The viability of transitioning food box delivery from motorised transport to electric trikes: a case study of Toha Kai.

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Report prepared for GEOG309 2022

Image sourced from: Avalex. (2022, October 12). *Musketier electric trike*. In De Buurt. https://indebuurt.nl/delft/nieuws/een-kapot-elektrisch-apparaat-ruilen-voor-een-gratis-spel-hier-in-delft-kan-het~173141/

1 Executive summary

- Our current food system exacerbates existing inequalities, food inaccessibility and climate change. Alterations to food systems are necessary to provide healthy food in a climate appropriate way.
- This project occurred in partnership with Toha Kai, a Christchurch food provider considering electric trikes (e-trike) for food box delivery. Considering this context, the GEOG309 team will be assessing whether *the transition from motorised vans to e-trike for food box delivery is a socially, economically, and environmentally viable option for local food providers?*
- The economic and environmental viability of an e-trike transition was evaluated using a cost-benefit analysis method and Geographic Information Systems network analysis with one week of delivery sample data from Toha Kai.
- The economic benefit-cost ratio found the e-trike to be economically viable, as the cost of the initial investment will be repaid within 2 years of use.
- The environmental benefit-cost ratio found the e-trike to be a viable option as it significantly reduced the emissions profile of Toha Kai.
- Using the Ministry of Transport Outcomes Framework, the social viability of the e-trike transition was found to be overwhelmingly positive. This was recognised through discussions of resilience and security, environmental sustainability, and economic prosperity.
- Based on a case study week of 45 box deliveries, the analysis concluded the transition from courier van to e-trike to be an environmentally, economically, and socially viable option for Toha Kai.
- A major limitation of this project was the inability to quantify social factors. Future study should focus on how these factors can be meaningfully quantified to reduce bias.
- The nature of the project being a case study also introduced limitations to the project as our analysis could not be used to draw conclusions on the viability of e-trike adoption for other food providers.
- Further research should investigate the role of e-trikes in the expansion of Toha Kai. In particular, the use of multiple e-trikes and pick-up community hubs.

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3 Introduction

Nutritious food is essential for human survival. However, the current food system contributes to a host of global issues. The food system exacerbates existing inequalities, restricting access to healthy and nutritious food in low-income communities (Azétsop & Joy, 2013). Additionally, production, distribution, consumption, and disposal of food products contribute approximately 17.3 billion metric tons of carbon dioxide (CO_2) every year, enhancing climate change (Xu & Jain, 2021). Local food provision allows for more effective, equal, and environmentally conscious distribution by establishing links between communities and local growers (Food Print, 2020). However, distribution of produce globally and locally often relies heavily on fossil fuel-based transport such as vans and trucks. Since road transportation accounts for 15% of global carbon emissions, shifting the reliance of distribution away from fossil fuels could reduce its climate impact (Mbow et al., 2019; Wang & Ge, 2019; Walker et al., 2010).

Improving social and environmental outcomes of the food system means limiting associated carbon emissions and inequity issues to support affected communities (Schnitter & Berry, 2019). Considering alternative food delivery mechanisms as an option to help achieve this, the following research question was developed: *is the transition from motorised vans to electric trike (e-trike) for food box delivery a socially, economically, and environmentally viable option for local food providers?*

This question will be assessed using Toha Kai, a non-profit Christchurch food provider, as a case study. Toha Kai aims to counteract food inaccessibility by providing organic, accessible, climate-appropriate kai, particularly to low-income areas (Toha Kai, n.d.). They are interested in reducing their emissions profile by transitioning from motorised courier vans to e-trikes for food box delivery. The Radkutsche, Musketier e-trike will be used as a model to address the research question.

The report will firstly review literature relevant to Toha Kai and the research question. Methods including Cost Benefit Analysis (CBA), Geographic Information Systems (GIS) analysis, and the Ministry of Transport (MoT) Outcomes Framework, will be used to assess the viability of this shift, environmentally, socially, and economically. The results of these methods will then be discussed along with their limitations. Finally, the viability of the e-trike will be determined, and associated recommendations presented.

4 Literature review

4.1 Our food system - climate change and food inaccessibility

Food inaccessibility is enhanced by social and economic factors including distance to supermarket and household income (Michimi & Wimberly, 2010; Wiki et al., 2018). The current food system exacerbates food inaccessibility, resulting in malnutrition, hunger, and obesity prevailing in society (FAO & INRAE, 2020; Stein et al. 2018). Due to the ethnic density effect and systematic inequality, indigenous groups are commonly over-represented in high deprivation index areas. Increasing the role of local food distribution could improve food accessibility, particularly in these low-income communities (Bécares et al., 2013).

Shifting to a more equitable food system is particularly important under a climate change context as low-income communities are more likely to be impacted by food chain disruption (Singh et al., 2021). Increased weather events associated with climate change disrupt food production and provision by eliminating food crops, impacting storage, and changing distribution patterns (Beddington et al., 2012; IPCC, 2022). This disruption will increase food inaccessibility and limit dietary diversity, generating negative population health outcomes.

4.2 Transportation and Electrification

Transport and food are pillars of our society; however, food distribution networks contribute significantly to global emissions (Li et al., 2022). Climate impacts could be reduced by decarbonising the transport system. Methods to do this could include transitioning from fossil-fuel powered combustion engine to electric engines and increasing the role of active transport, which involves physical activity, such as walking and cycling (Brand et al. 2021; Kedia et al., 2019; Mizdrak et al., 2020; Mueller et al., 2015). The benefits of a decarbonised transport system extend beyond emissions reductions and e-trikes contribute to this aspiration. E-trikes/bikes combine electrification and active transport which is desirable for a variety of reasons including lower running costs, improved public health and social outcomes, and greater energy security (Johnson & Rose, 2015; Philips et al., 2022; Yuan et al., 2021). However, there are limitations that come with these alternative modes like scarcity of the minerals required for batteries and limited cycle lane infrastructure.

4.3 Project relevance

This literature review emphasised the failure of our current food and transport system. This provided background to our research question and displayed the need to assess alternative transport options for food distribution to limit emissions and increase the equity of food distribution.

5 Method

A variety of research methods were used to investigate the research question – *is the transition from courier vans to electric trike for food box delivery an environmentally, economically, and socially viable option for local food providers?* These methods included: a CBA, GIS network analysis, and the MoT Outcomes Framework.

5.1 Cost Benefit Analysis

CBA considers the costs and benefits of a proposal to estimate its viability. An environmental and economic CBA was chosen because it allowed for the inclusion of multiple factors. This decision was supported by Holland et al. (2021) and Chapman et al. (2018) who discussed that it was beneficial to evaluate these factors for active transport and vehicle electrification.

The environmental viability of the transition was analysed by comparing courier van emissions to e-trike emissions. The research design included calculating CO_2-e emitted for one week of delivery by van, transportation of the e-trike from its manufacturing warehouse in Germany and charging of the e-trike battery. The economics of the e-trike were also considered, comparing the current food box delivery prices with the initial purchase price of the e-trike and accessories. Both environmental and economic factors were represented in a benefit-cost ratio (BCR).

5.1.1 GIS for route optimisation

Network analysis was used to generate a wide range of outputs. For example, service area analysis, optimized van and e-trike routes, and the route distance. The route distance was used for carbon emission calculations, used in the environmental benefit cost ratio. Address data supplied by Toha Kai was geocoded using QGIS, to give each address a spatial attribute so it could be recognized in further GIS analysis. The geocoded warehouse and delivery addresses were subsequently added to an ArcGIS Pro project alongside New Zealand (NZ) Road data from the University of Canterbury GeoHealthLab.

To create the road and junction network, a feature dataset was generated using the GeoHealthLab's nzgps_240215_roads_only layer and nzogsp_240215_nal_junctions layer. Network attributes including the cost incurred by travel (time and distance) were set and identified via field script for the estimated_travel_time and shape_length fields. A restriction was put onto the road network and travel type that required the route adhere to one-way street restrictions.

A similar method was used to create the e-trike network. However, to account for the e-trikes maximum speed of 25km/h, the edge source layer was altered to restrict the estimated_speed field to values of 25km/h or less. To account for the time ramifications of altering the speed values, the estimated_travel_time field also had to be recalculated. Equation 1 was used in the field calculator and coded in python to calculate updated travel times and convert units for consistency. The one-way restriction was not included in the e-trike network, as cycle lanes tend to go both ways, even on one-way streets. Refer to Appendix A for more detail on the network edge outputs and attribute tables.

$$estimated\ travel\ time\ = \left(\frac{\frac{shape\ length}{1000}}{new\ estimated\ speed} \right) \cdot\ 60$$

Equation 1. Travel time calculations

Route analysis layers were created using the van and e-trike networks to ascertain the optimized delivery route for both transport mechanisms. The delivery addresses were imported as stops on the route and the Toha Kai warehouse was set as the first and last stop.

