Figure 1. The corresponding fuel consumption results are shown in Table 4b.

TABLE 4a Hypothetical Model Parameters without VRP and Freight Consolidation

Number of vendors	Total 2-way distance (km)	Average 2-way distance (km)	Total energy usage (MJ)	Total food brought to the market (kg)	Transport energy intensity (MJ/kg)
20	1883	94	6752	4000	1.69

TABLE 4b Hypothetical Values using VRP and Freight Consolidation

Truck	Total round-trip distance travelled (km)	Total energy usage (MJ)	Total food brought to the market (kg)	Transport Energy Intensity (MJ/kg)
Truck 1	189	1356	1200	
Truck 2	256	1836	1400	
Truck 3	357	2560	1400	
Total	802	5752	4000	1.44

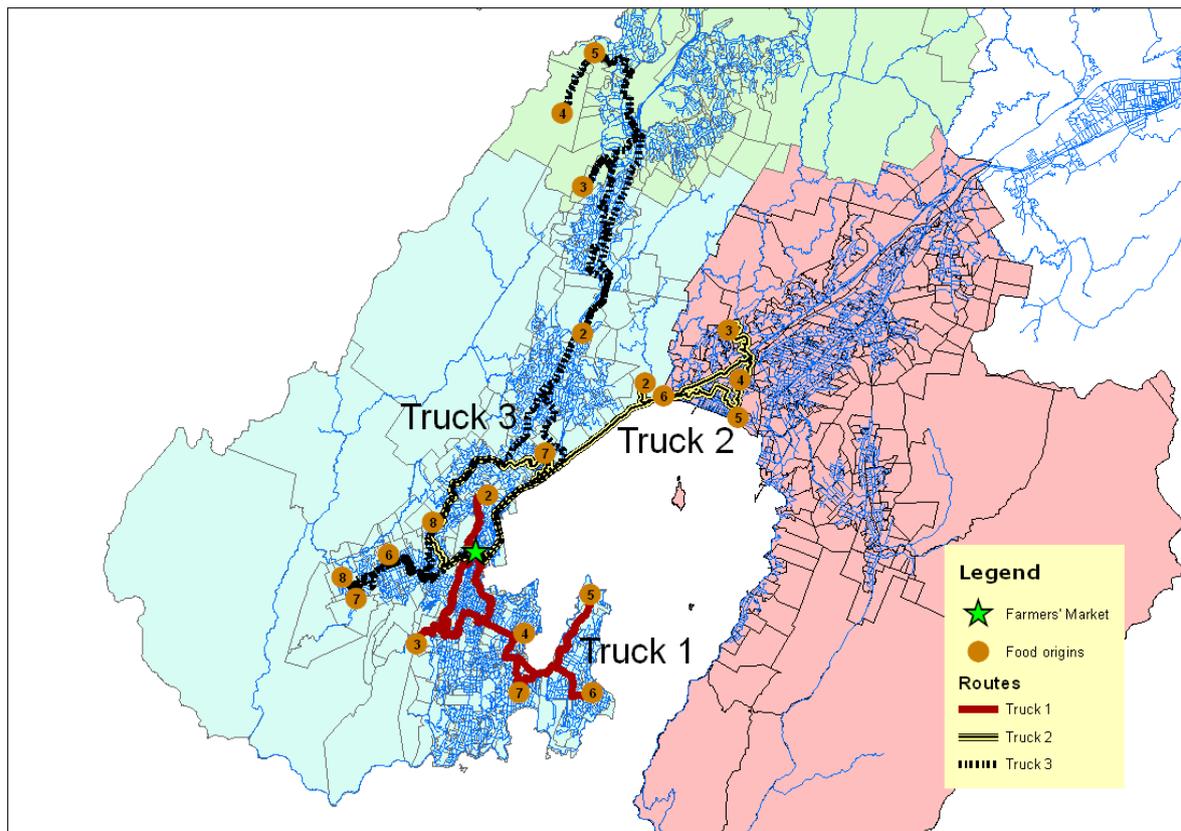


FIGURE 1 Hypothetical Simulation of the Vehicle Routing Problem Applied to the Farmers' Market.