5.1.2 Calculating emissions and economic cost

The economic and environmental viability of the e-trike was determined by producing a BCR based on the emissions and expenses. A BCR quantitatively compares previously calculated costs and benefits to produce a single variable (Equation 2). If this value exceeds 1, the benefits outweigh the costs, and the proposal is viable.

$$BCR\ =\ \frac{Expected\ Benefits}{Expected\ Costs}$$

Equation 2. Benefit-Cost Ratio

When assessing environmental viability, the Ministry for the Environment (MfE) emissions equation (Equation 3) was used to determine the emissions associated with courier deliveries (Ministry for the Environment, 2022). It is important to note that uncertainty regarding the equation exists due to the exclusive use of distance travelled to calculate emissions, which does not consider idle time, the weight of transported goods, and traffic congestion.

$$Emissions\ from\ Source\ in\ kg\ CO_2 - e\ per\ year (E) =\ Activity\ Data\ (Q)\ \cdot\ Emissions\ Factor\ (F)$$

Equation 3. Ministry of the Environment, Measuring Emissions

The distance travelled (km) as determined by the GIS analysis was used as the activity data (Q) in Equation 3. The emissions factor for the courier van also sourced from MfE considers the engine size, year, and fuel type. The total emissions (E) of the source were measured in kg of CO_2-e per year.

To assess the economic viability of a transition to e-trikes the initial purchase of the e-trike was compared to the cumulative courier van delivery cost. This determined whether the cost of the e-trike would be offset by expenditure saved from not having to pay for courier van delivery. In our research design, wages were not considered due to Toha Kai using volunteer staff. The economic viability was assessed according to a short (1 year), medium (5 years), and long (10 years) timeframe. Through this, the e-trike was able to be deemed viable, moderately viable, and not viable, respective of the time taken to offset the e-trike cost. The results for the three timeframes were summarised in a BCR.

5.2 Ministry of Transport Outcomes Framework

MoT selected five core outcomes to guide Aotearoa's transport system and acts as strategic framework to assess government policy interventions (Ministry of Transport, 2018). Based on Toha Kai's values, the three most relevant factors were considered and categorised into costs and benefits: environmental sustainability, resilience and security, and economic prosperity.

5.3 Infographic

To represent research findings to Toha Kai's consumer base in an effective way, an infographic was produced. Infographics are beneficial because they are a way of effectively communicating information in an engaging way (Beegel & The Infographic World Team, 2014). See Appendix B for infographic of results and findings from this report.

6 Results

6.1 Using GIS to optimise delivery

The optimized route for a courier van was calculated to be 68.92km over 140 minutes. In contrast, the optimized e-trike delivery route was found to total 65.88km over 158 minutes.

Comparing these routes, the e-trike route was found to be 3.04km shorter than the optimized van route (Figure 1). This difference due to one-way street restrictions which limit the van but not the e-trike. Despite the difference in distance, the e-trike route was 18 minutes longer than that of the delivery van. Refer to Appendix C for detailed attribute tables of the optimized routes.

The range of the e-trike in a Christchurch context was explored using service area analysis as depicted in Appendix D.

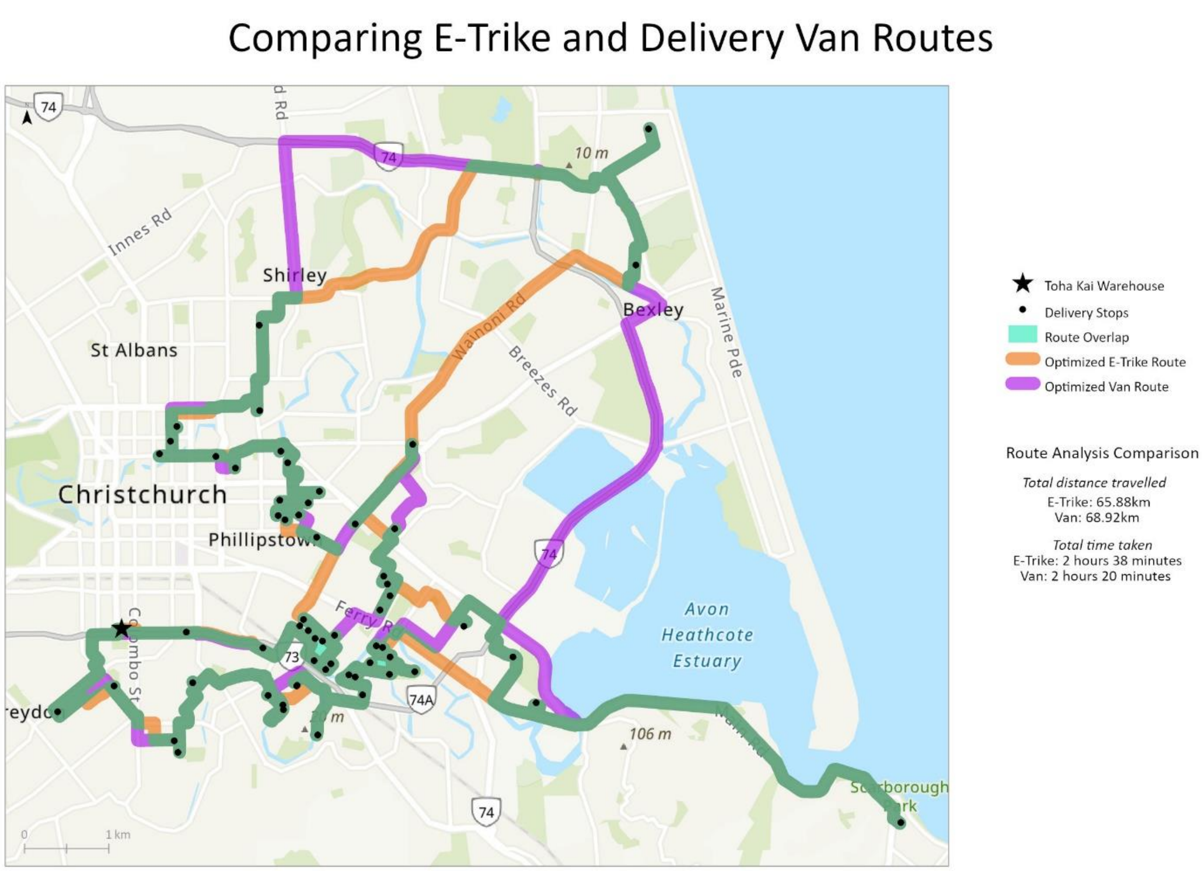

Figure 1. Map of optimised e-trike and van routes to service case study Toha Kai delivery locations. The orange line represents the optimised e-trike route while the purple line shows the optimised van route. The green line is where the two outputs overlap.

6.2 Emissions calculations

Toha Kai food boxes are delivered by a 2014 Toyota Hiace. Using the specifications from this vehicle and Equation 3 provided by MfE, the CO_2 emissions of the case study week were calculated as 18.8kg which accounts for 979.5kg CO_2-e yearly (Figure 2).

E = F x Q

where E = emissions, F = emissions factor provided by MfE, Q = distance.

Spec 2014 Toyota Hiace has a diesel engine 2000 – <3000cc, F = 0.273kgkm.

The average distance travelled was calculated to be 69km via GIS mapping, Q = 69.

E = 0.273 x 69 = ***18.8kg CO2-e per week***

E = 0.273 x 3588 = ***979.5kg CO2-e per year***

Figure 2. Calculation of CO_2 emissions from the courier van used at Toha Kai.

Assuming transportation occurred by cargo ship, the CO_2-e from delivery of the e-trike to Christchurch, NZ, was calculated at 20.3kg of CO_2-e (Figure 3).

E = F x Q

where E = emissions, F = emissions factor provided by MfE, Q = distance.

Cargo ship, F = 0.016tkm, F = 0.000016kgkm

The distance from Nehren to Christchurch is 18,625km

E = 0.000016 x 18625 = 0.298kg CO2-e

The weight of the e-trike is 68kg

E = 0.298 x 68 = ***20.3kg CO2-e***

Figure 3. Calculation of CO_2 emissions released during the delivery of E-trike from Germany to NZ.

Meanwhile, charging the upgraded e-trike battery once a week was found to release 5.21kg of CO_2-e annually (Figure 4).

E = F x Q

where E = emissions, F = emissions factor provided by MfE, Q = kWh.

Electricity, F = 0.12

Average kWh required to charge the e-trike battery is 0.835kWh, Q=0.835.

E = 0.12 x 0.835 = ***0.1002kg CO2-e per week to charge***

E = 0.12 x 0.835 x 52weeks = ***5.21kg CO2-e per year to charge***

Figure 4. Calculation of CO_2 emissions released to charge the E-trike battery.

Therefore, annually, the use of an e-trike produces 953.98kg CO_2-e less than courier vans. Using the CO_2-e values calculated from the MfE equation in Figure 3, 4, and 5, the BCR of the environmental impact continued to increase from the 1-year period when the BCR was 38.4 (Table 1).

Table 1. Benefit-Cost Ratio of emissions differential between courier vans and e-trikes, for a 1-, 5-, and 10-year period.

	Toha Kai (E-Trike)	**Toha Kai (Courier)**	**Toha Kai BCR**
1 year	25.51 kg CO2-e	979.5 kg CO2-e	38.40
5 years	46.35 kg CO2-e	4897.5 kg CO2-e	105.69
10 years	72.40 kg CO2-e	9795 kg CO2-e	135.28

6.3 Economic Costs

The upfront cost of the Radkutsche Musketier electric trike is NZD$10,995.00 with additional accessories (trailer and rear aluminium platform) and battery upgrades purchased by Toha Kai result in a total expenditure of $18,445.00 NZD (Radkutsche, n.d.). The trailer addition has a maximum load capacity of 600kg and can deliver 60 Toha Kai boxes, at 10kg each.

The cost of recharging the battery was assumed to be negligible and was not considered in the calculation. The courier delivery cost of each box is NZD$5.15 NZD. Using the case study week of 45 orders, this would amount to NZD$233.10. Costing Toha Kai NZD$12,121.20 annually, it would take 1.52 years of courier van use to offset the initial purchase cost of the electric trike. Past the point of offsetting the e-trike purchase, the business would experience a reduction in business expenses and would begin saving money after 18 months.

As demonstrated in Table 2, over a 1-year period, courier delivery is more affordable for the case study. As the BCR exceeds 1, the costs of the transition for the 1-year period outweigh the benefits. However, the initial cost of the bike will be offset after a payback period of 18 months which can be considered economically viable. The economic benefit of e-trike adoption increases as the time from the initial purchase increases, with a $1 investment will yielding a $6.57 return after 10 years.

Table 2. Benefit-Cost Ratio of economic differential between courier vans and e-trikes, for a 1-, 5-, and 10-year period.

	Toha Kai (E-Trike)	**Toha Kai (Courier)**	**Toha Kai BCR**
1 year	$18,445.00	$12,121.20	0.66
5 years	$18,445.00	$60,606.00	3.29
10 years	$18,445.00	$121,212.00	6.57

6.4 Ministry of Transport Outcomes Framework

The outcomes framework evaluates social factors by identifying each one as a cost or benefit (Figure 5). However, the values of other local food provider will guide what they categorise as a benefit or a cost.

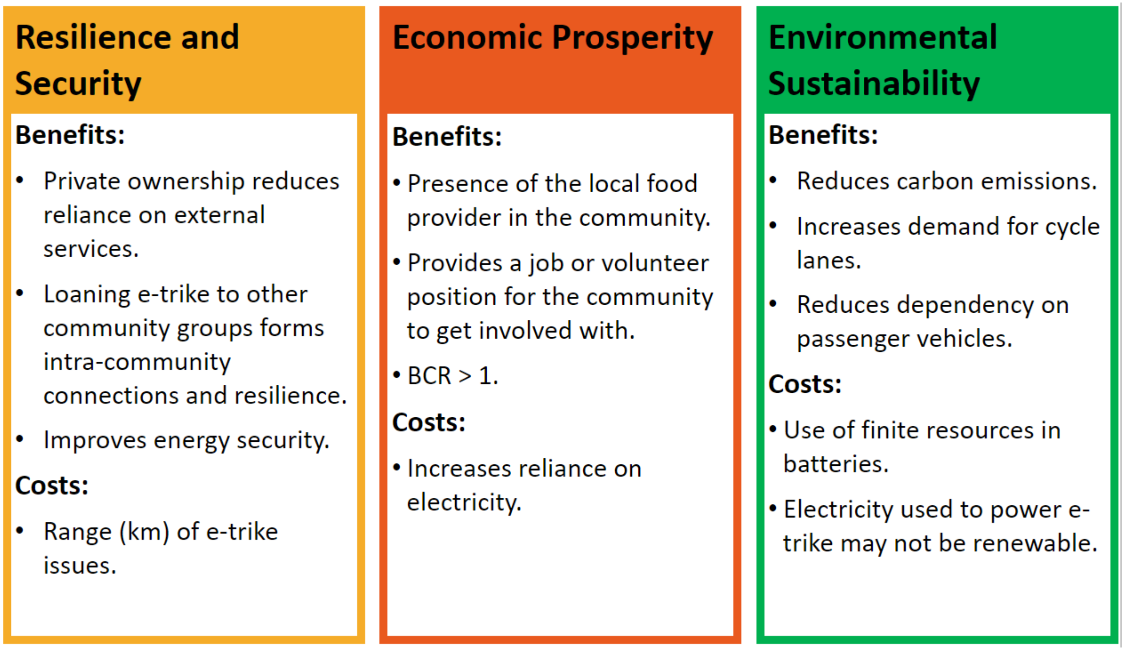

Figure 5. Qualitative social factors categorised into three outcomes guided by MoT Outcomes Framework (Ministry of Transport, 2018).

6.4.1 Environmental Sustainability

A key driver of transitioning to e-trike delivery is the reduction in emissions profile. This consequently leads to decreases in particulate matter entering air and water bodies, an impact that improves the quality of both and enhances biodiversity (Zhang & Fujimori, 2020). Furthermore, shifting from fossil fuel-intensive forms of transport to an e-trike could reduce road congestion (Weiss et al., 2015).

E-trike implementation has a flow-on effect of increasing demand for the cycle network. Increased use of cycle lanes encourages more investment in active transport infrastructure (Genter, 2020), a development that can be beneficial for e-trike delivery (Skov-Petersen et al., 2017).

However, detrimental environmental impacts are also associated with increased e-trike adoption. Along with the environmentally degrading mining processes, the resources required to produce the lithium-ion batteries used in e-trikes are limited with access often requiring mining in geopolitically tense regions (Frankel, 2016).

6.4.2 Economic Prosperity

The Outcomes Framework highlights the importance of supporting economic activity through improving the efficiency of travel. The e-trike is more distance-efficient than courier vans, taking a 3.04km-shorter route.

As expressed in the CBA, there are several costs associated with the e-trike like the upfront cost of the e-trike. In terms of benefits, the e-trike can be used as a marketing tool for the local food provider as transport is visible in the community (Ballard et al., 2017). Additionally, the e-trike creates a new volunteer opportunity for the community.

6.4.3 Resilience and Security

Increasing the resilience and security of the national and local transport system is critical. It minimises the impact of natural and man-made hazards and increases the sector's ability to recover from shocks (earthquakes, COVID-19, etc). E-trike adoption increases the resilience of local food providers as it is privately owned, reducing the reliance on external companies for delivery. However, e-trike range may reduce security due to the potential of stranding a cyclist stranded mid-delivery

There is an opportunity for local food providers to loan the e-trike to other community groups. This forms mutually beneficial connections in the community, increasing reliance to shocks (Solnit, 2010). Loaning utilises the time that the e-trike is not in use and reduces the environmental impact of the community group.

Additionally, the e-trike relies on electricity rather petrol and diesel. This improves energy security by decreasing the need for fossil-fuels to be imported (Li & Chang, 2019; Yuan et al., 2021). By internalising the energy system, reliance on external energy sources is reduced, limiting risks associated with change (potentially due to political tensions).

7 Discussion

7.1 Significance of Results

Research based on the Toha Kai case study week of 45 food boxes suggested the transition from courier vans to e-trikes is an economically, socially, and economically viable option.

The environmental benefit to cost ratio displayed a clear emissions reduction associated with e-trike adoption. Calculating the emissions produced from transporting the e-trike from Germany to New Zealand revealed that one week's worth of deliveries would offset these emissions (Figure 3). This is supported by Philips et al. (2022) who found e-trike adoption reduced carbon emissions.