Discussion of Results

The use of VRP dramatically reduces the total distance travelled by the vehicles combined. The energy intensity using this model is 1.44 MJ/kg which is a 15% reduction in the energy intensity without trip chaining freight consolidation (1.69 MJ/kg). However, this value is still much higher than the energy intensity of the supermarkets. The reason is still the large volume of goods distributed and higher utilisation of the capacity of the vehicles in the conventional supermarket system.

The model presented in this section is not a predictor of the logistical strategies of the markets. It also does not account the economic feasibility and physical viability of the scheme proposed.

C) Access to Stores by Potential Customers

The final aspect in the transport energy analysis is the “Active Mode Access” (AMA) of customers to the Farmers’ markets. This term is introduced in the paper of Rendall et. al (36). Active modes such as walking or biking to the stores are assumed not to consume any fuel.

The modelling technique used in this section determines how many customers and households are within a 2-km distance away from the stores. The 2-km impedance factor is a reasonable distance for both walking and biking. The model aims to compare the number of people and households that

are 2-km away from a supermarket or Farmers' market. People and households located within this 2-km network distance is said to have AMA to the store. Data sources that are used in evaluating the AMA to the stores by potential customers are summarised in Table 5.

TABLE 5 Summary of Data Sources and Processing Requirements

Description	Source	File Type	Processing Requirement
New Zealand Meshblocks (2006)	Statistics New Zealand (28)	Geospatial dataset (Vector polygon)	Include information about census of population and dwellings and classify according to TAs.
New Zealand 2006 Census of Population and Dwellings	Statistics New Zealand (28)	CSV files classified according to regions	None
New Zealand road network (road centrelines)	Land Information New Zealand (37)	Geospatial dataset (Vector linestring)	Classify and split according to TAs. Roads with no pedestrian /biking access will not be used in the service area analysis discussed below.
New Zealand supermarket locations	Zenbu (38)	Geospatial dataset (Vector point)	Split according to TA location.
New Zealand Farmers' market locations	Farmers' market website (30)	Address or location written on the website	Needs to be encoded into a geospatial dataset and split according to TA location.

Model Details

The model runs service area analysis in ArcGIS 10 for all supermarkets and Farmers' markets in a given territorial authority. Service areas may overlap hence people going to the stores may have AMA to more than 1 store. The polygons obtained are extracted and intersected with the original TA census data containing the demographic information which are divided into meshblocks. The meshblock is the smallest geographic unit for which statistical data is collected. Finally, the percentage of the area intersected with the polygon to the original area is used to obtain an estimate of the population and households in the polygons.

A comparison of service areas of 2 stores located in the same TA but with different levels of AMA is illustrated on Figure 2. For Store A, 1863 people and 793 households have AMA to the facility. In contrast for Store B, only 380 people and 136 households have AMA to the facility. The reason for this huge difference is the available walking/biking paths infrastructures as well as the density of the meshblocks in the neighbourhood of the stores.