Cost-benefit analysis of economic factors associated with e-trike transition found the initial cost of the investment is repaid within less than 2 years of use. The economic viability of the e-trike is supported by Doctor (2021) who found that e-trikes typically are more economical than traditional motor vehicle.

MoT Outcomes Framework found the social impact of e-trike adoption to be overwhelmingly positive. This conclusion is supported by literature such as Johnson & Rose (2015) and Kouridis & Vlachokostas (2022) who associated e-trike adoption with improved social and public health outcomes.

GIS analysis displayed the e-trike service areas covered the majority of Christchurch and all of Toha Kai's current delivery areas (see Appendix D). Furthermore, GIS route optimisation analysis produced a shorter distance output for the e-trike, compared to courier vans suggesting this could be a more efficient mode of delivery (Figure 1). However, the estimated delivery time was 18 minutes greater for the e-trike compared to the courier van.

Overall, our project concluded the transition from courier van to e-trike was a viable option socially, economically, and environmentally. This is significant as it displays that an e-trike can positively contribute to both Toha Kai's emissions profile, overall resilience, and economic prosperity, as well as the wider Christchurch community. Therefore, our research suggests that Toha Kai implement an e-trike for the delivery of their food boxes.

7.2 Limitations

7.2.1 Overall Project

Due to the scope, a limitation from the project was the inability to connect with Māori communities. Nonetheless, there is an opportunity for relationships to be built between Toha Kai and local iwi and marae. With Rehua Marae's involvement in a similar food box scheme, it may be valuable for Toha Kai to develop a relationship.

Another limitation to this research is that it is based on a case study, therefore, only uses data from Toha Kai to conduct analysis. Considering this a major limitation is the inability to extend our conclusion to other food providers. The e-trike may not be a viable option for other food providers which may have different company values, delivery networks and may not have the final means required in the up-front cost of the e-trike.

7.2.2 Research design

7.2.2.1 Ministry of Transport Outcomes Framework

The MoT Outcomes Framework does not produce a numeric output to quantify the social viability of the e-trike. It is therefore difficult to include the qualitative factors into the CBA, as they cannot be directly compared to the numeric values of the CBA. Instead, the qualitative output is based on a discussion of decided factors. Consequently, the framework may introduce bias into analysis as personal perspective and preference will influence how social factors are discussed. Another limitation is that all five MoT outcomes were not able to be assessed and three outcomes were chosen that were most relevant to Toha Kai. Johnson & Rose (2015) describe how electric bikes provide greater access for older populations and contribute to improved health and wellbeing. Due to the outcomes selected, factors like physical health and wellbeing were not discussed.

7.2.2.2 GIS Analysis

Network analysis assumed the e-trike was constantly travelling at its maximum speed of 25km/h and that the van constantly travelled at the maximum legal speed limit. This is not an accurate representation, as it does not account for stoppages, acceleration, deceleration, or velocity impacts of the physical exertion and fluctuating energy levels of the rider. It also assumes that all one-way streets have bike lanes on both sides of the road. The e-trike network is based solely on the NZ road networks as time constraints meant we were unable to integrate a separate layer of Christchurch cycleways into our route analysis. Consequently, our optimized e-trike route assumes that the cyclist will use cycleways when possible. These limitations, however, did not impact the CBA as they did not influence the distance output obtained.

Another limitation is that the sample data utilised from the case study week may not be a representative distribution of typical weeks. Toha Kai has also been looking to expand their reach and have consequently experienced increased sales. Considering these limitations, the distances calculated using the delivery addresses may quickly become redundant. Service area analysis (Appendix D) attempted to mitigate this by visualising distance extents accessible from the Toha Kai warehouse. This gives a more general understanding of the e-trike's reach, complementing the more thorough but sample data-dependent route analysis.

7.2.2.3 Economic cost

To calculate the economic benefits of the transition, outsourced courier delivery was considered exclusively. However, this may not be representative of other food delivery services who own their van and must pay for fuel or driver wages. Similarly, the exclusion of wage calculations from the electric trike costs would make the findings of this report less transferable to other companies who rely less heavily on volunteers.

8 Conclusion

Qualitative and quantitative methods were used to assess the viability of transitioning from courier van to e-trike. These methods overwhelmingly found this transition to be an environmentally, economically, and socially viable option for Toha Kai, based on the case study week of 45 food box deliveries. Although we are confident in our results caution and further research should be carried out before extending to this conclusion to other food providers who may have different service areas and company values. Additionally, the reliability of our conclusion may be altered if Toha Kai expanded or if their distribution areas altered significantly.

9 Recommendations

9.1 Toha Kai

Although, route optimisation was conducted, it is encouraged that Toha Kai continues to use a software containing local bike lanes to optimise their travel on the e-trike. This reduces the risk of riders being stranded far from the Toha Kai warehouse.

It is discussed that sharing e-trikes with other businesses can further offset the costs of purchasing the e-trike while also assisting in emissions reductions of the community. However, it is recommended that the maintenance of the product is considered as a part of this investigation.

Further research is recommended with regards to expansion of Toha Kai (see Appendix E). For example, the viability of multiple e-trikes and potential pick-up hubs should be assessed. The latter is particularly relevant if Toha Kai continues to grow outside the range of the e-trike battery. Mass delivery to community hubs would allow for customers located outside Toha Kai's current delivery range to be serviced. However, with this comes considerations into food accessibility.

The MoT Outcomes Framework provided analysis of qualitative data that was difficult to quantify. Therefore, there is an opportunity for future study to quantify these factors to reduce bias.

9.2 Wider context

It is encouraged that the government reacts to the shift towards electrified and active transport from e-trikes by further developing the cycle ways within Christchurch. As an environmental benefit (according to the MoT framework), increased infrastructure would positively influence the reduction in emissions and increase the use of bikes and e-trikes within Christchurch.

For small delivery-based companies wanting to reduce their emissions profile who do not have the capacity to transition to e-trikes due to local infrastructure or upfront cost of the e-trike, it is recommended that alternative emission reduction strategies should be considered. Notably, carbon credits, which are a tool that allow people to offset their CO_2 emissions, could be implemented. A single carbon credit is equivalent to 1 tonne of CO_2-e (Toitu Envirocare, 2018) and can be purchased for $81 in NZ (Carbon news, n.d.).

10 Acknowledgements

Over the course of this project, there have been many individuals who assisted in our investigation of the viability of e-trike adoption. We would like to acknowledge our community partner Michael Reynolds, the founder of Toha Kai, for his significant contribution to the project. We would also like to acknowledge Koen Faber, our supervisor who provided support throughout the project.

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12 Appendix A

GIS Network Edge Calculation Outputs

To ensure the e-trike network considered the maximum speed of the e-trike (25km/h), both the estimated speed and the estimated travel time of the e-trike network edges were recalculated. The original nzogps_240215_roads_only layer – and thus the recalculated e-trike network edges – contain road edge data for the whole of New Zealand. For our purposes, we created a subset of data in and around Christchurch (Figure A1).

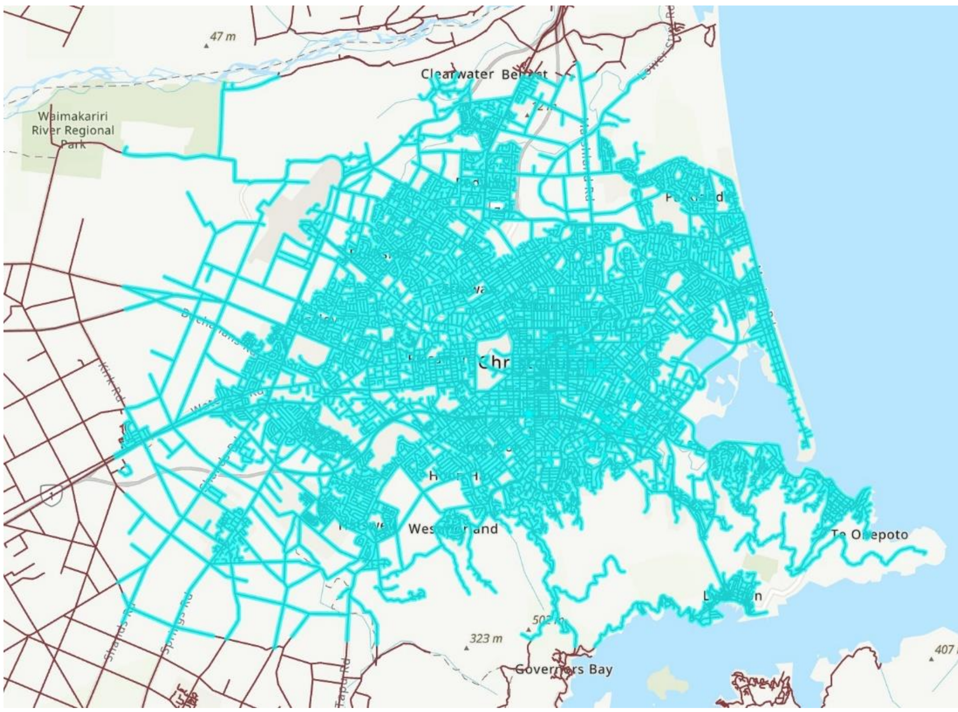


Figure A1. Map of nzogps_240215_roads_only layer (shown in red lines) with the area subset of wider Christchurch selected and shown in blue.

The edges of the delivery van network and the e-trike network can be seen in Table A1 and Table A2 respectively. As these tables contained over 13,500 rows of data, a sample has been selected. As can be seen, the Table A1 estimated_speed and estimated_travel_time values are different from those in Table A2. The Table A2 speed is set to 25km/h and thus tends to also have higher estimated_travel_time values that Table A1.

Table A1. Subset of the nzogps_240215_roads_only attribute table. This data was used to create the network edges of the delivery van network.

	OBJECTID *	Shape *	TARGET_FID	FID_nzogps_Corrected	type	label	descr	label3	city	region	country
39760	88587	Polyline	94268	26576	6	george bellew rd			christchurch...	canterbury	new zealand~[0x1d]nz
39761	88784	Polyline	94471	26574	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39762	88792	Polyline	94479	26573	6	syd bradley rd			christchurch...	canterbury	new zealand~[0x1d]nz
39763	89054	Polyline	94759	26577	6	george bellew rd			christchurch...	canterbury	new zealand~[0x1d]nz
39764	89055	Polyline	94760	26577	6	george bellew rd			christchurch...	canterbury	new zealand~[0x1d]nz
39765	89200	Polyline	94912	26575	6	syd bradley rd			christchurch...	canterbury	new zealand~[0x1d]nz
39766	89201	Polyline	94913	26575	6	syd bradley rd			christchurch...	canterbury	new zealand~[0x1d]nz
39767	89237	Polyline	94954	10771	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39768	89543	Polyline	95278	10771	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39769	89544	Polyline	95279	4669	6	ivan jamieson pl			christchurch...	canterbury	new zealand~[0x1d]nz
39770	89733	Polyline	95488	10772	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39771	89734	Polyline	95489	1821	6	bolt pl			christchurch...	canterbury	new zealand~[0x1d]nz
39772	89796	Polyline	95552	10768	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39773	89841	Polyline	95602	10770	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39774	89842	Polyline	95603	4724	6	robin mann pl			christchurch...	canterbury	new zealand~[0x1d]nz
39775	89904	Polyline	95670	27668	6	perimeter rd			christchurch...	canterbury	new zealand~[0x1d]nz
39776	89905	Polyline	95671	21752	6	perimeter rd			christchurch...	canterbury	new zealand~[0x1d]nz
39777	89980	Polyline	95751	10769	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39778	90009	Polyline	95780	10767	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39779	90024	Polyline	95795	27393	6				christchurch...	canterbury	new zealand~[0x1d]nz
39780	90044	Polyline	95818	21753	6	perimeter rd			christchurch...	canterbury	new zealand~[0x1d]nz

	oneway	toll	speed	roadclass	roadid	road_class	oneway_char	Urban_Rural	sinuosity	road_name	highway	surface	arterial	estimated_speed	estimated_travel_time	class_types	Shape_Length
39760	0	0	2	0	31429	Residential		0	1	GEORGE BELLEW RD	0	1	0	70	0.193684	Non Urban Straight	225.965121
39761	0	0	2	0	31427	Residential		0	1.021041	RON GUTHREY RD	0	1	0	70	0.160671	Non Urban Straight	187.449737
39762	1	0	2	0	31426	Residential	F	0	1.253932	SYD BRADLEY RD	0	1	0	40	0.465327	Non Urban Bendy	310.218017
39763	0	0	2	0	31429	Residential		0	1	GEORGE BELLEW RD	0	1	0	70	0.431975	Non Urban Straight	503.970949
39764	0	0	2	0	31429	Residential		0	1	GEORGE BELLEW RD	0	1	0	70	0.431975	Non Urban Straight	503.97091
39765	0	0	2	0	31428	Residential		0	1	SYD BRADLEY RD	0	1	0	70	0.411454	Non Urban Straight	480.030128
39766	0	0	2	0	31428	Residential		0	1	SYD BRADLEY RD	0	1	0	70	0.411454	Non Urban Straight	480.030036
39767	0	0	2	0	13498	Residential		0	1	RON GUTHREY RD	0	1	0	70	0.363022	Non Urban Straight	423.525444
39768	0	0	2	0	13498	Residential		1	1.000325	RON GUTHREY RD	0	1	0	30	0.439408	Residential	219.703941
39769	0	0	2	0	13474	Residential		1	1	IVAN JAMIESON PL	0	1	0	30	0.241019	Residential	120.509264
39770	0	0	2	0	13498	Residential		1	1	RON GUTHREY RD	0	1	0	30	0.305719	Residential	152.859269
39771	0	0	2	0	13455	Residential		1	1.064315	BOLT PL	0	1	0	30	0.22964	Residential	114.819832
39772	0	0	2	0	13498	Residential		1	1	RON GUTHREY RD	0	1	0	30	0.102327	Residential	51.163386
39773	0	0	2	0	13498	Residential		1	1	RON GUTHREY RD	0	1	0	30	0.073005	Residential	36.502341
39774	0	0	2	0	13475	Residential		1	1.121467	ROBIN MANN PL	0	1	0	30	0.254003	Residential	127.001384
39775	0	0	1	0	32466	Residential		1	1.000055	PERIMETER RD	0	1	0	30	0.263646	Residential	131.822936
39776	0	0	1	0	13380	Residential		1	1.008209	PERIMETER RD	0	1	0	30	0.369973	Residential	184.986563
39777	0	0	2	0	13498	Residential		1	1.003792	RON GUTHREY RD	0	1	0	30	0.267596	Residential	133.79791
39778	0	0	2	0	13498	Residential		1	1	RON GUTHREY RD	0	1	0	30	0.080369	Residential	40.184405
39779	0	0	1	0	32148	Residential		1	1		0	1	0	30	0.031641	Residential	15.820592
39780	0	0	1	0	13380	Residential		1	1.010216	PERIMETER RD	0	1	0	30	0.476981	Residential	238.490543

Table A2. Subset of ETrikeRoads attribute table. This data was used as the edge layer in creating the e-trike network.

	OBJECTID *	Shape *	TARGET FID	FID nzogps Corrected	type	label	descr	label3	city	region	country
39760	88587	Polyline	94268	26576	6	george bellew rd			christchurch...	canterbury	new zealand~[0x1d]nz
39761	88784	Polyline	94471	26574	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39762	88792	Polyline	94479	26573	6	syd bradley rd			christchurch...	canterbury	new zealand~[0x1d]nz
39763	89054	Polyline	94759	26577	6	george bellew rd			christchurch...	canterbury	new zealand~[0x1d]nz
39764	89055	Polyline	94760	26577	6	george bellew rd			christchurch...	canterbury	new zealand~[0x1d]nz
39765	89200	Polyline	94912	26575	6	syd bradley rd			christchurch...	canterbury	new zealand~[0x1d]nz
39766	89201	Polyline	94913	26575	6	syd bradley rd			christchurch...	canterbury	new zealand~[0x1d]nz
39767	89237	Polyline	94954	10771	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39768	89543	Polyline	95278	10771	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39769	89544	Polyline	95279	4669	6	ivan jamieson pl			christchurch...	canterbury	new zealand~[0x1d]nz
39770	89733	Polyline	95488	10772	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39771	89734	Polyline	95489	1821	6	bolt pl			christchurch...	canterbury	new zealand~[0x1d]nz
39772	89796	Polyline	95552	10768	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39773	89841	Polyline	95602	10770	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39774	89842	Polyline	95603	4724	6	robin mann pl			christchurch...	canterbury	new zealand~[0x1d]nz
39775	89904	Polyline	95670	27668	6	perimeter rd			christchurch...	canterbury	new zealand~[0x1d]nz
39776	89905	Polyline	95671	21752	6	perimeter rd			christchurch...	canterbury	new zealand~[0x1d]nz
39777	89980	Polyline	95751	10769	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39778	90009	Polyline	95780	10767	6	ron guthrey rd			christchurch...	canterbury	new zealand~[0x1d]nz
39779	90024	Polyline	95795	27393	6				christchurch...	canterbury	new zealand~[0x1d]nz
39780	90044	Polyline	95818	21753	6	perimeter rd			christchurch...	canterbury	new zealand~[0x1d]nz
39781	90115	Polyline	95889	4817	6	richard pearse rd			christchurch...	canterbury	new zealand~[0x1d]nz