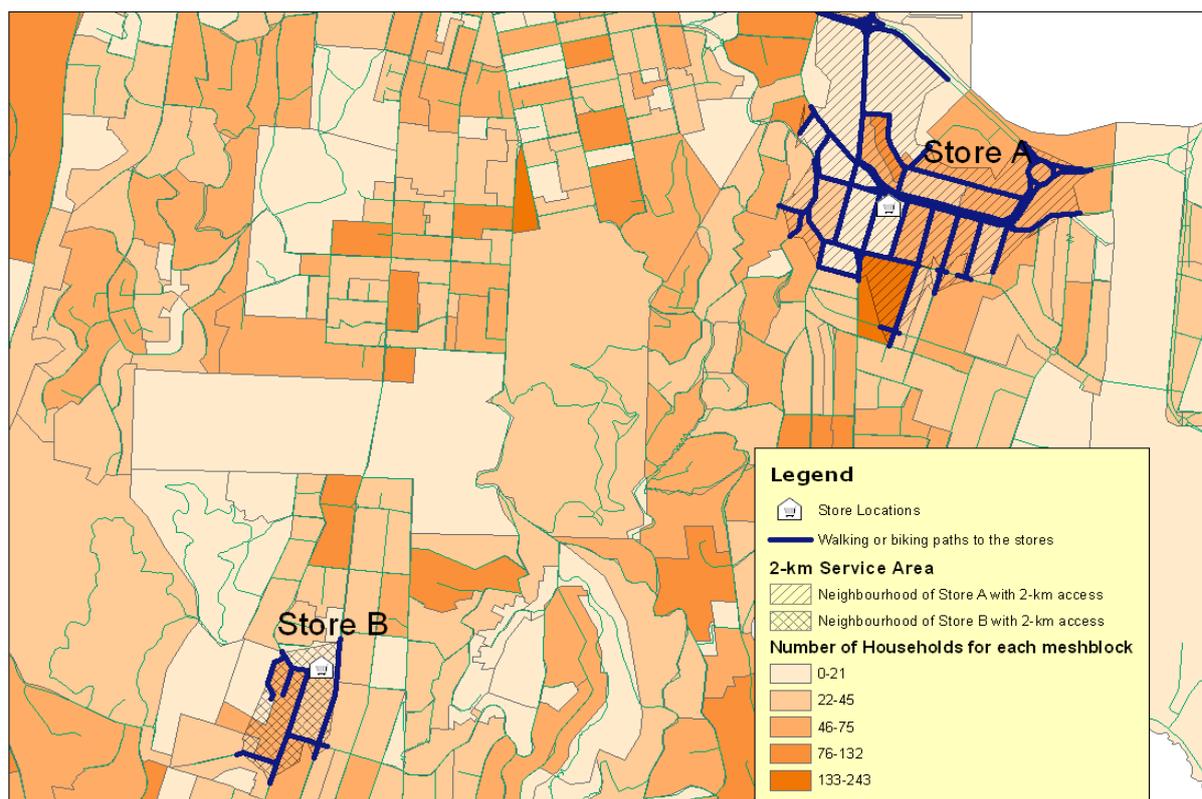


FIGURE 2 Comparison of the Service Areas of 2 Stores Located in the Same Territorial Authority.

TABLE 6 Summary of Population and Households with AMA to the Stores

		Supermarkets	Farmers Markets
High Density TAs	Number of Stores	182	11
	Average number of people with AMA	967	941
	Average number of households with AMA	382	424
Medium Density TAs	Number of Stores	110	2
	Average number of people with AMA	1124	908
	Average number of households with AMA	402	361
Low Density TAs	Number of Stores	374	19
	Average number of people with AMA	584	742
	Average number of households with AMA	234	296
Whole New Zealand	Number of Stores	666	32
	Average number of people with AMA	778	826
	Average number of households with AMA	302	346

Discussion of Results

The AMA for the stores described in this model is determined by the available walking/biking paths infrastructures as well as the density of the meshblocks in the neighbourhood of the stores. For high density TAs, although slightly more people have AMA to the supermarkets, more households have AMA to the Farmers' markets. The medium density TAs is in favour of the supermarkets however

since only 2 Farmers' markets are located in this TA classification, the results may not be as reliable. For lower density TAs, the Farmers' markets are usually located in the city centre or the town plaza hence could explain the higher AMA averages than the supermarkets.

The AMA model presented in this section makes no behavioural assumptions on customers' perception, shopping preference and utility derivation. For further reading, demographic profile of Farmer's market shoppers were discussed in the following papers (39-41). The AMA determines whether customers have access to the stores via walking or cycling rather than if they are willing to walk or bike to the stores.

CONCLUSION

The low volumes sold, lack of freight consolidation, and empty running return trips makes the Farmers' market more fuel intensive than the supermarkets in New Zealand. Applying logistical strategies such as the vehicle routing problem; trip chaining and consolidation of freight reduced the total combined distance travelled by the vehicles as well the freight energy intensity of the Farmers' markets. However, given the low volumes of goods sold at the market, the energy savings does not make the system more efficient than the supermarkets. The Farmers' markets and supermarkets have the same level of active mode access for customers; hence potential customers have other options than driving to the stores which is one of the main arguments against Farmers' markets. In particular for smaller towns, Farmers' markets are in good strategic locations and more customers can access the stores via active mode compared to the supermarkets.

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