		oneway	toll	speed	roadclass	roadid	road_class	oneway_char	Urban_Rural	sinuosity	road_name	highway	surface	arterial	estimated_speed	estimated_travel_time	class_types	Shape_Length
39760	1d]nz	0	0	2	0	31429	Residential		0	1	GEORGE BELLEW RD	0	1	0	25	0.542316	Non Urban Straight	225.965121
39761	1d]nz	0	0	2	0	31427	Residential		0	1.021041	RON GUTHREY RD	0	1	0	25	0.449879	Non Urban Straight	187.449737
39762	1d]nz	1	0	2	0	31426	Residential	F	0	1.253932	SYD BRADLEY RD	0	1	0	25	0.744523	Non Urban Bendy	310.218017
39763	1d]nz	0	0	2	0	31429	Residential		0	1	GEORGE BELLEW RD	0	1	0	25	1.20953	Non Urban Straight	503.970949
39764	1d]nz	0	0	2	0	31429	Residential		0	1	GEORGE BELLEW RD	0	1	0	25	1.20953	Non Urban Straight	503.97091
39765	1d]nz	0	0	2	0	31428	Residential		0	1	SYD BRADLEY RD	0	1	0	25	1.152072	Non Urban Straight	480.040128
39766	1d]nz	0	0	2	0	31428	Residential		0	1	SYD BRADLEY RD	0	1	0	25	1.152072	Non Urban Straight	480.030036
39767	1d]nz	0	0	2	0	13498	Residential		0	1	RON GUTHREY RD	0	1	0	25	1.016461	Non Urban Straight	423.525444
39768	1d]nz	0	0	2	0	13498	Residential		1	1.000325	RON GUTHREY RD	0	1	0	25	0.527289	Residential	219.703941
39769	1d]nz	0	0	2	0	13474	Residential		1	1	IVAN JAMIESON PL	0	1	0	25	0.289222	Residential	120.509264
39770	1d]nz	0	0	2	0	13498	Residential		1	1	RON GUTHREY RD	0	1	0	25	0.366862	Residential	152.859269
39771	1d]nz	0	0	2	0	13455	Residential		1	1.064315	BOLT PL	0	1	0	25	0.275568	Residential	114.819832
39772	1d]nz	0	0	2	0	13498	Residential		1	1	RON GUTHREY RD	0	1	0	25	0.122792	Residential	51.163386
39773	1d]nz	0	0	2	0	13498	Residential		1	1	RON GUTHREY RD	0	1	0	25	0.087606	Residential	36.502341
39774	1d]nz	0	0	2	0	13475	Residential		1	1.121467	ROBIN MANN PL	0	1	0	25	0.304803	Residential	127.001384
39775	1d]nz	0	0	1	0	32466	Residential		1	1.000055	PERIMETER RD	0	1	0	25	0.316375	Residential	131.822936
39776	1d]nz	0	0	1	0	13380	Residential		1	1.008209	PERIMETER RD	0	1	0	25	0.443968	Residential	184.986563
39777	1d]nz	0	0	2	0	13498	Residential		1	1.003792	RON GUTHREY RD	0	1	0	25	0.321115	Residential	133.79791
39778	1d]nz	0	0	2	0	13498	Residential		1	1	RON GUTHREY RD	0	1	0	25	0.096443	Residential	40.184405
39779	1d]nz	0	0	1	0	32148	Residential		1	1		0	1	0	25	0.037969	Residential	15.820592
39780	1d]nz	0	0	1	0	13380	Residential		1	1.010216	PERIMETER RD	0	1	0	25	0.572377	Residential	238.490543
39781	1d]nz	0	0	2	0	13523	Residential		1	1.168467	RICHARD PEARSE RD	0	1	0	25	0.472424	Residential	196.843231

13 Appendix B

Infographic for Toha Kai to communicate the findings of this research project.

To communicate the findings in a more digestible manner for Toha Kai's consumer base, an infographic was produced. The infographic outlines the problems being addressed by Toha Kai's proposed transition and then presents the key findings. To contextualise the emissions calculation in a more impactful way, the MfE emissions factors and calculations were used. These calculations determined the 12 Christchurch to Wellington flights would be saved annually as a result of the transition. By contextualising the emissions reduction, conclusions drawn from the evidence provided become more familiar for both Toha Kai and their consumers.

GEOG309 Research Project Results

Conducted by Aimee Hudson, Breanna Greaney, Lin Li Yeoh, Gemma Langley, and Kaya Thorn.

TOHA KAI

Toha Kai currently uses courier vans for food distribution which contributes to climate change and air pollution.

We partnered with Toha Kai to investigate an alternative.

Is the transition from motorised vans to e-trike a **socially, economically, and environmentally viable option** for local food providers?

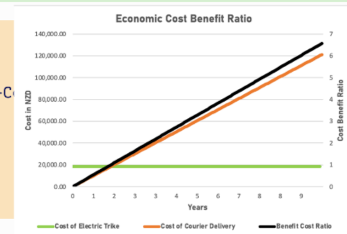
How did we do it?

Environmental Calculations

Using GIS, we calculated the distance that the e-trike and courier van would travel, so we could calculate the amount of carbon emissions released.

Cost-Benefit Analysis

A Cost-Benefit Analysis produced a Benefit-Cost Ratio to show if the e-trike is a beneficial investment compared to a courier van.



Ministry of Transport Outcomes Framework

We used the framework to assess social factors. The e-trike contributes to **3 outcomes.**

For Toha Kai, an e-trike is not just an economic decision.

What did we find?

After 2 years, the e-trike will be repaid.

Reduced carbon emissions + air pollution.

Increases the resilience + security of Toha Kai's delivery services.

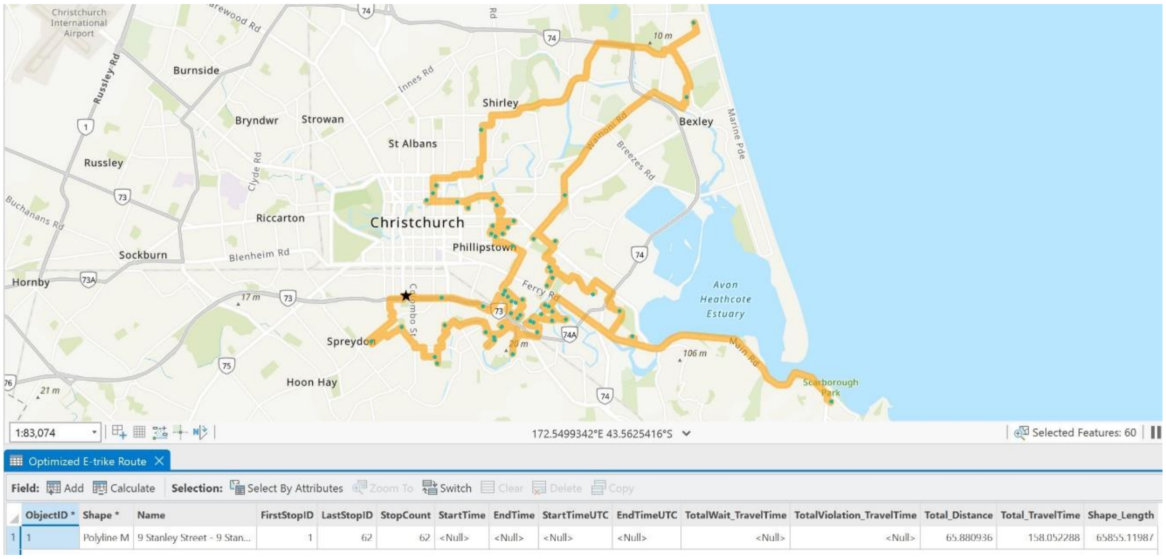
Upfront costs outweigh the continual cost of paying for courier vans.

Implementing the e-trike would save 12 Christchurch-Wellington flights worth of CO2-e every year.

The electric trike is a viable delivery option for Toha Kai.

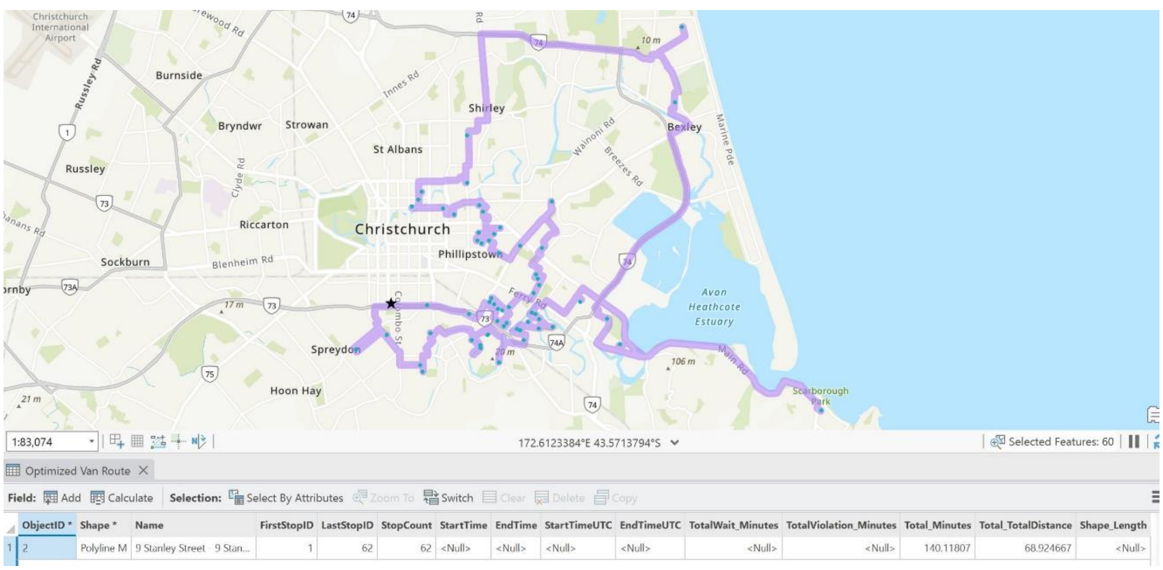
14 Appendix C

Optimized Route Analysis Details



	ObjectID *	Shape *	Name	FirstStopID	LastStopID	StopCount	StartTime	EndTime	StartTimeUTC	EndTimeUTC	TotalWait_TravelTime	TotalViolation_TravelTime	Total_Distance	Total_TravelTime	Shape_Length
1	1	Polyline M	9 Stanley Street - 9 Stan...	1	62	62	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	65.880936	158.052288	65855.11987

Figure C1. Output attribute table of optimized e-trike route alongside route map where the e-trike route is represented by the orange line.



	ObjectID *	Shape *	Name	FirstStopID	LastStopID	StopCount	StartTime	EndTime	StartTimeUTC	EndTimeUTC	TotalWait_Minutes	TotalViolation_Minutes	Total_Minutes	Total_TotalDistance	Shape_Length
1	2	Polyline M	9 Stanley Street - 9 Stan...	1	62	62	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	140.11807	68.924667	<Null>

Figure C1. Output attribute table of optimized van route alongside route map where the van route is represented by the purple line.

15 Appendix D

Distance-Based Service Area Analysis

Service area analysis was conducted to visualize the distance away from the warehouse to give a more generalized perspective of e-trike travel accessibility. Using the e-trike network, the analysis was constructed to find the furthest areas reachable within 5, 10, and 15km radius from the Toha Kai warehouse.

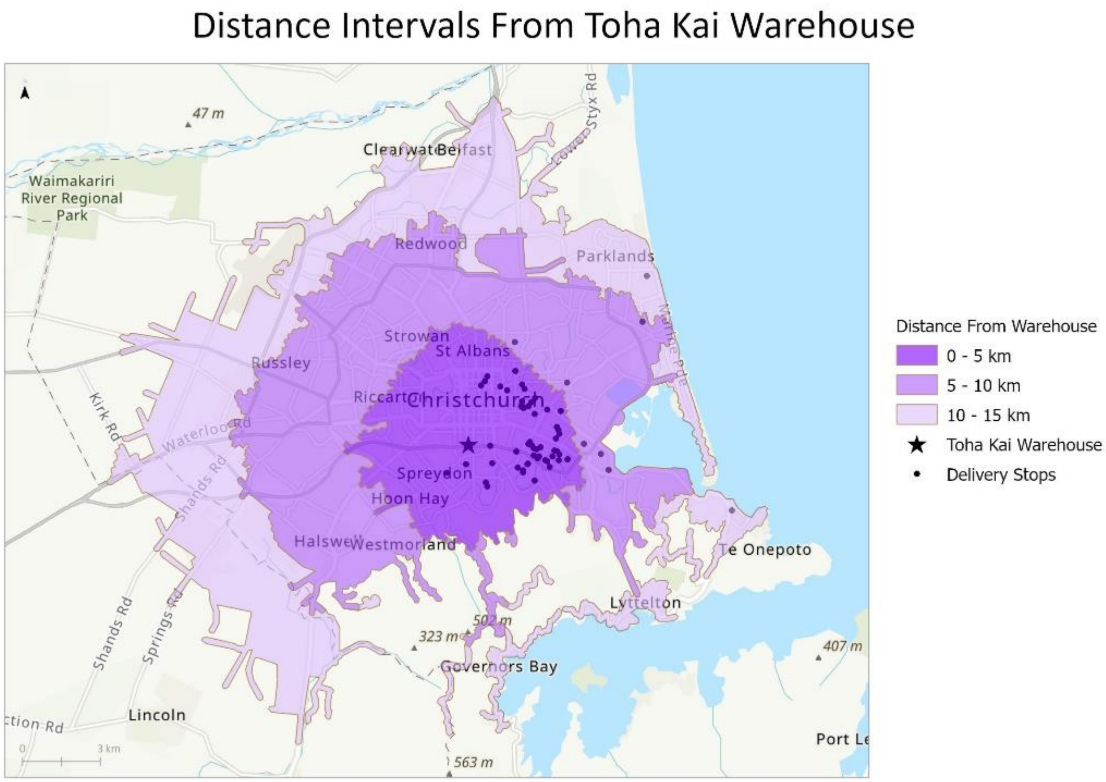


Figure D1. Map of distance-based service areas moving outwards from the Toha Kai warehouse. Increasing in intervals of 5km, the service area polygons get lighter in colour with greater distance from the warehouse, represented by the black star. The black dots are the locations of the sample delivery addresses, though these were not used in calculating the service areas.

This figure shows a clearer representation of the wider range that the e-trike can access compared to the route analysis which is dependent on an isolated sample of delivery data. It is noted that the majority of Christchurch and all anonymised sample delivery locations are encapsulated by the 15km boundary (shown by the light purple colour), and majority is within 5km of the warehouse. This evidence supports the e-trike's viability as a practical delivery option for Toha Kai.

16 Appendix E

Examples of Future Analysis Possibilities

As mentioned in our recommendations, Toha Kai and future research on e-trike viability on larger scales may want to consider options like using multiple e-trike or instating pick-up hubs. Though in-depth analysis into such scenarios was outside of the scope of our research we wanted to give an idea of what such outputs could look like using GIS network analysis techniques of vehicle routing problem analysis, route optimization, and service area analysis.

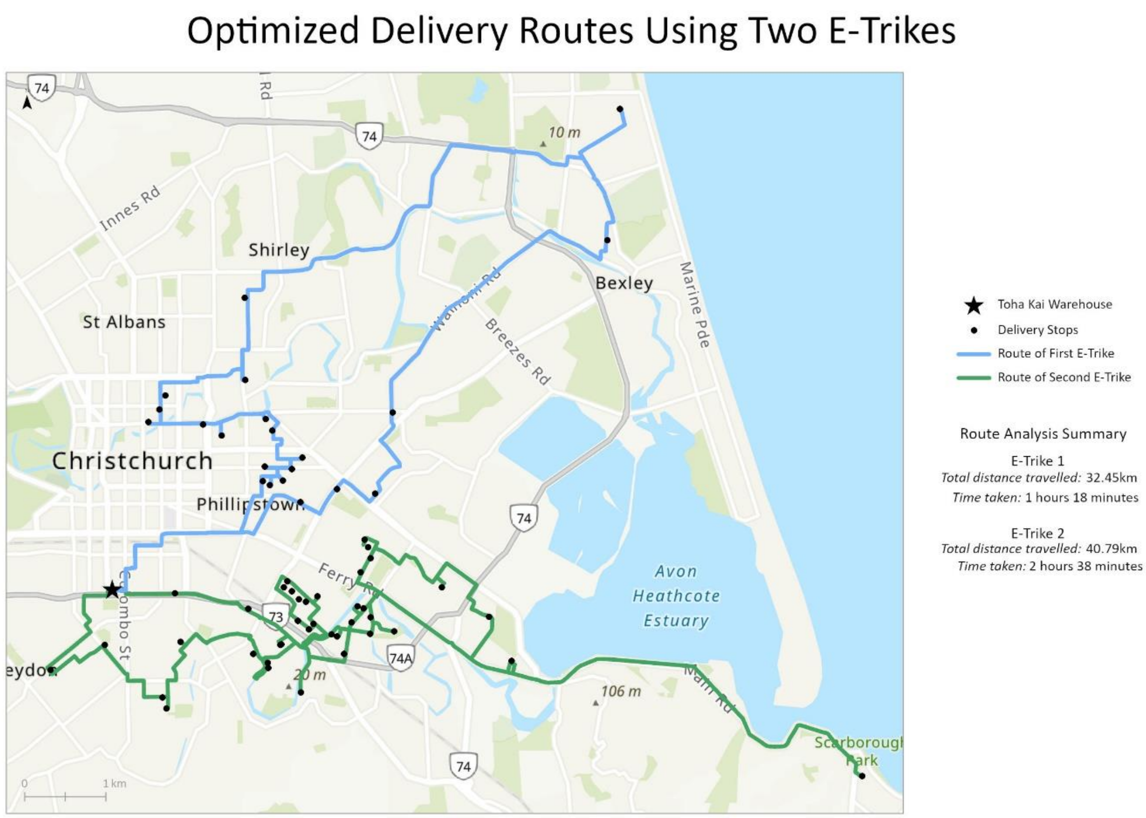


Figure E1. Map of optimized e-trike delivery route to sample week Toha Kai locations using two e-trikes. This analysis was undertaken using Vehicle Routing Problem Analysis.

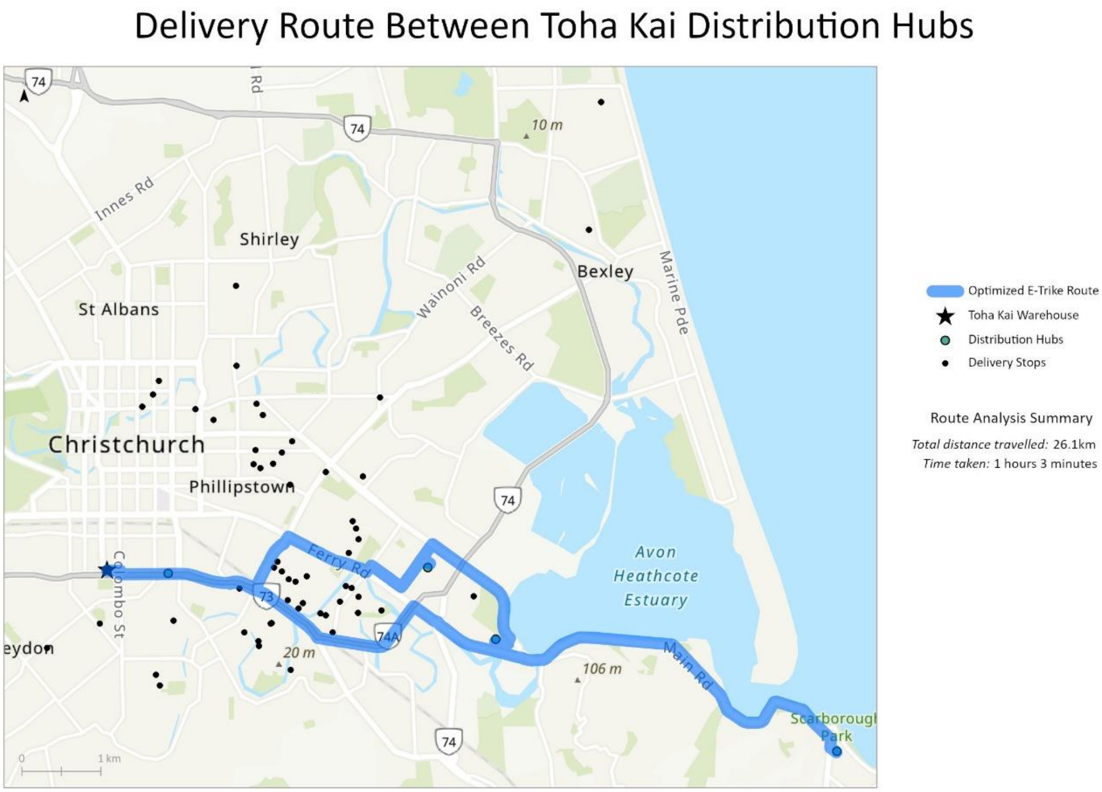


Figure E2. Map of optimized e-trike route which services the pick-up hubs only. This was achieved with route analysis that used the current Toha Kai distribution hubs as stops.

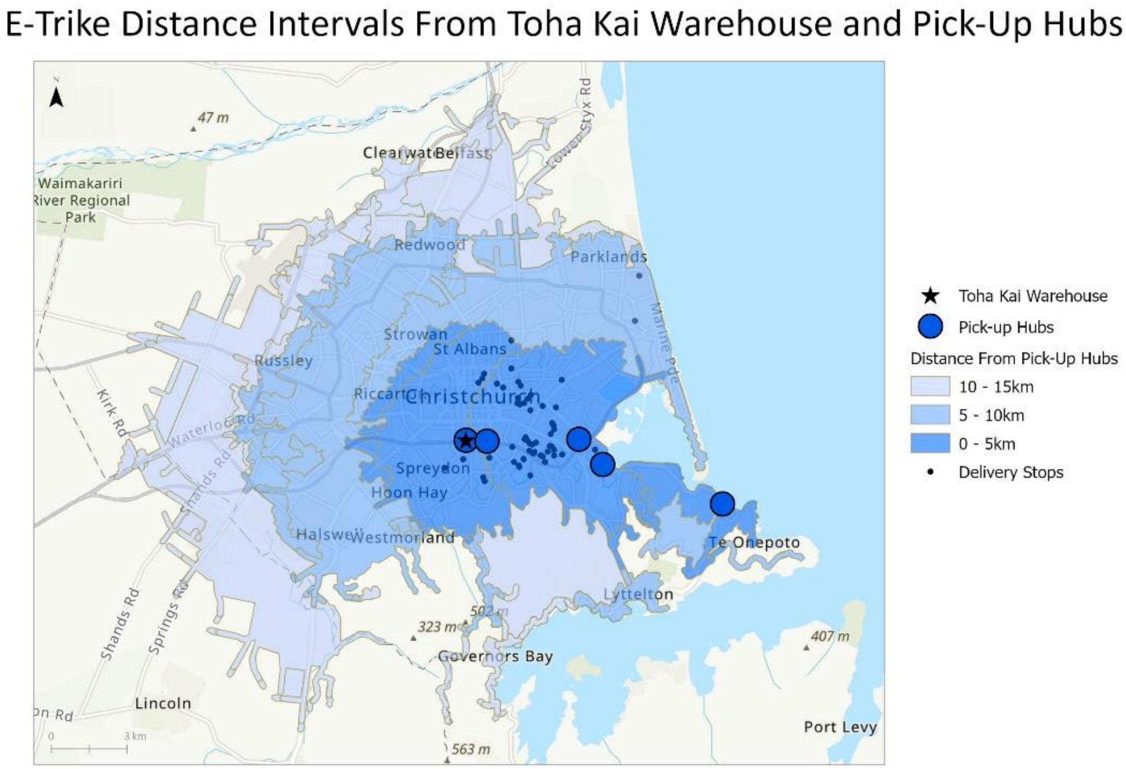


Figure E3. Map of distance-based service areas from the Toha Kai warehouse and the pick-up hubs. This was generated through service area analysis using both the warehouse and the pick-up hubs as facilities of origin.